Workshop on Accelerator Operation

Jan 28 - Feb 2, 2001

Pillars sur Ollon, Switzerland

Editors: R. Bailey and T. Kehrer
Propriété littéraire et scientifique réservée pour tous les pays du monde. Ce document ne peut être reproduit ou traduit en tout ou en partie sans l’autorisation écrite du Directeur général du CERN, titulaire du droit d’auteur. Dans les cas appropriés, et s’il s’agit d’utiliser le document à des fins non commerciales, cette autorisation sera volontiers accordée.

Le CERN ne revendique pas la propriété des inventions brevetables et dessins ou modèles susceptibles de dépôt qui pourraient être décrits dans le présent document ; ceux-ci peuvent être librement utilisés par les instituts de recherche, les industriels et autres intéressés. Cependant, le CERN se réserve le droit de s’opposer à toute revendication qu’un usager pourrait faire de la propriété scientifique ou industrielle de toute invention et tout dessin ou modèle décrits dans le présent document.

Literary and scientific copyrights reserved in all countries of the world. This report, or any part of it, may not be reprinted or translated without written permission of the copyright holder, the Director-General of CERN. However, permission will be freely granted for appropriate non-commercial use.

If any patentable invention or registrable design is described in the report, CERN makes no claim to property rights in it but offers it for the free use of research institutions, manufacturers and others. CERN, however, may oppose any attempt by a user to claim any proprietary or patent rights in such inventions or designs as may be described in the present document.

ISSN 0007–8328
ISBN 92–9083–182–0
ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

WORKSHOP ON ACCELERATOR OPERATION (WAO 2001)

Villars sur Ollon, Switzerland
28 January – 2 February 2001

PROCEEDINGS
Editors: R. Bailey and T. Kehrer
ABSTRACT

The 3rd Workshop on Accelerator Operation (WAO 2001) followed earlier workshops in 1996 and 1998. Most topics relevant for the efficient and effective operation of accelerators were covered. These included the tools and utilities necessary in the control rooms; the organization of accelerator operation (process monitoring, shift work, stress); the monitoring of beam quality; safety issues and standards; and questions particularly relevant for superconducting accelerators, in particular cryogenics.
PREFACE

The Workshop, held in Villars, Switzerland from 28 January to 2 February 2001, was the third in a series on Accelerator Operations. The previous two were both held in North America, the first at TJNAF, Newport News, Virginia, USA in June 1996 and the second at TRIUMF, Vancouver, British Columbia, Canada in May 1998. Some 100 participants from around the world were in Villars.

The organization of the workshop was undertaken from CERN by two largely independent committees, composed as follows.

**Local Organizing Committee**
- S. Baird (CERN) (Chairman)
- B. Allardyce (CERN)
- R. Bailey (CERN)
- J. Boillot (CERN)
- D. Dagan (CERN)
- T. Kehrer (CERN)
- M. Lindroos (CERN)

**Programme Committee**
- R. Bailey (CERN) (Chairman)
- S. Baird (CERN)
- R. Bloemhard (TRIUMF)
- E. Karantzoulis (ELETTRA)
- T. Katoh (KEK)
- R. Lauzé (TJNAF)
- M. Stanek (SLAC)
- E. Takada (NIRS)

The programme was organized in eight half-day sessions, as shown below. There was also an informal poster session running throughout the workshop.

**Workshop programme**

<table>
<thead>
<tr>
<th>Session</th>
<th>Chairman</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. What’s required in today’s control rooms for efficient and effective operation?</td>
<td>Ron Lauzé TJNAF, USA</td>
</tr>
<tr>
<td>2. Tools and Utilities</td>
<td>Eiichi Takada NIRS, Japan</td>
</tr>
<tr>
<td>3. How should accelerator operations be organized?</td>
<td>Rick Bloemhard TRIUMF, Canada</td>
</tr>
<tr>
<td>4. How should we monitor beam quality?</td>
<td>Emanuel Karantzoulis ELETTRA, Italy</td>
</tr>
<tr>
<td>5. How should we handle safety?</td>
<td>Ghislain Roy CERN, Switzerland</td>
</tr>
<tr>
<td>6. What is so special about running a superconducting machine?</td>
<td>Karel Cornelis CERN, Switzerland</td>
</tr>
<tr>
<td>7. Reserve</td>
<td>Roger Bailey CERN, Switzerland</td>
</tr>
<tr>
<td>8. Summary talks</td>
<td>Roger Bailey CERN, Switzerland</td>
</tr>
</tbody>
</table>
The first six sessions targeted specific topics, some organizational, some technical. Each session consisted of scheduled talks, with at least a third of the time spent on discussion.

The reserve session was devoted to hot issues that came up through the workshop and were grouped into three main areas:

- The Global Accelerator Network (presented and animated by Steve Peggs, BNL)
- Problems of stress and how to get organized to minimize them
- What should an operations group be responsible for?

The summary session consisted of five presentations, where the session chairmen distilled the material presented and discussed in their sessions. Because of a significant overlap between the talks in the first two sessions, for the purposes of the summary they were grouped together into one.

Two invited speakers completed the programme. Steve Myers from CERN gave the opening speech entitled ‘Accelerator Operations: the heart (and soul) of a CERN accelerator division’, and Christine Stewart from the British Airports Authority gave an invited talk on the operation of Heathrow Airport. I thank them both for their interesting and entertaining contributions.

I would also like to thank everyone involved in setting up and executing the workshop programme. This includes all members of the Programme Committee, and the session chairmen. A workshop organized like this sinks or floats by the chairmen; they are responsible for the details of their session, for the running of it, and for producing and presenting a summary. They all did a great job.

For the proceedings, thanks to all speakers for submitting their papers at or shortly after the workshop. This has allowed us to get the ball rolling for publication very soon after the workshop was held. In this respect I would like to give special thanks to Tjitske Kehrer for all she has done in following the programme and pulling everything together for the proceedings; her help has been invaluable.

Finally, a suggestion was made at the workshop to set up a Programme Advisory Committee to help in organization of future workshops. This would provide continuity of the topics discussed in this series, and such a body would be an invaluable help to future organizers. I fully support this idea.

Roger Bailey
Chairman of the Programme Committee
## CONTENTS

Preface .......................................................................................................................... v

### SUMMARY OF SESSIONS 1 AND 2

**WHAT IS REQUIRED IN TODAY’S CONTROL ROOMS FOR EFFICIENT AND EFFECTIVE OPERATION? TOOLS AND UTILITIES** ................................................................. 1  
  Ronald Laueré, Eiichi Takada, Noel Okay

**ERGONOMICS IN KEKB CONTROL SYSTEM** ..................................................... 5  

**ELECTRONIC LOGGING IN ACCELERATOR OPERATIONS** ....................... 10  
  Isadoro Terry Carlino

**APPLICATIONS OF BEAM-LINE SIMULATORS** ........................................... 22  
  Nicole van den Elzen

**OPERATION WITHOUT OPERATORS** .............................................................. 29  
  U. Georg, R. Catherall, T. Giles, O.C. Jonsson

**A NEW MODEL FOR A 500 MEV BEAM LINE AT TRIUMF** ......................... 34  
  John Kaminski

**CYCLOTRON BEAM TRANSPORT DEVELOPMENT USING BEAMLINE SIMULATOR** ................................................................. 43  
  D.B. Mackay

**APS STORAGE RING OPERATION BEAM MONITORING AND ANALYSIS** .......... 47  
  Chihyuan Yao

**THE REFILL WIZARD - IMPROVING EFFICIENCY AT DALESBURY LABORATORY’S SYNCHROTRON RADIATION SOURCE** ................................................................. 54  
  C.I. Hodgkinson and J.A. Clarke

### SUMMARY OF SESSION 3

**HOW SHOULD ACCELERATOR OPERATIONS BE ORGANIZED?** .................... 62  
  Rick Bloemhard and Mike Stanek

**ENGINEERING PROCESS MONITORING FOR CONTROL ROOM OPERATION** ........ 65  
  Mario Baiz

**THE ORGANISATIONAL STRUCTURE OF OPERATIONS GROUPS IN A COMMERCIAL ACCELERATOR FACILITY** ................................................................. 69  
  Nigel R. Stevenson

**COMPLEXITY MANAGEMENT THROUGH INFORMATION TECHNOLOGY AT ALS** ................................................................. 73  
  Jan Pustina

**BUILDING AN OPERATIONS GROUP** .............................................................. 77  
  Pierre Bicault

**STRESS AND SHIFT WORK** ........................................................................... 78  
  Mina Michal
SUMMARY OF SESSION 4

HOW DO WE MONITOR BEAM QUALITY? ................................................. 79
  Emanuel Karantzoulis

OPERATION OF THE ANKA SYNGHROTRON RADIATION SOURCE UNDER
A STANDARD QUALITY MANAGEMENT SYSTEM .................................. 83
  M. Hagelstein and V. Saile

MONITORING BEAM QUALITY IN THE PS COMPLEX DURING THE LHC ERA .......... 87
  M. Benedikt, G. Cyvock, S. Hancock, A. Jansson, M. Lindroos, G. Meiral,
  PS operations team

MONITORING BEAM QUALITY AT HERA ................................................. 92
  M. Bieler

BEAM QUALITY CHARACTERISATION AT THE ESRF ................................ 97
  L. Hardy

BEAM QUALITY AT JEFFERSON LAB ..................................................... 101
  M.F. Spata

QUALITY CONTROL AND CUSTOMER SERVICE AT BESSY .......................... 108
  J. Feikes and K. Holldack

SUMMARY OF SESSION 5

HOW SHOULD WE HANDLE SAFETY? .................................................... 109
  Markus Albert and Ghislain Roy

APPLICATION OF FUNCTIONAL SAFETY STANDARDS IN A PARTICLE ACCELERATOR
ENVIRONMENT ....................................................................................... 114
  L. Scibile, S. Grau, P. Ninin

HOW DOES THE CONTROL ROOM HANDLE SAFETY AT THE ESRF? ................. 118
  Ph. Duru, L. Hardy, P. Berkvens, P. Colomp

FIRST YEAR EXPERIENCE WITH THE RHIC PERSONAL ACCESS SAFETY SYSTEM (PASS) .. 122
  N. W. Williams

SAFETY ISSUES IN ACCELERATOR OPERATION: GROUNDWATER CONTAMINATION .... 128
  Peter F. Ingrassia

OPERATIONS AT CERN UNDER INB REGULATIONS .................................. 131
  André Faugier

ASPECTS OF OPERATIONS AND DOE REGULATION OF ACCELERATORS AT FERMI
NATIONAL ACCELERATOR LABORATORY ........................................... 134
  Daniel A. Johnson and Pepin T. Carolan

SUMMARY OF SESSION 6

WHAT IS SO SPECIAL ABOUT OPERATING BIG SUPERCONDUCTING ACCELERATORS? .... 140
  K. Cornelis

OPERATIONAL EXPERIENCES DURING RHIC COMMISSIONING: FY2000 .............. 142
  Paul W. Sampson

TOOLS TO CONTROL LARGE SUPERCONDUCTING COLLIDERS ...................... 159
  Bob Mau

WHO OPERATES CRYOGENICS? .......................................................... 163
  Philippe Gayet on behalf of CERN–LHC ACR group

viii
INTERLOCK AND PROTECTION SYSTEMS FOR SUPERCONDUCTING ACCELERATORS:
MACHINE PROTECTION SYSTEM FOR THE LHC ........................................... 170
K.H. Meß and R. Schmidt

OPERATIONAL CHALLENGES OF HERA’S SUPERCONDUCTING PROTON MACHINE ...... 179
M. Bieler and B. Holzer

OPERATING ATLAS; THE WORLD’S FIRST SUPERCONDUCTING HEAVY-ION ACCELERATOR 183
G.P. Zinkann

JAERI TANDEM BOOSTER AND ITS CRYOGENIC SYSTEM .............................. 188
T. Yoshida

SESSION 7
RESERVE ........................................................................................................ 193
Roger Bailey and Guy Crockford

POSTER PRESENTATIONS .................................................................................. 197
ACCELERATOR OPERATION AT THE GSI HIGH CURRENT INJECTOR ................. 199
W. Barth and U. Scheeler

PARTNERS IN OPERATIONS: ADVANCED LIGHT SOURCE CONTROL ROOM AND PROCEDURE CENTER ................................................................. 203
Rita Jones

EFFICIENT AND EFFECTIVE OPERATION OF THE APS LINAC ....................... 208
S. Pasky, M. Bortland, J. Stein, R. Soliday, S. Christensen

OPERATION OF HIMAC AND CANCER THERAPY ........................................ 214
Chihiro Kobayashi, Hideki Fujiwara, Tomihiro Nishimura, Yoshinobu Sano,
Hirotugu Ogawa, Eiichi Takada

CLOSING REMARKS .......................................................................................... 220
SUMMARY OF SESSIONS 1 AND 2
WHAT IS REQUIRED IN TODAY'S CONTROL ROOMS FOR EFFICIENT AND EFFECTIVE OPERATION? TOOLS AND UTILITIES

Ronald Lauzé
JLab, Newport News, VA 23606, USA
Eiichi Takada
NIRS, Chiba, 263-8555, Japan
Noel Okay
JLab, Newport News, VA 23606, USA

Abstract
There were a total of eight presentations in the two sessions. We will summarize these sessions, drawing simple conclusions where possible but mostly providing information for further thought.

We have separated the information into five categories.
1. Ergonomics
2. Electronic logbooks
3. Simulators
4. Tools (setup and analysis)
5. Operating without operators

1. INTRODUCTION
We all know there is no universal way to run an operations department; every facility has unique requirements. But we also know that what works for one group, even if it cannot be strictly applied to our own situation, is worth considering. Ask yourself the following questions as you review this session’s material.

1. Would this work for us?
2. How could this be tailored so that it would work for us?
3. How could this be made even better?

2. ERGONOMICS
Exhaustive studies have been conducted and books written suggesting what the ‘ideal’ ergonomic work environment would be like. While these proposed ideal environments differ to some extent, they do have many common threads. There are two that we believe are the most important: operator comfort, and fooling the circadian rhythm.

There are many comfort solutions that are easily implemented, including chairs that provide adequate back and arm support, keyboard wrist pads, tabletops placed at the correct height, and monitors placed in appropriate locations. Unfortunately, in reality, there are as many opinions as to what is exactly the right height, size, shape, colour, etc. as there are operators. This makes arriving at a workable solution that satisfies everyone almost impossible.
In the case of control room lighting, virtually every book written on ergonomics tells us how important it is to keep the control room lighting bright at all times (~1000 lx). Doing so should fool an operator's circadian clock into thinking that it is daylight, making for a more alert control room staff. We have no doubt that this should be helpful. In practice, however, virtually every control room that we have visited is, per the request of the control room staff, kept dark.

2.1 Observations

While the ergonomic design of a control room is important, even more critical is having the end users (operators in our case) involved in the design process as early as possible. This can be accomplished either through verbal input from the operators, or by involving them in the process of writing the control room design requirements document, a document that details the proposed changes. Designers of these types of systems must be patient and understanding. To be successful, the designer may have to take time educating the operators as to the benefits of the installed solutions. Doing so will improve acceptance and integration of the improvements as part of the work environment.

3. ELECTRONIC LOGBOOKS

It is clear that many facilities are converting their paper logs into some form of electronic log. Electronic logs provide a number of advantages, but there are some disadvantages as well.

3.1 Advantages

- Multiple viewings can occur simultaneously. If properly configured, the logbook is accessible from any computer terminal across a site. We have all experienced trying to physically lay our hands on a single paper logbook.
- Neatness is something that can be very important. Electronic logs may have an occasional misspelled word, but you no longer have to struggle with poor penmanship. They also don’t fall apart when carried about. We have all seen paper logs in a 2 cm binder that fan out to 15–20 cm because of a large number of paper printouts attached to log entries.
- Electronic logs provide the ability to search for information. A well-designed electronic log will include a search engine capable of finding information almost instantly. Searching on keywords or by system, for example, can greatly reduce the amount of time it takes to find key information.
- Single entries can have multiple functions. A single log entry, for example, can be posted into multiple logbooks or key information can be entered into a spreadsheet for downtime analysis.
- Autologging is a feature that saves time and provides data entry consistency. By automatically logging certain information when a process is started and/or completed, one can be certain that all required information is contained in the log entry. This also saves the operator from having to make an entry by hand.

3.2 Disadvantages

- Off-the-shelf software is scarce and costly. There are companies who sell this type of software, but there is a very good chance that it will have to be modified to suit your needs.
- Paper logs are typically easier to maintain. Once filled, you simply stick it into a bookshelf. Electronic logs on the other hand, require ongoing software and hardware maintenance as well as planning for long-term accessibility (media changes).
- Legal uncertainties may come into play. There may be issues regarding the legality of log entries that are made electronically. Because of this concern, it is important to make certain that entries can be traced to the proper time, date and person making the entry.
3.3 Observations

Many facilities have already converted to electronic logs. Those who have yet to convert seem to be interested in doing so. Facilities with small numbers of people or budgets just large enough to keep them afloat might not be able to afford the overhead associated with electronic logging. It is very important to remember two things about electronic logs. First, make certain that a requirements document is written prior to developing or purchasing one, and second, ensure that a flexible, reliable search engine is an integral part of the log.

4. SIMULATORS

Simulators are used at most facilities mainly for design purposes. Some operations personnel have found them to be very useful as training aids, diagnostic tools and for minor configuration changes.

Training Aids: Operators can use simulators to learn how various parameters affect overall machine performance without affecting beam to the user. This allows the operators to learn about machine operation when they have the time, rather than having to learn when the machine is available for training.

Diagnostic Tools: Using simulators as diagnostic tools enables one to troubleshoot a problem or potential problem off-line by downloading real-time parameters for later analysis. Many simulator programs are used in this fashion.

Configuration Changes: It has been shown that using simulators to verify future suggested changes could save valuable time. Verifying the settings for a new energy, for example, could be completed off line. Once verified as correct, the settings could be saved as a file that is then simply downloaded at the appropriate time.

4.1 Observations

Scientists at most facilities use simulators. We have shown that they can also be very useful when used by operators. Unfortunately most simulators are cumbersome to use and do not have user-friendly Graphical User Interfaces (GUIs). With the proper GUI, one could imagine using a simulator in a real-time mode. Real-time machine data could, for example, be entered into a simulator, with each input also having a means of change by an operator. The program would then process the change and provide an output that reflects the consequences of the change. This would allow operators to tweak a 'virtual' machine and observe the effects, without affecting the end User.

5. TOOLS (SETUP OR ANALYSIS)

We discussed two types of tools used for setup and analysis; those used in real-time and those used off-line.

Real-Time (automated) tools are particularly useful when a process must be performed the same way every time or perhaps when the amount of time required needs to be the same every time. These tools work best in situations where little or nothing can go wrong and the process is well understood. This limits the amount of complicated error trapping required to handle the many things that could go wrong. There is, however, a down side to automation. Many have observed the loss of knowledge about a process once that process has been automated. After an automated tool has been in use for some time, people tend to rely on it and no longer learn the manual process. So, when the tool is inoperable, performing the task manually is no longer an option and things come to a grinding halt until the automated tool is fixed.

Off-Line Analysis: Every facility has some form of off-line analysis process. These tools include, but are not limited to, data loggers, alarm handlers, graphing and plotting utilities. It should be obvious that having the ability to save, retrieve and display data is vital. With today's complex systems, it would be next to impossible to troubleshoot a problem without such tools.
5.1 Observations

We believe it safe to say that all facilities use tools of this nature. There are definite advantages and disadvantages. Automating processes can be very helpful but can also lead to a loss of information. It is a good idea to keep a written version of what the automated process is doing in order to allow manual operation if required. Data collection tools can be very helpful as troubleshooting aids, but they can also lead to many gigabytes of useless stored data. Setup and analysis tools need to be implemented with much forethought regarding their potential consequences.

6. OPERATIONS WITHOUT OPERATORS

Why would any facility want to operate a machine without operators? There are a number of reasonable answers to this question.

- Users would be integrated more closely with daily operations.
- Users would have a better feel for what is possible and what is not.
- Users might have fresh ideas that can be incorporated into the daily routine.
- System complexity (or the lack thereof) might be such that operators would become bored. That is to say, if the system were simple to set up, and the machine availability very high, then what would the operators do once beam is being delivered?
- Fewer operations staff would be required.

There are, however, some disadvantages.

- Additional in-depth training would be required for every user.
- Controls would need to be more self-explanatory (not necessarily a disadvantage).
- Communicating from one user experiment to the next would be difficult.

6.1 Observations

Operations without dedicated operators can work; however, there are limitations. It is doubtful that such a program would work on a large and complicated system. In addition, stable configurations and good communication would be essential.

7. CONCLUSIONS

The authors acknowledge that these sessions, in the time allotted, only scratched the surface of the multitude of possibilities. We believe, however, that the sessions accomplished the goal of stimulating conversation and discussion and provided a forum for sharing ideas. For all their differences, the facilities represented share common goals that make this shared information extremely useful. While no single set of tools will work for everyone, all facilities stand to benefit if the information is used as a springboard for improvement.
ERGONOMICS IN KEKB CONTROL SYSTEM

KEK, Tsukuba, JAPAN

Abstract
The ergonomic design implementation of the operators' consoles for KEKB accelerators will be described in comparison with the former TRISTAN accelerator control consoles. The basic construction policy of the KEKB operators' console is the flexibility for re-configuration in both hardware and software ways. For TRISTAN, there were several sets of identical console desk made of iron frames in which two touch-panels, two graphic display monitors, and ten TV monitors are packed. Each set of console was directly controlled by a mini-computer in the TRISTAN control computer network.
On the contrary, in the KEKB control system, all the man-machine interface devices are based on X-window system and application software runs on a UNIX server workstation. There are 30 to 40 X-window terminals realized by Macintosh and IBM PC/AT compatible PCs with X-server software. Low-cost Network Stations are also introduced as X-terminals with single screen. A Macintosh or PC is equipped with up to four display controllers or a multi-screen display controller and works as an X-terminal with only a set of a mouse and a keyboard. We adopted TFT(Thin-Film Transistor) flat-panel LCD(Liquid Crystal Display)s, which are thin and light in weight, for the PCs to reduce glaring of the surface. And the sets of cordless keyboard/mouse are also introduced for the purpose of making the table-top clear and giving freedom of positioning.

1. INTRODUCTION

1.1 The TRISTAN control computer system and control consoles
The TRISTAN accelerator complex was composed of the linac which supplied 2.5 GeV electron and positron beams to AR (Accummulation Ring). AR accelerated both beams up to 8 GeV and sent to TRISTAN MR (Main Ring). MR accepted both beams and stored them in its 3 000 m circumference ring. Then it accelerated both electrons and positrons up to 33 GeV to make two beams collide at four experimental halls. The TRISTAN control computer system [1] was based on the distributed mini-computer system with an optical-fibre token-ring network. There were 25 mini-computers (HIDIC-80) placed around TRISTAN accelerator. The devices controlled by the system are connected mainly via CAMAC modules through 2.5 Mbps serial highway. The mini-computers were allocated to the hardware groups as shown in Table 1. The computing speed of the mini-computer is about 1 MIPS with 16-bit word architecture. There were 6 sets of operators' consoles in the central control room. Each set was connected to corresponding mini-computer and had two 14-inch touch-panels, two 20-inch colour graphic displays and ten 10-inch TV monitors. The touch-panels were used as the data input devices and connected to a mini-computer via CAMAC modules (character display controllers and touch-panel interface controllers). The graphic display controller can display 4096*3072 pixels with 12-bit colours.

1.2 PF-AR accelerator and its control consoles
TRISTAN AR was converted to an SOR(Synchrotron Orbit Radiation) facility which stores 6.5 GeV electron beam. It is now called as PF(Photon Factory)-AR(Advanced Ring). For this accelerator,
15 mini-computers were left and 3 sets of TRISTAN control consoles are left for the PF-AR. Three of six console computers are in use and the left are stand-by.

Table 1: Number of mini-computers used for TRISTAN

<table>
<thead>
<tr>
<th>Groups</th>
<th>AR</th>
<th>Common</th>
<th>MR</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnet and Power Supply</td>
<td>1</td>
<td>-</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Radio Frequency</td>
<td>1</td>
<td>-</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Vacuum</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Beam Monitor</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Beam Transport</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Operators’ Consoles</td>
<td>-</td>
<td>6</td>
<td>-</td>
<td>6</td>
</tr>
<tr>
<td>Library</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>General Purpose</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Alarm</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>6</td>
<td>9</td>
<td>10</td>
<td>25</td>
</tr>
</tbody>
</table>

MR: TRISTAN Main Ring     AR: TRISTAN Accumulation Ring or PF Advanced Ring

1.3 The KEKB control computer system and KEKB control consoles

The KEKB accelerator complex consists of an 8 GeV electron/3.5 GeV positron injector linac, a 3.5 GeV positron ring, LER (Low Energy Ring), and an 8 GeV electron ring, HER (High Energy Ring). Control computer system for the KEKB accelerators consists of two systems. One is the linac control computer system [2] and the other is the KEKB control computer system [3], [4]. The former was designed and constructed before KEKB project started and upgraded just before the construction of KEKB. The KEKB control computer system is based on EPICS(Experimental Physics and Industrial Control System) [5]. A portable channel access server was introduced for communication between linac and KEKB control systems [6].

In the EPICS environment, the system is centralized as far as operation is concerned, X-terminals are used as man-machine interface devices. Application programmes using MEDM, SAD [7] and Python run on the server workstation in the system and they output information on the X-terminals. Therefore, operators’ consoles for the KEKB accelerator complex are composed basically of X-terminals. Network Stations [8] and PCs(PC/AT compatibles and MacIntoshes) are used with X-terminal emulation software because of their flexibility. More than two, up to four monitor screens are connected to one PC to get as much information as operators need [9].

2. DESIGN CONCEPTS

2.1 TRISTAN control consoles

A photograph of the TRISTAN accelerator control consoles are shown in Figure 1. Various devices such as touch-panels, graphic display monitors and TV monitors were mounted on the rigid iron-framed racks. The consoles were designed to satisfy JIS (Japanese Industry Standard) recommendations. And we tried to use as many ergonomic equipment as possible to decrease human fatigue. They are:

1. Over-scanned character display monitors for touch-panels,

2. Positive images on the touch-panel displays. For this purpose, we developed a new CAMAC module which generates 80 chars. x 32 lines with bright background frame.
But in order to prevent reflections from the CRT surface, we provided louvers at the lighting on the ceiling of the control room. They decreased significantly the glaring from the surface of the CRTs, but at the same time, the illuminance on the surface of the desk was decreased down to ~300 lx, about 1/3 of the recommended illuminance (~1 000 lx) by JIS for the office environment.

![Diagram of TRISTAN Control Consoles]

Fig. 1: Layout of the TRISTAN control consoles

2.2 KEKB control consoles

On the contrary, in the KEKB control system, the consoles are provided as flexible as possible to satisfy the requests from the customers, e.g. operators, KEKB accelerator commissioning team, and other personnel. Several large simple tables are distributed in the central control room as shown in Figure 2. PC based X-terminals are placed on the large tables (4.0 m × 1.6 m) and the latest 15-inch and 18.1-inch TFT LCD monitors and keyboards are placed on the table. These LCDs are light in weight and thin so that they require only a little space. As many LCD monitors as we could afford to buy are put on the table. Wireless keyboard and mouse sets are also used partially and they make the table clean and simple.

As the nature of a new accelerator like KEKB many accelerator physicists want to operate and make studies about the accelerator during the commissioning period. All of them want to use their own X-terminals in the CCR. There are more than 30 general purpose X-terminals and 4 PCs dedicated to the injector controls with Microsoft Windows NT. In order to provide a lot of information for one person, we introduced multi-screen display controllers for PCs and we put several video interface cards into Macintoshes. The maximum number of screens for one PC is now four. It also gives us other benefit of decreasing number of keyboards and mice and leaving space on the table. We obtained high illuminance (~1000 lx) enough for satisfying JIS recommendations.

2.3 Differences between TRISTAN and KEKB control rooms

The most different point is the illuminance of the control room. Previous TRISTAN consoles are made of iron-framed racks and various devices are mounted in them. In order to keep the operators from the reflected images of the light sources on the round surface of the monitors, the lighting in the control room was limited in strength and direction. It was so dark and the operator needed to have a stand lamp when he want to write on the log book. Consequently, it resulted eye-fatigue of the operators.

By using flat display monitors like LCDs, the reflection problem has completely gone and we can make the room as high illuminance as required for the office room. The enough illuminance gives us
benefit of easiness and comfort of reading and writing. Those who have dark eyes require more illuminance than those who have light coloured eyes.

At present, KEKB and PF-AR control consoles co-exist and the central control room is divided into two parts that have different illuminance due to glaring problem.

![Fig. 2: Layout of the KEKB and PF-AR control consoles](image)

3. **EQUIPMENT USED FOR KEKB CONTROL CONSOLES**

3.1 **LCD monitors**

Various types of TFT colour LCD monitors are used. An 18.1-inch monitor displays an SXGA (1280 × 1024 pixels) screen and a 15-inch monitor displays an XGA (1024 × 768 pixels) screen. There are also NTSC colour LCD TV monitors to display usual TV signals. Latest LCD monitors have characteristics of wide viewing angles of more than 120 degrees.

3.2 **Large screen plasma display monitors**

For the common display use in the central control room, we have been using 27-inch colour TV monitors for years. Some of them were damaged but we can not get the same monitor any more. Therefore, we replaced them by 40-inch plasma display monitors. A plasma display monitor is thin (about 15 cm thick) and light (about 30 kg) compared to a CRT display of 27 inches (about 60 cm deep and 50 kg in weight).

3.3 **PCs with multiple-screen display controllers**

There are many PCs (IBM PC/AT compatibles and Macintoshes) used as X-terminals. Multiple-video-display controllers can be installed into PCs and one can use two to four screens. By using multiple-screens, you can display much more information than single-screen not by overlapped but by separated windows. The most beneficial merit we get is that the use of multiple-screen decreases the number of keyboards and mice and you can get more space for log-books, etc.

For IBM PC/AT compatibles, we adopted a PCI-bus graphic display controller board. It can display one to four SXGA (1280 × 1024 pixels) screens at one time and you can have a Windows screen with 2560 × 2048 pixels with true colour. For a Macintosh, three conventional PCI graphic cards can be added to get three more screens.
3.4 Wireless keyboards and mice

As we have many keyboards and mice with connecting cables, sometimes they are tangled or tied together. We adopted a set of wireless keyboard and mouse for IBM PC/AT compatibles. For a Macintosh, a USB to PS/2 converter can be used to utilize the same set of keyboard and mouse.

3.5 Wrist-rest for keyboard and mouse

In order to reduce muscle-fatigue and stiff shoulders, we introduced wrist-rest for keyboard and mouse. They are used mainly by the operators but by commissioning group members.

3.6 Ergonomic chair

We tried to use so-called ergonomic chair for computer operations. One can adjust various parts of the chair, e.g. angles of the arm-supports, height of the arm-supports, reclining angle of the back. We found it takes a little long time for operators to get accustomed to this type of chairs.

4. CONCLUSION

For commissioning of the KEKB accelerators, the simplest and versatile console tables and up-to-date equipment recently available are provided. By using these devices, we get freedom of designing consoles and flexibility in modification. Console desks are in the chaos now, but it will be settled in the future in the proper state. Though we provide ergonomic environment, only the operators use as we expected. The commissioning group people want to modify every thing as they like. We became aware of the importance of letting them know the merit of using ergonomic equipment.

5. ACKNOWLEDGMENT

We wish to express our thanks to the members of the KEKB accelerator department, especially to the KEKB commissioning group for their valuable advice and cooperation.

References


[8] Product of IBM Corp.

ELECTRONIC LOGGING IN ACCELERATOR OPERATIONS

Isadoro Terry Carlino
Thomas Jefferson National Accelerator Facility, Newport News, VA 23606 USA

Abstract
Electronic logging is replacing the paper logs used in the control rooms and experimental halls at many facilities. TINAF has used electronic logging long enough to have developed an appreciation for the strengths of electronic logging, and long enough to discover the potential weaknesses. I was recently tasked with investigating the requirements for converting one of our few remaining paper logs to an electronic format. This log contains more legally sensitive material than any of our existing elogs. The issues that were revealed have applicability to all electronic logging. In this paper I will discuss the concept of electronic logging, explore electronic recordkeeping’s strengths and weaknesses, and solutions to its problems. An understanding of these issues can make a difference in successful migration to electronic logs.

1. INTRODUCTION
The ability to utilize electronic logbooks can fundamentally change the way in which the day-to-day information concerning accelerator operations is delivered to the persons requiring this data. Not very long ago, at just about every accelerator site, summarized operational data on accelerator machinery was recorded on paper and kept in logbooks. These books were typically stored in the control rooms, to be eventually archive in an on-site, or off-site records depository. This material had a very limited distribution. It was only available to personnel with access to the control station. Most of the time its primary purpose was as a short-term record to assist in the transmittal of information during change of operational responsibilities at shift turnover. Some of this information had long-term value, which is why such logbooks are retained.

In the last five or six years a revolution has taken place. Electronic record keeping has changed the way operational logs are used, the kinds of information recorded in them and even who can create these records. It has solved old problems in new ways, but created new problems unique to the electronic media.

2. OVERVIEW AND DEFINITIONS
Machine operating records can generally be divided into two types: raw data and summarized data. Raw data was most often previously recorded on strip charts or magnetic tape. Operators, system specialists and experimenters wrote summarized data in logbooks. The move to electronic control systems has resulted in a new way to keep raw machine data through the use of archivers and other methods. In many cases magnetic tape is still used to preserve raw data, though the specific tape format may be different from that previously used. The move to electronic logbooks, to replace the paper machine operating logs, has come at a slower pace. Some installations were early adopters of the electronic log concept. Fermilab and Jefferson Lab both moved to electronic logging in the mid to late nineties. Other installations have been slower to move from paper and pen to electronic logs.

Part of the reluctance to move to this new medium has been the lack of packaged software to meet the needs of the operations staffs. The typical machine-operating log includes graphs, pictures, and tabular data of various kinds. The primary purpose of this data is to facilitate the passage of information from one shift to the next. At first glance each installation might seem to have unique
needs. A deeper look will show that the basics of electronic logging are applicable to almost all facilities.

There are several ways to describe electronic logging applications. As computer software these programs typically consist of several discrete components. There are client applications for input to the log. A server application receives input from the client applications and processes the data, creating the log records. A log reader application gives users access to the saved records.

Another component should be included in any modern electronic logging scheme. This component is a Record Management Application. The Record Management Application allows electronic records to be managed in a way similar to the way paper records are managed. The difference between a log reader and an RMA is that a Record Management Application allows the archivist or record manager to manipulate the metadata that should be included with every log record.

What is metadata? Metadata is data about data. Who created the record and when are examples of metadata? Metadata is also information such as how long the record must be maintained, what kind of format the record has, who is responsible for maintaining the record and whether or not the record is a vital record. Some of this data should be visible to the casual user, and so will be included in data that can be read with the log display program. Other fields will only be visible, and should only be manipulated by a Record Management Application. Like the log reader application the RMA should not be capable of changing the record itself.

The RMA should help insure that the record format and media has persistence. That is that the log will not become inaccessible as the machines and media that it uses are replaced by newer technology.

3. DEPLOYMENT OF AN ELECTRONIC LOGGING SYSTEM

A comprehensive plan to deploy an electronic logging system should start with determination of the capabilities necessary for the system. Fermilab’s requirements, as posted on their Medusa website, gives a practical list of needs that would fit just about every facility. Indeed though our solution at Jefferson Lab is different than the one chosen by Fermilab, our requirements are remarkably the same.

The list of preferences included:

- Start of shift; includes shift roster, day/date and type of shift automatically filled in.
- Logbook entry; includes timestamp, author initials.
- Ability to enter graphic files easily. Comments to accompany graphics should be included.
- Entire shift viewable from one page, scrollable if necessary.
- End of shift; includes end of shift numbers and summary.
- Table of Contents. TOC will include hyperlinks to actual logbook files.
- Search capabilities to search within dates specified or through entire year of logbook files. Search results will include
  - hyperlinks to actual logbook files.
  - Ability to add comments to an entry.
- Must be hosted from reliable machine with UPS and automated backups

The first step in the deployment of a system as complex as an electronic logging system is to start with a requirements document. The document should list the general requirements all electronic logs at the site must adhere to and the specific requirements for the particular log in question. This will be mandated by the equipment or system involved. Programming hooks by which the log can be accessed
by external applications must be included. Possible external client applications, which might need to transfer information to the electronic log, include web-based browser applications for posting entries, and accelerator machine-specific applications that include autologging. Technical requirements for the client and server applications should be specified. The questions should be asked: What kind of platform will each be run on? What kind of error handling and fault tolerance is allowed or required? The requirements for the Record Management Application should be included, to insure the long-term availability of the information.

Finally, criteria for acceptance of the software must be included in the requirements document. This is necessary whether the software is to be purchased commercially, written in-house or contracted out. As we have found at Jefferson Lab one undiscovered flaw can bring the whole logging system to a halt, making the creation of new entries impossible or even making the entire log inaccessible to users.

Once criteria have been set, the decision must be made about procurement. Until 1998 all logging programs had to be created in-house. There were quite simply no applications available commercially. In 1997 the U.S. Department of Defense issued their Design Standard for Electronic Records Management Software Applications [DOD 5015.2-STD] Ref. [1]. Included was a set of criteria, by which a commercial vendor could have their software certified to meet 5015.2 standards.

In the United States the DOD is the big dog on the block. They have a massive budget and they generate enough of a market for vendors to create applications just for DOD use. The rest of us can benefit from this market. Commercial electronic record applications are now available. The cost is much less than that of custom written applications and sometimes even competitive with in-house code generation. And because DOD tests the software prior to certification, it works.

4. CLIENT COMPONENTS

No matter whether an integrated or dispersed solution is decided upon, all logs start on the client side. At Jefferson Lab we have a dispersed system. By that I mean that any number of different applications can be used to generate an elog.

![dttlite tcl/tk logging application](image)

**Fig. 1:** dttlite tcl/tk logging application
4.1 dtilite

The most common method to create an elog from the CEBAF control room is through the use of the tcl/tk program dtilite. The dtilite Graphical User Interface (GUI) is actually a window to a suite of similar, but specialized, logging client applications. The dtilite application can be used to make entries in several logbooks. Multiple logbooks can be selected so that the same entry can be entered in both the E-log (for the CEBAF machine) and CHL (Central Helium Liquefier) log, for example. A selection of other functions is also available from a variety of pull down menus. These include a spelling checker.

Special log formats can be selected for Downtime accounting log entries, Tunetime accounting log entries, as well as NEWTS Maintenance Tracking entries, which create both a log entry and a maintenance request. Helper applications, which either invoke an autologging function or open up a different kind of logging helper application, can also be started by selection from a pull down menu.

Using these tools, tables and lists can be generated for inclusion in the log. Documents on paper can even be fed into a scanner and included as a graphic in a log entry. Up to two on screen graphics can be captured from the terminal where dtilite is being run. This allows the inclusion of graphics showing EPICS control screens in elog entries. Video from beam viewers can also be included in this way.
4.2 Web interface

Manual elogs can also be entered using a web based entry form, without any of the special features available from dtlite. Logs entered using the web based interface are identified by the phrase ‘This entry was created by the WWW interface’ appended to the log entry. This method of log entry is most often used by personnel outside the control station to convey information to all who read the various electronic logs.

4.3 Crew Chief Stamp

If we review the Fermilab requirements also we see that the first requirement is ‘Start of shift; includes shift roster, day/date and type of shift automatically filled in.’ JLab has the same requirement. The Crew Chief Stamp is used to accomplish this. This is a separate tk/ke application that provides a form to the crew chief. When completed it generates a standard elog entry.
4.4 Beam Operations Objective Monitor

BOOM, The Beam Operations Objective Monitor is a program that measures the amount of time that the accelerator is delivering usable beam to the Halls. BOOM also counts the number of Fast Shutdown faults during the shift. BOOM categorizes the machine state, and the state of each experimental hall as UP, DOWN, TUNE or OFF. Time spent doing daily or weekly system checks can also be accounted for.

At the end of the shift BOOM makes an automatic log entry with these numbers tabulated and gives a list of each Fast Shut Down (FSD) trip, which caused beam to terminate. These numbers are thus available for later analysis.
Fig. 6: Boom log
4.5 Autologs

Autologs are created by machine control applications to document specific actions such as bypassing RF cavities, or cycling magnets. No operator action is required to initiate these clogs, the action itself causes the elog to be generated.

4.6 Search Utility

A search utility makes finding specific log entries easier.

![Log Search Utility](image)

**Fig. 7:** elog Search Utility

4.7 Elog Viewer

The elog is read using a web browser.
5. THE MISSING PIECES: FILE CONVERSION APPLICATION AND RECORD MANAGEMENT APPLICATION

Jefferson Lab’s electronic logging system was not so much revolutionary as evolutionary. It was not created as an integrated logging system, but rather evolved from individual parts. No requirements document was ever written. In many cases no central coordinating force was in place. This has resulted in problems that could have been avoided had a design plan been in place from the very beginning.

Several bad design decisions were made during the initial implementation. As designed each client application creates its own log entry. Log time and date are used to create the log record filename. Resolution of time is at one second. The result of this design is that if two users or two autologging client applications or a combination of users and autologging applications attempt to post a log at the same second the system rolls over and dies. At that point intervention by a computer system administrator is required to recover the system.

![Diagram of TJNAF log System](image)

The log record structure design was also not correctly implemented. The file is structured so that what should be metadata is embedded in the log record. One of the pieces of information that should be metadata is the log entry number. This number is assigned based upon the previous log number by an applet that transfers the Entry Number from a file, augments the number by 1 and then rewrites the file. It is possible for the application to become confused if two programs attempt to access it in the same second, resulting in either multiple entries with the same number, or no number.

The resulting file is then written to a temporary directory. This is the source of the time/date file resolution problem. Files are named based on the date and time in the format: YearMonthDayTime (001208142315.html) to a one second resolution. If two applications attempt to create a file with the same name the system does not elegantly handle the file collision.

The file sits in the temporary directory waiting for the Harvester application to empty the directory. It does this approximately every ten minutes. The Harvester application takes all the files in the temporary directory, creates a structure of directories based on days and months, and transfers the HTML files and their associated graphic files to these directories.

Another problem has been with third party applications. For this discussion we will define a third party application as any application not part of the dtlite elog applet or browser based elog entry applet.
This is somewhat misleading since some of the applets that are invoked from dltie have similar problems for like reasons.

There is no written standard outlining how a third party application should create a log entry. Generally the application must assign a log entry number, give date and time, and create a keyword line. However, the Harvester application performs no error checking. It will create an elog entry without a proper Entry Number, keywords or text comment. In fact if the file exists as a filename it will attempt to create a 0 length file that results in an invalid log entry.

Several years ago a script segment was written which can be included in a tcl/tk program, which will perform an autolog. Some programs use this script, and some do not. At one time, every instance of the script used the same temporary file when it was invoked, causing the predictable problems when two applications attempted to use it at the same time.

Since the records are not properly structured there is no separation between record data and metadata. The record data itself should be in a format that is unchangeable once the log is posted. Attached to each record should be metadata, which should include data classifying the record, including such information as how long the record must be kept, disposition authority and the unique record identification number. This metadata should be manageable using a record management application. As it is there is no easy way to manage the records database.

The solutions to these problems are known. To implement them will require a redesign of the log software, time and money.

Instead of each logging client application creating its own log record directly, the client application should send the record information to a File Conversion Utility. This application will attach the metadata to each record, assign the unique log identification number and then create the file record, in a format not based on the day/time stamp. All software will have to create a log the same way, through the File Conversion Utility.

Another complication that must be addressed is the complexity of the computing environment. Logs can be posted from various LAN systems, as well as through the Internet using secure connections from various geographical locations. Timestamping becomes a vitally important issue. The time the log is written and sent to the system is not necessarily the time that it will be posted. A robust system must be able to deal with outages and service interruptions. Logs that are posted from various sources must eventually be added to the logging system, with both the posting time and record creation time noted.

Solving these problems will require a complete rewrite of our present electronic logging software, and perhaps of all the third party programs that create elog entries. It will be a massive undertaking, but a necessary one. The requirement to keep accurate and complete records of machine operations makes solving these problems mandatory.

6. STEPS TO IMPLEMENTATION

To avoid problems in deploying an electronic logging system follow these steps.

1. Start with a Requirements Document.

2. Include standards for all client applications (User input and autologging.)

3. Use a File Conversion Application

4. Include requirements for File Management; including error logging, backup and troubleshooting.

5. Include requirements for Record Management; including record scheduling, archiving, and metadata management.
6. Include requirements for the log viewer applications, if it is expected that a web browser will be used, ensure that the HTML code conforms to W3C recommendations.

7. Include requirements for a search utility to allow multiple threaded searches on log data, by both specific fields and text.

8. Require a policy document to detail how log files will be backed up and how records will be archived.

Electronic Logging System

Client Applications
- User entry
- Web Based Entry
  - WWW form
- Control Scripts autologging
- Beam Time Accounting autologging

Server Applications
- File Conversion Utility
- Log Database
- Record Management Application
- File Management Utilities

WWW Applications
- Log Viewer Application
  - (Web Browser)

Fig. 11: Electronic Logging System

References and Bibliography


This work is supported by DoE Contract No DE-AC05-84ER40150.
APPLICATIONS OF BEAM-LINE SIMULATORS

Nicole van den Elzen
TRIUMF, 4004 Westbrook Mall, Vancouver, B.C. Canada V6T 2A3

Abstract
At TRIUMF’s smaller cyclotrons, help was needed with tuning, training and solving beam-line problems. The use of a beam-line simulator program was investigated at this facility that has a high demand on isotope production. Could it help with operator training? Could it be used to solve problems with beam line tuning and/or beam-line optics? Some of these challenging problems will be discussed and it will be shown how one beam-line was modified using the analysis of such programs.

1. INTRODUCTION
This paper discusses how a user-friendly beam-line simulator program was used at TRIUMF to assist with the operation of an isotope-production cyclotron. Such a program has been used not only as an aid in routine beam-line tuning but in the solution of beam transport difficulties as well. It has also proven to be an excellent teaching aid for new operators.

About 11 years ago when the TR30 cyclotron was commissioned, it was capable of extracting about 700 μA of protons split between two beam lines of which about 500 μA was transmitted to two targets. Five years or so later the machine received an upgrade which enabled it to extract about 1 mA of protons. On a good day it could be pushed as high as 1.2 mA. The beam transport system was well designed for the 350 μA beams, but the increased capability pushed it to its limits. A beam-line simulator program [1] was used to help with finding beam tunes at these higher currents while keeping beam spills to a minimum.

2. STUDY OF A BEAM LINE OF A SMALL CYCLOTRON
2.1 Definition of a real-life problem
The TR30 is a 30 MeV H- cyclotron used for the commercial production of isotopes. It is capable of producing a 1 mA proton beam that is divided between 2 beam lines. Prior to February 1999, a 450 μA beam was routinely extracted into each beam line, of which 350 μA reached each target. Thus about 100 μA was being spilled on each beam line. Further, to increase isotope production, it was desired to double the current to a target half the size of the existing one. Given that 100 μA of beam were lost now, the challenge was to find how the current to a smaller target could be doubled and the beam spill reduced simultaneously.

For about two weeks, various operators tried to tune the beam manually but given the limited diagnostics and other limitations of the system it was found that it could not be done easily. Eventually, a beam tune was found but the beam spills were high and they worsened quickly as the extraction foil started to wear.

A computer in the control room had an easy to use graphical program [1] that was already set up for the beam line in question. That is to say, the extraction parameters and relevant beam-transport element data had already been entered. It was decided to put the beam-line tuning parameters into it, in an attempt to understand what was happening and possibly, to find a way of reducing the beam spills in the beam line.
The configuration of the beam line is shown schematically in Fig. 1.

![Fig. 1: A schematic of the existing beam line](image)

In this beam line, the quadrupoles are equally spaced and are arranged in a horizontal-vertical-horizontal (HVH) configuration. Horizontal and vertical slits (Slit #2) are located at the exit of the quadrupole triplet. When the simulator program was run with the appropriate data of this beam line, it immediately became apparent that the horizontal beam envelope was too large at the location of these slits. This is shown in Fig. 2A, a plot generated by the program of the beam envelope in the horizontal plane. The vertical plane is shown in Fig. 2B from which it is clear that there is no vertical problem. For completeness, Fig. 2C shows the size of the beam spot predicted relative to the target (represented by the rectangle) in the existing configuration. The target shown is one-half the size of the original target. The remaining figures are discussed later.

On the existing beam line this resulted in large spills (10 to 20 µA) at the slits. In fact, the beam line was noticeably more radioactive there and frequent O-ring failures occurred because of radiation damage.

Using the simulator, the beam envelope was narrowed at the slits by increasing the field of the first quadrupole. However, although the beam envelope down stream of the triplet was narrowed, the horizontal beam width at the target was increased. This was confirmed when the tuning parameters were changed the same way on the real beam line.
Fig. 2: Calculated beam envelopes. A) Shows the beam being collimated horizontally within the beam line with a high level of spills on the slits. D) Represents the changes after the beam line was modified by adding the fourth quadrupole. Relative to A, the spills are reduced to a negligible levels. B, C, E and F show that overall the beam shape was maintained at the target.

2.2 Solution of the problem

Confidence in the program increased as it was confirmed, by using the program, that a problem existed and that the beam envelope behaved as predicted. It was decided to vary several parameters with the program that would not be so easy to change in practice. For example, different positions of the quadrupoles and different polarities could be tested in the simulator.

As noted above, the three quadrupoles operate in an HVH configuration. Using the program, the polarities were changed from HVH to VHV and it was quickly found that that would not help. Then the distance between the second quadrupole and the last was increased and again, it was found not to help.

Finally, an extra quadrupole was added. This had been discussed a few years ago as a possible beam-line optimization but was not needed then because the extracted current was lower and the target was larger. After many variations of the positions and polarities of the quadrupoles, the most effective model was found. It was to leave the first three quadrupoles in their initial locations and to add a fourth
in the target room as shown in Fig. 3. It was now possible to make the beam profile smaller than the target aperture. This was good because it allowed an operating margin when the extraction foil starts to deteriorate. In Fig. 2 the beam is tuned to create the same spread at the target, while reducing spills upstream. Figure 2D indicates smaller beam horizontally, 2E shows there was no change in the vertical beam profile and 2F shows the beam shape on target was maintained.

For completeness, Table 1 shows (some of) the various beam-line configurations modeled with the program. It shows the sequence of quadrupoles, i.e. HVH space H, and the distances to various beam-line magnets. The highlighted row yielded the best solution and required minimal change to the existing beam line.

<table>
<thead>
<tr>
<th>Beam Line Configuration</th>
<th>Combination Magnet</th>
<th>Drift Length</th>
<th>Quadrupole</th>
<th>Drift Length</th>
<th>Quadrupole</th>
<th>Drift Length</th>
<th>Quadrupole</th>
<th>Drift Length</th>
<th>Quadrupole or Dipole</th>
<th>Drift Length</th>
<th>Quadrupole or Dipole</th>
<th>Drift Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVH-H</td>
<td>CM</td>
<td>1119</td>
<td>Horizontal</td>
<td>139.8</td>
<td>Vertical</td>
<td>139.8</td>
<td>Horizontal</td>
<td>706.5</td>
<td>Vertical</td>
<td>118</td>
<td>Dipole</td>
<td>4796.8</td>
</tr>
<tr>
<td>HVHH</td>
<td>CM</td>
<td>1119</td>
<td>Horizontal</td>
<td>139.8</td>
<td>Vertical</td>
<td>139.8</td>
<td>Horizontal</td>
<td>684.7</td>
<td>Vertical</td>
<td>118</td>
<td>Dipole</td>
<td>4796.8</td>
</tr>
<tr>
<td>HVHV</td>
<td>CM</td>
<td>1119</td>
<td>Horizontal</td>
<td>139.8</td>
<td>Vertical</td>
<td>139.8</td>
<td>Horizontal</td>
<td>684.7</td>
<td>Vertical</td>
<td>118</td>
<td>Dipole</td>
<td>4796.8</td>
</tr>
<tr>
<td>VHVV</td>
<td>CM</td>
<td>1427</td>
<td>Vertical</td>
<td>139.8</td>
<td>Horizontal</td>
<td>139.8</td>
<td>Vertical</td>
<td>379.7</td>
<td>Horizontal</td>
<td>118</td>
<td>Dipole</td>
<td>4796.8</td>
</tr>
<tr>
<td>VH-VH</td>
<td>CM</td>
<td>1427</td>
<td>Horizontal</td>
<td>139.8</td>
<td>Vertical</td>
<td>139.8</td>
<td>Horizontal</td>
<td>776.7</td>
<td>Dipole</td>
<td>2303.8</td>
<td>Dipole</td>
<td>2500</td>
</tr>
<tr>
<td>HV-VH</td>
<td>CM</td>
<td>1427</td>
<td>Horizontal</td>
<td>139.8</td>
<td>Vertical</td>
<td>139.8</td>
<td>Horizontal</td>
<td>776.7</td>
<td>Dipole</td>
<td>2303.8</td>
<td>Dipole</td>
<td>2500</td>
</tr>
<tr>
<td>HVH-1</td>
<td>CM</td>
<td>1427</td>
<td>Horizontal</td>
<td>139.8</td>
<td>Vertical</td>
<td>139.8</td>
<td>Horizontal</td>
<td>776.7</td>
<td>Dipole</td>
<td>2303.8</td>
<td>Dipole</td>
<td>2500</td>
</tr>
<tr>
<td>HVH-1</td>
<td>CM</td>
<td>1427</td>
<td>Horizontal</td>
<td>139.8</td>
<td>Vertical</td>
<td>139.8</td>
<td>Horizontal</td>
<td>776.7</td>
<td>Dipole</td>
<td>2303.8</td>
<td>Dipole</td>
<td>2500</td>
</tr>
<tr>
<td>HVH-VH</td>
<td>CM</td>
<td>1119</td>
<td>Horizontal</td>
<td>139.8</td>
<td>Vertical</td>
<td>305</td>
<td>Horizontal</td>
<td>129.8</td>
<td>Vertical</td>
<td>379.7</td>
<td>Dipole</td>
<td>4796.8</td>
</tr>
<tr>
<td>VH-VH</td>
<td>CM</td>
<td>1119</td>
<td>Vertical</td>
<td>139.8</td>
<td>Horizontal</td>
<td>305</td>
<td>Vertical</td>
<td>139.8</td>
<td>Horizontal</td>
<td>379.7</td>
<td>Dipole</td>
<td>4796.8</td>
</tr>
</tbody>
</table>

Fortunately, a quadrupole with the correct effective length and bore diameter was available at TRIUMF. The solution was also tested on a different simulator program [2] and similar results were obtained.

This solution, the addition of another quadrupole downstream of the existing dipole, was presented to the administration who decided to adopt it.

![Fig. 3: A schematic of the existing beam line](image)

2.3 Final results with the above solution

After the fourth quadrupole was installed, tests were run with the beam on target to commission the new beam-line configuration.

Table 2 shows one example of several tests, which demonstrated good agreement of the predicted beam shape with what was attained. The total beam extracted for this test was 266.5 μA.
Table 1: Predicted result versus actual

<table>
<thead>
<tr>
<th>Total System Loss:</th>
<th>Predicted</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>32.60%</td>
<td>28.70%</td>
</tr>
<tr>
<td><strong>Combination Baffle</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left Collimator:</td>
<td>0.00 μA</td>
<td>0.15 μA</td>
</tr>
<tr>
<td>Right Collimator:</td>
<td>0.00 μA</td>
<td>2.47 μA</td>
</tr>
<tr>
<td><strong>Protection Slit #1</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top Collimator:</td>
<td>0.00 μA</td>
<td>0.07 μA</td>
</tr>
<tr>
<td>Bottom Collimator:</td>
<td>0.00 μA</td>
<td>0.46 μA</td>
</tr>
<tr>
<td>Left Collimator:</td>
<td>0.53 μA</td>
<td>2.90 μA</td>
</tr>
<tr>
<td>Right Collimator:</td>
<td>0.79 μA</td>
<td>2.73 μA</td>
</tr>
<tr>
<td><strong>Protection Slit #2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top Collimator:</td>
<td>0.00 μA</td>
<td>0.15 μA</td>
</tr>
<tr>
<td>Bottom Collimator:</td>
<td>0.00 μA</td>
<td>2.37 μA</td>
</tr>
<tr>
<td>Left Collimator:</td>
<td>0.00 μA</td>
<td>0.00 μA</td>
</tr>
<tr>
<td>Right Collimator:</td>
<td>0.00 μA</td>
<td>0.10 μA</td>
</tr>
<tr>
<td><strong>Bender Baffle</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collimator:</td>
<td>0.00 μA</td>
<td>0.10 μA</td>
</tr>
<tr>
<td><strong>Target Collimators</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top Collimator:</td>
<td>21.59 μA</td>
<td>14.0 μA</td>
</tr>
<tr>
<td>Bottom Collimator:</td>
<td>23.18 μA</td>
<td>13.0 μA</td>
</tr>
<tr>
<td>Left Collimator:</td>
<td>19.72 μA</td>
<td>19.0 μA</td>
</tr>
<tr>
<td>Right Collimator:</td>
<td>21.05 μA</td>
<td>19.0 μA</td>
</tr>
<tr>
<td><strong>Total Beam Loss</strong></td>
<td>86.88 μA</td>
<td>76.5 μA</td>
</tr>
<tr>
<td><strong>Beam Hitting Target</strong></td>
<td>179.62 μA</td>
<td>190 μA</td>
</tr>
<tr>
<td><strong>Total Beam Extracted</strong></td>
<td>266.5 μA</td>
<td>266.5 μA</td>
</tr>
</tbody>
</table>

3. USEFULNESS OF BEAM-LINE SIMULATOR AS A TUNING AID

3.1 To refine and improve a beam-line tune

Suppose it is desired to increase the target current on one of the beam lines. Without a simulator one would start by entering the parameters for a standard tune. Based on their experience and knowledge, the operators would then try to adjust the field strengths of the quadrupoles. In practice it was found that the results varied considerably depending on the skills of the operators.

Using a beam-line simulator program an operator can see immediately the effect of various quadrupoles settings. This would help them to know which way to vary the parameters.

Consider for example, the situation shown in Fig. 4. Figure 4A shows the beam profile in the horizontal plane of an existing beam line. Clearly, there is beam spill on some slits. The beam profile in the vertical plane, shown in Fig. 4B, shows no such spill. With the use of a beam-simulator program, an operator has obtained the horizontal and vertical beam profiles shown in Figs. 4C and 4D. It is apparent that the beam spill in the horizontal plane has been reduced without causing spill in the vertical plane.

Thus, with the use of a simulator program, an operator has achieved a solution to a beam-spill problem without doing any ‘knobbing around’ on a real machine. It immediately becomes apparent to the operator what is really happening when settings are changed on the beam line. This is a safer, as well as a faster, way of finding a means to an end.
Fig. 4: The beam envelopes before and after ‘tuning’ with the simulator program. A) Shows the beam being collimated horizontally within the beam line with a high level of spills on the collimators. C) Represents the changes in the beam envelope after changing the parameters in the beam-line simulator program. B) and D) show that the beam shape was maintained for the target in vertical plane.

In this example, a relatively simple beam line with only three quadrupoles was discussed. Imagine the complexities that would arise in a beam line that has many quadrupoles, or many types of targets, or if tuning for different energies was required. In each case, the parameters could be tried on a beam-line simulator.

3.2 To obtain a new tune

A new tune can be found with much less frustration. Once an optimum tune is found on the simulator, it should be producible on the real machine. The simulator would no longer be needed after a working tune has been established, but it could still be used as a teaching tool.

3.3 As a teaching aid

All that has been discussed above can equally well be used to teach new operators the basic concepts of beam dynamics. For example, they could be instructed in:

- beam envelope or multi-particles diagrams.
- collimation.
- quadrupole tuning and how it affects the beam envelope.
- effects of different energies.
- how positioning of elements affects beam size and loss.
3.4 As an aid in visualizing beam shape

Before we had the beam-line simulator program, we tried to explain how to focus the beam with a quadrupole. We told the operator to imagine that the beam was like a balloon, and the quadrupole was squeezing it in only one direction at a time. For example, when the balloon was squeezed horizontally it would blow up vertically and vice versa. This can be easily demonstrated with the beam-line simulator. As each quadrupole is adjusted the operator can see the effect on the beam envelope.

4. CONCLUSION

The usefulness of a beam-line simulator has been demonstrated in one operating group at TRIUMF. Of course, the simulation is only as good as the model being used. That is, the properties of the extracted beam and all of the beam-line elements must be well known. It is necessary to know accurately:

- the parameters of the extracted beam (emittance, horizontal and vertical sizes and divergences, and momentum spread).
- the effective lengths of all elements.
- the relative positions of the elements.

It is the author’s opinion that a user-friendly, graphical program of this kind is not only useful but is essential for any accelerator control room.

5. ACKNOWLEDGEMENTS

I wish to thank TRIUMF for its support of this project and in particular the following: Dr. Glen M. Stinson, Dr. Thomas Kuo, Dr. Morgan Dehnel, Mr. Jeff Lofvendahl, and Mr. René van den Elzen.

References

[1] Beamline Simulator version 1.3c. Dehnel Consulting Ltd. WWW.DEHNEL.COM.

OPERATION WITHOUT OPERATORS

U. Georg, R. Catherall, T. Giles, O.C. Jonsson
Division PS, CERN, 1211 Geneva 23, Switzerland

Abstract

Small facilities like ISOLDE cannot afford to have enough operators to serve experiments with beam 24 hours a day. In year 2000 almost 40 research groups worked at ISOLDE to perform 70 different experiments lasting from several hours to several days. The guest researchers operate the separator themselves during their beam time, and are only assisted in case of technical problems by local specialists. This implies an easily-understandable user interface, considerable user training and a reliable and robust machine.

1. INTRODUCTION

Facilities that run 24 hours a day and 7 days a week need a certain minimum number of operational staff, like 7 operators working in 8 hour shifts plus several machine specialists and supervisors. This need of personnel is in severe contrast to the manpower available at ISOLDE. For the year 2000 only four staff spent 50% of their time dedicated to ISOLDE operation. It is therefore a long tradition, that the users, i.e. the guest researchers, operate the facility themselves during the performance of their experiments.

2. FACILITY DESCRIPTION

The on-line isotope mass separator, ISOLDE, is a facility dedicated to the production of a large variety of radioactive ion beams. The radioactive nuclides are produced in thick high-temperature targets via spallation, fission or fragmentation reactions. The targets are placed in the external proton beam of the PS Booster, which has an energy of 1 or 1.4 GeV and an average intensity of 2 μA. The facility consists of two mass separators, a General Purpose Separator (GPS) and a High Resolution Separator (HRS) with a separate target station for each. Isotopes produced at these target stations are ionised and accelerated with 60 kV. The ion beam is sent through a magnet, and the mass-separated beam is guided into the experimental hall. This hall is accessible during all operations. It should be noted here that all beam steering and focusing elements are electrostatic, i.e. mass independent. Therefore beam tuning can always be performed with a conveniently strong ion beam of a non-radioactive isotope. For an experiment interested in radioactive species, after the successful tuning it is sufficient to change the magnetic field of the mass separator magnet and the desired isotope will pass to the experiment. The intensities of such radioactive beams used at ISOLDE vary from \(10^{12}\) particles per second to below 1 particle per hour.

A layout of the facility is shown in Fig. 1, also showing the target handling facilities like the two robots and a hot cell. The different names in the experimental hall label the different beam-lines and permanently installed experiments. Normally the whole facility is controlled from the ISOLDE control room but remote interventions are also possible through CERN’s office network.
3. **ISOLDE OPERATION**

ISOLDE is fully integrated into CERN’s accelerator structure and therefore generally runs from April until the beginning of December. During that period the beam time is organised in shifts of 8 hours, distributed by the physics co-ordinator to approved experiments. The typical running time of a target/ion source unit is between several days and a few weeks, depending on the physics demands and on the performance of the unit itself. Then a target change follows, causing a one to four days interruption of the physics programme of that separator. This down-time of the facility can be considerably reduced by running the two separators GPS and HRS in a so-called push-pull mode, i.e. setting-up one separator while the other one is serving the physics programme. In year 2000 about 350 shifts of radioactive ion beams have been delivered to the experiments.

The ISOLDE standard operation can be split into two parts:

1. The target change is done by an ISOLDE supervisor (ISS) using the robots. After a period of heating-up the target and ion-source to its nominal temperature, the ISS also sets up the ion beam from the ion source to the focal plane of the separator magnet. The set-up procedure includes the tuning of the ion source, the beam steering and an initial calibration of the mass separator magnets. The proper adjustment of the proton beam onto the target is also done by the ISS.

2. After this, the users take over the beam and do the remaining beam tuning from the focal plane to their experimental set-up. From the moment of taking over, the users are also responsible for the surveillance of the whole facility including target and ion source as well as the proton beam.

The setting up of the first part takes only a minor part of the running time, meaning that the facility is mainly operated by non-specialists.
3.1 Users as operators

The fact that non-specialists operate the facility during most of the time implies that they need proper training and that the control system should offer a rather self-explanatory user interface. In order to hand over the machine smoothly from one experiment to the other, good documentation of the operation history via logbooks, and communication with the surveying ISS is needed.

3.1.1 User training

From each group of users, at least one member should be able to operate the whole separator at a basic level. In order to ensure this, ISOLDE organises separator courses every year for new users. Here they are trained and introduced to the duties of the so-called ‘physicist in charge’ (PIC). One course lasts two full days and is attended by at most four students. It is a real hands-on course showing all aspects of the operation of ISOLDE.

The course starts with a general introduction to the tasks of the PIC, and provides a list of the most important contact points during the beam-time: the ISOLDE physics co-ordinator, the ISS, CERN’s radio-protection service and the PS control room. It also introduces future users to the layout of the beam-lines, the actual location of the equipment and the naming conventions, allowing the PIC to make a first attempt to recover the machine in case of failure before calling in the ISS for assistance. About 75% of the time is used to learn how to focus and steer an ion beam through the beam-lines, observing it with tools like beam scanners, wire grids and Faraday-cups by sending it to different points in the experimental hall. Using the GPS’s ability to run up to three beams in parallel allows the students to run a beam on their own most of the time and to become familiar with the control system. While facing their first problems, the students collect experience in fault finding and solving, and in co-ordinating with each other. Important procedures like the calibration of the mass separator magnets or the changing of the acceleration voltage are also explained thoroughly. The course ends by pointing out safety hazards of the facility, in particular during the operation with radioactive ion beams.

3.1.2 A user friendly control system

As the typical ISOLDE user only occasionally uses the separator, it would be hard to memorise the exact names of all beam-line elements. They are therefore not listed in working sets but displayed by a synoptic program which can be seen in Fig. 2. This kind of user interface is almost self-explanatory, especially as it runs in a standard office environment, i.e. on personal computers (PCs) with MICROSOFT Windows as operating system. To gain control over a particular element, it is sufficient to click on the graphical display and the assigned control window will pop up. This possibility exists for almost every element of the separator, including beam observation and vacuum control. The use of standard PCs also offers to registered users an easy way to control the ion beam from near their experimental set-ups by just connecting additional computers to the CERN network.
3.1.3 Communication and documentation

A very crucial point, when the operators change so often, is to establish communication and to pass information between not only the ISOLDE staff, but also other CERN groups, as for example the operational team of the proton accelerators.

The on-going operation is documented in an electronic logbook, running on a dedicated PC — one for each separator. These logbook files are publicly available all over CERN via the office network. In the logbooks the users as well as the ISS mark important information like the current status of the operation, who is in charge of the machine, and detected problems and failures. These notes serve later as input for technical support groups in case an intervention needs to be scheduled. Information that describes certain procedures like the calibration of the separator magnets or the use of implantation chambers is available from a web-based help system. There the user can also find some documentation pages about the use and properties of equipment installed in the separator, like the beam-gates or the availability of timing signals. Other pages help in case the user needs assistance from specialists or the ISS.

3.2 ISOLDE supervision

Up to now, one ISS was in charge for the entire run of a particular target. His duty started with mounting the target on the machine and ended when the next target was put on. He did the initial setting-up as explained above, and was on call to assist the users in case of technical problems with the separator during the performance of their experiments. These service periods lasted typically between five days and two weeks. In case that the GPS and the HRS were running in parallel, two ISS were on duty.

From 2001, the on-call service of the ISSs will be implemented in a new way. There will be only one ISS on duty per week, regardless of whether one or two separators are running. The set-up of a target will be made by another ISS during normal working hours the week before it is to be used. In the optimal case this will be the ISS who will also be first in charge of the running of that target unit. During the outgasing and heating, the target and ion-source parameters will be monitored by the operating team of the PS Booster.
4. CONCLUSION

The method of operation outlined above has worked very well for a long time. However it may not be easy to apply it to other facilities. One reason is that the machine should be of limited complexity, allowing one to gain control over all main parameters rather quickly. For ISOLDE this is certainly the case. Once everything is set up, the operation consists mostly of surveillance. There are periods of many hours when no action on the machine is needed. By comparison with highly sophisticated timing sequences usually applied in accelerators, it should be noted that the timing system of ISOLDE consists of less that 10 signals. Most of them are even provided by the PS Booster, and all have fixed settings independent of the actual running mode. Also the risk of damage to the machine due to failure during the operation is rather limited at ISOLDE. There are occasionally radiation hot-spots created due to losses of radioactive beams inside the beam-lines, but there is no risk of really damaging the beam-line tubes with the beam, as the intensity and energy are by far too low. Those hot-spots are normally caused by rather short-lived isotopes, meaning that they will decay rather quickly.

The exchange of information should be considered as a major challenge. It is really a problem to keep everybody up to date when the number of operators is unlimited, and it needs lots of discipline concerning keeping the logbook. Another problem is the efficiency of using the machine, which might be slightly lower than with professional operators. However the financial saving of 7 operators’ posts far outweighs these problems.

For the future it is planned that the users will continue to do the operation as they did in the past, but in case of problems, the ISS contacts will be replaced by the PS operating team, who will organise assistance from the various specialists who are on call anyway for the PS accelerators.
A NEW MODEL FOR A 500 MEV BEAM LINE AT TRIUMF

John Kaminski
TRIUMF, 4004 Wesbrook Mall, Vancouver, B.C., Canada V6T-2A3

Abstract
The program INTRAN that was developed at TRIUMF has been used to test a new model for the high current (150 uA) 500 MeV primary beam line. An older model is discussed first to indicate the reason it was felt that a new model of the beam line was required. The development of a new model and its applicability are then discussed.

1. INTRODUCTION
TRIUMF is a sector-focussed H⁻ cyclotron; its six sectors are arranged in a pinwheel shape. Extraction of beam is accomplished by intercepting the circulating H⁻ beam with a thin carbon foil that strips the two electrons from the H⁻ ions and produces an H⁺ or proton beam. Because this proton beam is of an opposite charge to the circulating H⁻ beam, the proton beam is deflected out of the cyclotron. Proton beams are extracted at energies varying from 180 MeV to 510 MeV and intensities from a few nanoamperes to 150 microamperes.

At present, as many as four beams may be extracted simultaneously into four different beam lines, each of which runs at a different energy and a different intensity. Of these, the primary beam line that feeds the experiments in the meson hall is called beam line 1A. This beam line routinely operates at an energy of 500 MeV and beam currents of 150 µA to maximize meson production at its two production targets 1AT1 and 1AT2. It is the modelling of this beam line up to the first target 1AT1 that is the subject of this paper.

The proton beam is guided to the target by conventional quadrupole, dipole, and steering magnets. An optics program such as TRANSPORT [1] or INTRAN [2] may be used to compute the settings of these elements to produce the desired beam properties at the target locations and to predict the beam size along the beam line under those conditions. Of course, a realistic model of the beam line is necessary in order that reasonable results are obtained for the actual beam line.

This paper will start with a discussion of the old model— its creation, configuration, and file structure. Then the discussion will turn to why an attempt has been made to replace the old model with a newer model. The intent would be to make the new model the reference model for tuning beam line 1A and to reflect the present status of the beam line.

2. THE INTRAN PROGRAM AND ITS DATA FILE STRUCTURE
In this study of beam line 1A, I have used INTRAN (INteractive TRANsport), an optics program developed at TRIUMF. Because INTRAN uses TRANSPORT as a subroutine, it too represents elements of a beam line with matrices and calculates the effect of the elements by matrix multiplication. INTRAN allows the user to interactively change element settings and to display the results of such changes in both graphical and tabular form. As examples, the beam envelope or accumulated transfer-matrix elements may be plotted as a function of distance along the beam line. Phase-space ellipses may be plotted at any point along the beam line. Similarly, beam parameters and transfer-matrix elements may be tabulated along, or at any point in, the beam line.

Input data for INTRAN follows the same prescription as that for TRANSPORT and may be created with a text editor. At TRIUMF, an input data file describes the beam line as a sequence of
elements from the extraction foil to the end of the beam line. These elements consist of a description of the initial beam followed by a list of the various magnets, their magnetic properties, and the distances between them. Also included are specifications of specific calculations to be done.

For the specific case of beam transport on beam line 1A, the input data file can be considered to be split into a description of three general regions.

Region 1: 1a) Parameters that describe the beam at the stripper foil. These are:
- the horizontal half-width of the beam $x$ (cm),
- the half-width of the horizontal divergence $\theta$ (mr),
- the vertical half-width of the beam $y$ (cm),
- the half-width of the vertical divergence $\phi$ (mr),
- the half-width of the longitudinal beam extent $\ell$ (cm),
- the half-width of the momentum spread $\delta p$ (%) in TRANSPORT (and INTRAN) notation these are $\gamma_{21}$ and $\gamma_{43}$.

1b) Parameters that describe the orientation of the phase-space ellipses at the stripper foil. In the case of beam line 1A only the orientations of the $x$-$\theta$ and $y$-$\phi$ ellipses are required. In TRANSPORT and INTRAN notation these are $\gamma_{21}$ and $\gamma_{43}$.

Region 2: 2) Transfer matrix from the stripper foil to the exit of the combination magnet. These elements are obtained from computer calculations based on fields measured in the cyclotron and transfer the beam from the foil to exit of combination magnet. In TRANSPORT notation these are the matrix elements $R_{11}$, $R_{12}$, $R_{16}$, $R_{21}$, $R_{22}$, $R_{26}$, $R_{33}$, $R_{34}$, $R_{43}$, and $R_{44}$.

Region 3: 3) The beam transport components and their separations. Each transport element has its own code. Quadrupole parameters are its effective length (meter), pole-tip field strength (kG), and half-aperture (cm). Dipole parameters are its effective length (meter), magnetic field (kG), and field index ($n$). Element separations are given in meters.

3. OLD MODEL

Measurements of the magnetic field of the cyclotron allowed the calculation of the expected beam parameters at the stripper foil (regions 1a and 1b) and of the matrix elements required for region 2. These, together with the properties and locations of the beam-transport elements, were used to create an input data file called 1ASTD that described the beam optics of the beam line. I used this file to determine if the data is still valid for the present beam line. I ran INTRAN using 1ASTD as the input data file and obtained the predicted size of the beam spot at the first seven profile monitors of the beam line. A comparison of the predicted beam size with that of the observed spot size on 14 April, 2000 at each of the profile monitors is given in Tables 1A and 1B. The large discrepancies of the horizontal beam sizes at monitors 1VM3 to 1VM7 and of the vertical beam sizes at monitors 1VM1 to 1VM4.6 are obvious. Monitors 1VM2 to 1VM7 are secondary-emission profile monitors with a $3 \, \text{mm} \times 3 \, \text{mm}$ (horizontal by vertical) wire spacing; that of monitor 1VM1 is $2 \, \text{mm} \times 2 \, \text{mm}$ and that of monitor 1AT1 is $1 \, \text{mm} \times 1 \, \text{mm}$.

To isolate and understand why the discrepancies occurred, an examination of the data in the file 1ASTD was undertaken. I began by examining the data for each of the three regions noted in section 2 above. Of these, region 3 was the easiest part of the input data file to verify. The design specifications of the quadrupoles and dipole were checked to verify that these elements were properly described. Drift spaces between and locations of the elements were checked against blueprints of the beam line. Any errors in drift distances, quadrupole effective lengths and apertures or dipole effective length were corrected in the input data file.
The next step was to obtain accurate values of the quadrupole and dipole magnetic fields. To determine the quadrupole field the following equation from reference 3 was used:

\[ B' = 2\mu_0\eta\frac{NI}{R_0^2} \]  
(1)

with \( \mu_0 = \) permeability of free space = \(4\pi \times 10^{-7} \text{ N} \cdot \text{A}^{-2}\), 
\( \eta = \) efficiency = 1, 
\( N = \) the number of linked turns per pole, 
\( I = \) the current in each turns in amperes, 
\( R_0 = \) the radius of the aperture in meters, 
\( B' = \) the quadrupole field gradient in Tesla per meter.

The dipole field was calculated from the following equation, also taken from reference 3.

\[ B = \mu_0\eta\frac{NI}{g} \]  
(2)

with \( \mu_0 = \) permeability of free space = \(4\pi \times 10^{-7} \text{ N} \cdot \text{A}^{-2}\), 
\( \eta = \) efficiency = 1, 
\( N = \) the number of linked turns per pole, 
\( I = \) the current in each turns in amperes, 
\( g = \) the half-gap of the dipole in meters, 
\( B = \) the central dipole field in Tesla.

Values for the currents that flow through the quadrupoles and dipole were obtained from the control system read-back. Those for \( N, R_0, \) and \( g \) that occur in the equations were obtained from the design specifications for these elements. The magnetic fields for the quadrupoles and dipole were calculated and up-dated in the input data file 1ASTD which was then renamed MG.txt.

The parameters of region 1 and region 2 were difficult to determine accurately because the 6 beam input values and the 10 matrix values of the transfer matrix dated back to the early 1970s. Further, the beam input parameters (i.e. the beam emittance) change with the tune and type of the ion source, the centre region of the cyclotron, and cyclotron tune itself. INTRAN has the provision of TRANSPORT to vary some of the physical parameters of the elements of the system and to impose various constraints on the beam design. The constraints imposed in this case were the actual beam sizes observed at the seven profile monitors on 14 April, 2000. The initial parameters varied were the 10 elements of the transfer matrix of region 2. A first-order run was made to fit the constraints and the new matrix values were saved to the input data file MG.txt.

The next step was to impose the same constraints but to vary the input beam (that is, the emittance) of the extracted beam. However, one small problem had to be dealt with before continuing; the first quadrupole was run in an asymmetrical configuration. It has the capability to steer the beam vertically by shunting some of the current away from the coil that effects the focussing/defocussing of the beam in the vertical plane. Because there is no real model for this particular configuration in INTRAN, all beam profile monitor printouts were made with the steering capability set to zero, thus giving the first quadrupole true quadrupole properties. A second first-order run was then made. The results, tabulated in Tables 2A and 2B, are seen to closely match the observed profiles on beam line 1A.
4. A NEW MODEL

Although the modified model MG.txt is a reasonable representation of the present beam line, I felt that I could improve the model. The region that I focussed on was the transfer matrix of region 2. This is a 6 x 6 matrix in INTRAN but for our purpose it can be reduced to a 5 x 5 matrix with R55 equal to unity and with the only other non-zero elements being the 10 listed in section 2. However, in varying these 10 elements INTRAN would choose to vary those just to fit the imposed constraints without regard as to whether they were physically meaningful. Consequently, I had little confidence in the results and decided that another method was needed to describe the beam path from extracted foil to exit of combination magnet.

The cyclotron pole faces look like an odd-shaped dipole. The INTRAN input data file for a (uniform field) dipole only needs the magnetic field and the effective length. A plot was obtained of cyclotron magnetic field along the path of the extracted protons from extraction foil to combination magnet exit horn. The plot was then segmented into regions of constant magnetic fields. Where non-linear fields existed small increments of distance were taken. These numerous dipole segments were then edited into the input data file MG.txt. Their effective lengths were taken as the actual lengths of the various segments. This approach was taken because the cyclotron magnetic field is vertical and uniform. It must be noted that there might be small region of the cyclotron in which the beam path is over the edge of a cyclotron pole and this could skew the results. By representing the cyclotron with a string of magnetic segments, the 10 transfer-matrix values could be removed and, the combination magnet could be added as a standalone device. A first-order run was done; the results are given in Tables 3A and 3B. The input file was saved and renamed NM.txt.

5. COMPARISON OF INPUT FILES 1ASTD, MG.TXT, AND NM.TXT

Tables 4A, 4B, and 4C compare the results of the three input data files. Table 4A lists the values of the emittance for input data file 1ASTD. The tabulated results are the emittance of the beam as determined in late 1970. The fitting routine of INTRAN was used to determine new values for the emittance used in the other input files. Table 4B lists the matrix elements of the transfer matrix that were used. Finally, Table 4C tabulates the changes made for in the magnetic fields of the eight quadrupoles and the dipole.

6. CONCLUSION

The INTRAN program was initially used as a training tool for understanding the beam optics and beam line transport devices. The input data file 1ASTD was used as a reference-starting model of the beam line 1A. After running the TRANSPORT program and comparing the results of the program versus the actual beam line profile monitor, it was apparent that the old model needed to be up-dated. The procedure was to correct any errors in the information data regarding the various devices like quadrupole, dipole and steering magnet. The distances between the devices were compared to those in blueprints. Once the old model was up-dated to reflect the present beam line 1A configuration, a second look at simplifying the model was undertaken.

Removal of the transfer matrix of region 2 of the input data would greatly simplify the model. This lead to regarding the cyclotron pole region as a sequence of many dipoles. The path of the beam from the extraction foil to combination magnet exit was calculated from magnetic field data taken done in 1970. At present, an NMR probe located in a region of stable magnetic field gives an accurate cyclotron magnetic field reading. It was felt that scaling the magnetic field reading throughout the beam extraction path might be feasible.

The only data to be up-dated was the emittance of the beam at the extraction foil. This left only four values to be determined. Two values the horizontal (x) and vertical (y) size of the beam can be determined by using various probes in the cyclotron to intercept the beam. These probes have current read-back capability.
The only difficult values to determine were the horizontal and vertical angular divergences of the beam at the foil. One method to determine these values would be to fit them with the fitting capability of INTRAN/TRANSPORT. However, a difficulty with this procedure is that the program will choose values that the chosen values may or may not necessarily be consistent with the known emittances. Further, the orientations of the phase-space ellipses must also be considered during the fitting procedure. Consequently, an alternate approach may be needed.

From a knowledge of the horizontal and vertical emittances at the ion source and the measured beam sizes from the probe measurements, approximate values for the horizontal and vertical divergences may be calculated. Although these computed values would represent upright phase-space ellipses at the stripper foil, they could be used as a starting point for further calculations, some of which could involve varying the $r_{21}$ and $r_{43}$ parameters to tilt the horizontal and vertical phase-space ellipses.

Validation of the new model will begin with a test scheduled in April, 2001. The procedure will be to change the magnetic field of a quadrupole and to observe the effect on beam sizes at the downstream monitors. These observed beam sizes will then be compared to the sizes predicted by INTRAN when the new model is used as an input data file.

7. ACKNOWLEDGEMENT

I would like to thank TRIUMF for giving me the opportunity to attend the WAO2001 conference and in particular Dr. G. Stinson for his valuable support and encouragement, from helping me understand the beam line optics to the final editing of this paper.

References


### TABLE 1A
A comparison between observed horizontal beam sizes and those predicted by the original INTRAN data file

<table>
<thead>
<tr>
<th>Profile monitor</th>
<th>1ASTD prediction mm</th>
<th>Observed 14 April, 2000 mm</th>
<th>Difference mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1VM1</td>
<td>4.0</td>
<td>3.0</td>
<td>1.0</td>
</tr>
<tr>
<td>1VM2</td>
<td>2.6</td>
<td>4.5</td>
<td>1.9</td>
</tr>
<tr>
<td>1VM3</td>
<td>14.2</td>
<td>7.5</td>
<td>6.7</td>
</tr>
<tr>
<td>1VM4.6</td>
<td>23.2</td>
<td>5.3</td>
<td>17.9</td>
</tr>
<tr>
<td>1AM6</td>
<td>17.2</td>
<td>4.5</td>
<td>12.7</td>
</tr>
<tr>
<td>1AM7</td>
<td>15.2</td>
<td>6.0</td>
<td>9.2</td>
</tr>
<tr>
<td>1AT1</td>
<td>2.0</td>
<td>2.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

### TABLE 1B
A comparison between observed vertical beam sizes and those predicted by the original INTRAN data file

<table>
<thead>
<tr>
<th>Profile monitor</th>
<th>1ASTD prediction mm</th>
<th>Observed 14 April, 2000 mm</th>
<th>Difference mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1VM1</td>
<td>9.4</td>
<td>26.0</td>
<td>16.6</td>
</tr>
<tr>
<td>1VM2</td>
<td>3.0</td>
<td>13.5</td>
<td>10.5</td>
</tr>
<tr>
<td>1VM3</td>
<td>12.0</td>
<td>18.0</td>
<td>6.0</td>
</tr>
<tr>
<td>1VM4.6</td>
<td>7.0</td>
<td>19.5</td>
<td>12.5</td>
</tr>
<tr>
<td>1AM6</td>
<td>14.4</td>
<td>16.5</td>
<td>2.1</td>
</tr>
<tr>
<td>1AM7</td>
<td>4.8</td>
<td>4.5</td>
<td>0.3</td>
</tr>
<tr>
<td>1AT1</td>
<td>7.0</td>
<td>7.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>
### TABLE 2A
A comparison between observed horizontal beam sizes and those predicted by the modified INTRAN data file

<table>
<thead>
<tr>
<th>Profile monitor</th>
<th>MG.txt prediction</th>
<th>Observed 14 April, 2000</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1VM1</td>
<td>3.0</td>
<td>1.4</td>
<td>1.6</td>
</tr>
<tr>
<td>1VM2</td>
<td>4.5</td>
<td>2.8</td>
<td>1.7</td>
</tr>
<tr>
<td>1VM3</td>
<td>7.5</td>
<td>7.4</td>
<td>0.1</td>
</tr>
<tr>
<td>1VM4.6</td>
<td>5.3</td>
<td>6.2</td>
<td>0.9</td>
</tr>
<tr>
<td>1AM6</td>
<td>4.5</td>
<td>4.0</td>
<td>0.5</td>
</tr>
<tr>
<td>1AM7</td>
<td>6.0</td>
<td>4.2</td>
<td>1.8</td>
</tr>
<tr>
<td>1AT1</td>
<td>2.0</td>
<td>4.2</td>
<td>2.2</td>
</tr>
</tbody>
</table>

### TABLE 2B
A comparison between observed vertical beam sizes and those predicted by the modified INTRAN data file

<table>
<thead>
<tr>
<th>Profile monitor</th>
<th>MG.txt prediction</th>
<th>Observed 14 April, 2000</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1VM1</td>
<td>26.0</td>
<td>26.0</td>
<td>0.0</td>
</tr>
<tr>
<td>1VM2</td>
<td>13.5</td>
<td>13.2</td>
<td>0.3</td>
</tr>
<tr>
<td>1VM3</td>
<td>18.0</td>
<td>18.8</td>
<td>0.8</td>
</tr>
<tr>
<td>1VM4.6</td>
<td>19.5</td>
<td>18.4</td>
<td>0.9</td>
</tr>
<tr>
<td>1AM6</td>
<td>16.5</td>
<td>18.0</td>
<td>1.5</td>
</tr>
<tr>
<td>1AM7</td>
<td>4.5</td>
<td>8.4</td>
<td>0.9</td>
</tr>
<tr>
<td>1AT1</td>
<td>7.0</td>
<td>9.6</td>
<td>2.2</td>
</tr>
</tbody>
</table>
### TABLE 3A
A comparison between observed horizontal beam sizes and those predicted by the further modified INTRAN data file

<table>
<thead>
<tr>
<th>Profile monitor</th>
<th>NM.txt prediction mm</th>
<th>Observed 14 April, 2000 mm</th>
<th>Difference mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1VM1</td>
<td>3.0</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>1VM2</td>
<td>4.5</td>
<td>3.6</td>
<td>0.9</td>
</tr>
<tr>
<td>1VM3</td>
<td>7.5</td>
<td>5.8</td>
<td>1.7</td>
</tr>
<tr>
<td>1VM4.6</td>
<td>5.3</td>
<td>6.6</td>
<td>1.3</td>
</tr>
<tr>
<td>1AM6</td>
<td>4.5</td>
<td>3.4</td>
<td>1.1</td>
</tr>
<tr>
<td>1AM7</td>
<td>6.0</td>
<td>2.2</td>
<td>3.8</td>
</tr>
<tr>
<td>1AT1</td>
<td>2.0</td>
<td>3.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

### TABLE 3B
A comparison between observed vertical beam sizes and those predicted by the further modified INTRAN data file

<table>
<thead>
<tr>
<th>Profile monitor</th>
<th>NM.txt prediction mm</th>
<th>Observed 14 April, 2000 mm</th>
<th>Difference mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1VM1</td>
<td>26.0</td>
<td>24.0</td>
<td>2.0</td>
</tr>
<tr>
<td>1VM2</td>
<td>13.5</td>
<td>12.2</td>
<td>1.3</td>
</tr>
<tr>
<td>1VM3</td>
<td>18.0</td>
<td>17.8</td>
<td>0.2</td>
</tr>
<tr>
<td>1VM4.6</td>
<td>19.5</td>
<td>18.6</td>
<td>0.9</td>
</tr>
<tr>
<td>1AM6</td>
<td>16.5</td>
<td>20.0</td>
<td>3.5</td>
</tr>
<tr>
<td>1AM7</td>
<td>4.5</td>
<td>8.2</td>
<td>3.7</td>
</tr>
<tr>
<td>1AT1</td>
<td>7.0</td>
<td>8.8</td>
<td>1.8</td>
</tr>
</tbody>
</table>
### TABLE 4
A comparison of input parameters used in the three data files

A: The input parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>1ASTD</th>
<th>MG.txt</th>
<th>NM.txt</th>
</tr>
</thead>
<tbody>
<tr>
<td>(x) (cm)</td>
<td>0.26800</td>
<td>0.17215</td>
<td>0.17215</td>
</tr>
<tr>
<td>(\theta) (mr)</td>
<td>1.08100</td>
<td>0.05096</td>
<td>0.05096</td>
</tr>
<tr>
<td>(y) (cm)</td>
<td>0.67800</td>
<td>0.63279</td>
<td>0.63279</td>
</tr>
<tr>
<td>(\phi) (mr)</td>
<td>0.66700</td>
<td>1.85495</td>
<td>1.85495</td>
</tr>
<tr>
<td>(\ell) (cm)</td>
<td>0.05000</td>
<td>0.00000</td>
<td>0.00000</td>
</tr>
<tr>
<td>(\delta\phi) (%)</td>
<td>0.20000</td>
<td>0.38494</td>
<td>0.38494</td>
</tr>
</tbody>
</table>

### TABLE 4B
The transfer matrices

<table>
<thead>
<tr>
<th>Parameter</th>
<th>1ASTD</th>
<th>MG.txt</th>
<th>NM.txt</th>
</tr>
</thead>
<tbody>
<tr>
<td>(R_{11})</td>
<td>-0.06700</td>
<td>-0.06700</td>
<td>0.0</td>
</tr>
<tr>
<td>(R_{12})</td>
<td>0.34800</td>
<td>0.34800</td>
<td>0.0</td>
</tr>
<tr>
<td>(R_{16})</td>
<td>1.30000</td>
<td>1.30000</td>
<td>0.0</td>
</tr>
<tr>
<td>(R_{21})</td>
<td>-2.95000</td>
<td>-2.95000</td>
<td>0.0</td>
</tr>
<tr>
<td>(R_{22})</td>
<td>0.26000</td>
<td>0.26000</td>
<td>0.0</td>
</tr>
<tr>
<td>(R_{26})</td>
<td>1.70000</td>
<td>1.70000</td>
<td>0.0</td>
</tr>
<tr>
<td>(R_{33})</td>
<td>1.07000</td>
<td>1.11658</td>
<td>0.0</td>
</tr>
<tr>
<td>(R_{34})</td>
<td>0.62700</td>
<td>0.61736</td>
<td>0.0</td>
</tr>
<tr>
<td>(R_{43})</td>
<td>0.25600</td>
<td>-0.04733</td>
<td>0.0</td>
</tr>
<tr>
<td>(R_{44})</td>
<td>1.08500</td>
<td>1.13774</td>
<td>0.0</td>
</tr>
</tbody>
</table>

### TABLE 4C
The quadrupole and dipole field strengths

<table>
<thead>
<tr>
<th>Parameter</th>
<th>1ASTD</th>
<th>MG.txt</th>
<th>NM.txt</th>
</tr>
</thead>
<tbody>
<tr>
<td>1ACM</td>
<td></td>
<td></td>
<td>3.06557</td>
</tr>
<tr>
<td>1VQ1 (H)</td>
<td>5.55170</td>
<td>5.65966</td>
<td>5.65966</td>
</tr>
<tr>
<td>1VQ2 (V)</td>
<td>6.44503</td>
<td>6.33824</td>
<td>6.33824</td>
</tr>
<tr>
<td>1VQ3 (H)</td>
<td>6.49836</td>
<td>6.36351</td>
<td>6.36351</td>
</tr>
<tr>
<td>1VB1</td>
<td>9.55200</td>
<td>10.01889</td>
<td>10.01889</td>
</tr>
<tr>
<td>1AQ4 (H)</td>
<td>2.33930</td>
<td>2.37143</td>
<td>2.37143</td>
</tr>
<tr>
<td>1AQ5 (V)</td>
<td>4.01830</td>
<td>3.65279</td>
<td>3.65279</td>
</tr>
<tr>
<td>1AQ6 (H)</td>
<td>2.08420</td>
<td>2.0808</td>
<td>2.08086</td>
</tr>
<tr>
<td>1AQ7 (V)</td>
<td>3.97637</td>
<td>3.67084</td>
<td>3.67084</td>
</tr>
<tr>
<td>1AQ8 (H)</td>
<td>4.09420</td>
<td>4.55335</td>
<td>4.55335</td>
</tr>
</tbody>
</table>

42
CYCLOTRON BEAM TRANSPORT DEVELOPMENT USING BEAMLINE SIMULATOR

D.B. Mackay
MRC Cyclotron Unit, London, U.K.*

Abstract
The Scanditronix MC40 cyclotron at Hammersmith is a multi-particle, variable-energy machine. It is connected to an extensive beam transport system. Development of the facility has been made easier by the use of a beam transport modeling program. The program used is Beamline Simulator (Dehnel Consulting Ltd.). This work describes the developments that have taken place and the experience in the use of the Beamline Simulator program.

1. INTRODUCTION
The MRC Cyclotron unit’s main research interest is in PET imaging techniques. It runs 2 cyclotrons and has access to five PET scanners and supports large clinical, radiochemistry research and PET methodology groups. The unit’s main accelerator is a Scanditronix MC40 cyclotron (Fig. 1). The PET research activity requires predominantly irradiations with a 19MeV proton beam to produce $^{11}$C and $^{18}$F. Other applications exploit the versatility of this multi-particle, variable energy machine. The cyclotron is connected to a beam transport system (Fig. 2) which allows great flexibility in the number and types of solid, liquid and gas targets that can be irradiated. The facility is available for use 114 hours per week, 48 weeks per year.

2. DEVELOPMENTS
An increasing number of requests for new radioisotopes and increased availability of enriched materials has led to a significant increase in the range of beam energies being run and development of all the available beam lines. The trend to smaller targets and expensive enriched materials has resulted in beam diameters of 10 mm being required, instead of 20 mm which used to be standard. Examples of present activities include a 30 MeV proton beam for $^{81}$Rb/Kr generators, a 12.5 MeV proton beam for $^{124}$I, a 52 MeV $^{3}$He beam for $^{52}$Fe, a 28 MeV alpha beam for $^{211}$At production. Some work has been done on assessing how efficiently the beam can be shaped to impinge on apertures as small as 3 mm diameter. The beam diagnostic aperture for the 10 mm targets is shown (Fig. 3). The target aperture is framed by 4 insulated sectors made of carbon. The data is acquired and displayed in the control room via a Labview-based system.

* Currently being privatised as Imaging Research Solutions Limited

Fig. 1

Fig. 2

Fig. 3
3. USE OF BEAMLINE SIMULATOR

The Beamline simulator program, supplied by Dehnel Consulting Ltd, Nelson, B.C., Canada has been very useful in expediting beam development work and has also been a useful teaching aid for operator training. It is a real-time simulator for industrial beam transport systems and is available on a PC/Windows platform. The initial impetus to develop the program followed a question from myself to Morgan Dehnel at EPAC 94. It is not the purpose of this article to provide a full tutorial in the use of this program, but to highlight ways in which it has proved useful in our situation, so what follows is a brief outline of our experience.

3.1 Data required for beamline simulator

Defining the beam source requires the particle, ionization state, energy and emittance and whether a beam envelope or multi-particle computation (up to 10,000 particles) is required. A particular difficulty in our case was that emittance data was only available for full energy beams from installation in 1985.

Beam lines are built up by adding elements such as quadrupoles, dipoles and drift tubes. A representation of the beam line is built up by assembling icons (Fig. 4). A difficulty for us was that due to lack of space for steering magnets in some of the beam lines, the quadrupoles were given a secondary function as steering magnets. This was achieved by separately varying the currents in each individual winding of the quadrupoles.

![Fig. 4](image)

The sizes and shapes of the beam line apertures for each element are tabulated separately. However, it would be more convenient if all the data for each beam line element was entered at the same time because errors can easily arise if an extra item were inserted in the beam line. The MRC beam transport system has a number of apertures where there is ample width but restricted height, e.g. in many of the bending magnet vacuum boxes. Using the beam source in envelope mode, a quick appreciation can be gained of where the beam is in danger of striking the sides of the beam line aperture. The display shows the width of the beam along the beam line (X vs Z), (Fig. 5a) or its height (Y vs Z), (Fig. 5b) along with the shape of the beam on the target aperture (Y vs X), (Fig. 5c). This particular combination of low beam energy and long beam line was a difficult challenge both to model and to tune adequately.

![Fig. 5](image)
In multi-particle mode, the beam spill on current-measuring irises can be displayed (Fig. 6). This is very similar to the way in which information is made available to the operator from the control room display (Fig. 7).

![Fig. 6](image)

![Fig. 7](image)

A very useful feature of the program is that the effects of changes to beam line conditions can be easily seen. It is as simple as clicking on the icon for that beam element, increasing or decreasing its value with the up/down arrow keys on the 'vary parameter' window, and seeing the outcome as the program instantly re-runs itself with every click. For operator training, this feature allows the operator to quickly see the effect of adjusting any of the variable elements on the beam line and results in a better understanding of the factors involved in tuning up the beam line.

### 3.2 Comparison of simulator with real beam line

The results shown are for beam line 4 and a 12.5 MeV proton beam. This beam line has three sets of quadrupole magnets. There are also two 30° bending magnets which can be seen to have a strong influence on the horizontal focusing. The agreement was adequate to give a starting point for real tuning to obtain beam on target in one session. The table below (Table 1) allows a comparison to be made between values as used in practice and those predicted by the simulator.

<table>
<thead>
<tr>
<th></th>
<th>Quadrupole magnet pole tip strength settings (kG)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Q1</td>
</tr>
<tr>
<td>Experimental</td>
<td>1.58</td>
</tr>
<tr>
<td>Simulation</td>
<td>1.58</td>
</tr>
</tbody>
</table>

The values shown in the table for the focusing elements correspond to the beam envelopes shown in Fig. 4 above. The actual beam spills are compared with the simulator prediction (Table 2). Quantitative predictions of beam spill are very dependent on the values chosen for the emittance and until better information than that based on 40 MeV proton measurements from 15 years ago becomes available, the correspondence is unlikely to improve. Up to this time, the majority of the development work has been done on proton beams but the simulator has also been applied to deuteron, alpha and \(^3\)He beams.
Table 2

<table>
<thead>
<tr>
<th>Iris</th>
<th>Other losses</th>
<th>Beam to target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td>Bottom</td>
<td>Left</td>
</tr>
<tr>
<td>Experimental</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Simulation</td>
<td>2</td>
<td>5</td>
</tr>
</tbody>
</table>

4. CONCLUSION

Beamline simulator has been an effective tool for rapid development of new beam energy options at the MRC Cyclotron unit.

5. ACKNOWLEDGEMENTS

I would like to thank Morgan Dehnel, Marco Schippers (KVI, Groningen) and my colleagues in the engineering and operations team at Hammersmith for help and support at various times with beam development activities.
APS STORAGE RING OPERATION BEAM MONITORING AND ANALYSIS

Chihyuan Yao
APS, Argonne National Laboratory, Argonne, IL 60439, USA

Abstract

Various software tools and applications have been developed for APS beam monitoring and analysis. These tools have been proven critical for fault identification and beam quality monitoring. A brief description of these software tools and their applications in APS storage ring beam operation analysis is presented.

1. INTRODUCTION

The Advanced Photon Source (APS) is a dedicated synchrotron radiation facility with a 7-GeV third-generation synchrotron radiation storage ring (SR) and injector that has been in operation since 1996. The injector consists of a 650-MeV electron linac, a 450-MeV accumulator ring (PAR), and a 7-GeV booster. Currently we have 23 insertion device beamlines and 21 bending magnet beamlines for user experiments. For fiscal year 2000, scheduled user beam time was 5000 hours and beam availability was 95.4%. A new operation mode, called top-up, in which the stored beam current is kept a top level by injecting repeatedly at fixed intervals, has been commissioned and is now used for user operations. APS storage ring operation parameters are listed in Table 1.

<table>
<thead>
<tr>
<th>Max. Current</th>
<th>102 mA</th>
<th>Beam Energy</th>
<th>7 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifetime</td>
<td>&gt;20 hours</td>
<td>Refill Period</td>
<td>12 hours</td>
</tr>
<tr>
<td>H. Emittance</td>
<td>7.8 nm-rad</td>
<td>V. Emittance</td>
<td>0.82 nm-rad</td>
</tr>
<tr>
<td>H. Tune</td>
<td>35.2</td>
<td>V. Tune</td>
<td>19.3</td>
</tr>
<tr>
<td>H. Chromaticity</td>
<td>4.0</td>
<td>V. Chromaticity</td>
<td>6.0</td>
</tr>
<tr>
<td>H. rms Motion</td>
<td>2.2 μm</td>
<td>V. rms Motion</td>
<td>1.3 μm</td>
</tr>
</tbody>
</table>

Beam availability, orbit reproducibility and stability, beam lifetime, and beam emittance are the most important performance parameters of APS storage ring beam operations. Continuous improvement in these areas is the main goal of the APS Operations Group.

APS storage ring has 1414 magnet power supplies, 360 beam position monitors, 16 rf cavities and 4 rf stations. Several automatic control processes perform various tasks such as slow beam orbit correction, fast orbit correction, rf frequency adjustment, etc. The storage ring has two independent interlock systems: an Access Control Interlock System (ACIS), which provides radiation safety protection and tunnel access control, and a Machine Protection System (MPS), which protects the ring components from damage by synchrotron radiation.

The control system is an EPICS-based (Experiment Physics and Industrial Control System [1]) distributed control system, which consists of workstations, local control computers (IOC), and a communications network. Machine equipment devices are represented in the IOC database as process variables (PVs). The system has a total of around 350 000 process variables. The system provides basic control and monitoring functions through its MEDM [1] control screens and alarm handlers [1].

47
Hundreds of MEDM screens and several alarm handlers are utilized for machine operation and maintenance. These screens and alarm handlers are used by operation crews to monitor equipment status and perform control function to individual devices.

In order to minimize user beam downtime, restoring user beam is always the first priority when beam is lost. Typically the crew spends a limited amount of time assessing the fault after a beam loss. If the fault can be cleared, the storage ring is filled and user operation continues. Detailed analysis of the fault cause is often done afterwards, and remedies for potential problems are then planned. Given the amount of information to monitor and the need to investigate events afterwards, it is obvious that the screens and alarm handlers are not sufficient. More sophisticated high-level data logging and analyzing tools are needed. As a result, many software tools have been developed for beam operation analysis. The software tools described here are part of a more general Operation Analysis Application package [2] developed at APS.

2. MONITORING AND REVIEW TOOLS

2.1 Data Logger and Review

Data loggers are general data collection processes running on workstations. They collect machine and beam data according to a set of configuration files. The configuration files define the data set and collection method. Currently the system has about 50 data categories, covering everything from beam and machine parameters to utility system status. The sampling rate for each category is set according to the rate of change of the process variables and the desired time resolution. Data files are kept for different durations from a week to more than a year, depending on their usage and the storage requirement.

Several review tools are provided for searching, filtering, sorting, plotting and printing of the logged data. Both preformatted plot settings and user-selectable plot options are supported. An orbit review tool displays the beam position data as a sequence of beam orbits around the ring, which is very useful for understanding the nature of orbit disturbances.

These logged data and review tools are particularly good for detecting slow drifts, such as slow changes of beam orbit, lifetime and emittance, temperature of ring components, vacuum pressure, etc. They are also good for finding correlations among process variables. Because of their limited time resolution, Data Logger and Review tools are not very effective for analyzing fast and nonrepeating events such as beam loss, beam orbit glitches, etc.

2.2 Alarm Logger and Review

The EPICS control system provides interfaces for monitoring the alarm status of process variables. The alarm loggers run on workstations and collect status changes of process variables according to a set of configuration files. The data contain PV name, alarm status, and timestamps. Timestamp resolution varies from tenths of a second to several seconds depending on the database configuration of the IOCs.

Currently the following subcategories are included:

- SR — storage ring magnet, beam current, rms beam motion, insertion devices
- SRF — storage ring rf cavities, klystrons, waveguides, high-voltage power supplies, etc.
- ACIS — Access Control Interlock System
- MPS — Machine Protection System
- RTFB — the fast orbit feedback system
- Timing system
The Alarm Review tool can sort, filter, search and display the logged alarms. Several display formats are provided, including a list by time and PV name, histogram by time or PV name, etc. The list by time provides a time-ordered list of the alarms in a category with alarm status information and timestamps, which is most frequently used for correlating hardware alarms with beam events.

2.3 MPS Dump Data and Review

The MPS system gets trip input from beam position monitors (BPMs), beam current monitors, rf systems, and other storage ring subsystems. It has special hardware to latch the occurrence and timestamp of its input events. The timestamp resolution is around 1 microsecond. The MPS dumpdata, which are saved whenever there is a beam loss, contain information associated with the beam loss, such as beam current before and after the beam loss, status and timestamp of input channels, etc.

Also included in the MPS DumpData are BPM histories, which contain turn-by-turn beam position and BPM sum readings of a selected set of BPMs. A review tool provides a list of events and timestamps and several plots showing the BPM histories.

2.4 Glitch Data Logger and Review

The Glitch Data Logger is similar to the Data Logger, except that the data acquisition is triggered by certain events. It acquires several seconds worth of data around the triggering event. The triggering event can be a beam loss, or a large orbit glitch, or a hardware event. The Glitch Data Logger has several categories, the most useful ones being beam orbit and rf system. A Glitch Data Review tool can search, select and plot the data. For orbit glitches, the review tool displays step-by-step plots of beam orbit around the storage ring. A source analysis function of the review tool analyzes the possible source corrector for each acquired orbit, which is very helpful for identifying glitches caused by magnet power supply faults. Because both the slow orbit correction and the fast orbit feedback are running, sometimes the analysis may only indicate the reaction from these systems, not the initial cause.

3. BEAM MONITORING DISPLAYS

Several real-time displays are setup on workstations in Main Control Room for beam quality monitoring. Some of them are also distributed to the beamline users through web pages.

3.1 Beam Current and Lifetime Display

This is a 24-hour stripchart showing storage ring beam current together with beam lifetime and operation mode (Fig. 1).

![Beam Current and Lifetime Display](image)

**Fig. 1**: Beam Current and Lifetime Display

3.2 Beam Emittance and rms Beam Motion Display

Beam profile is measured by an image processing system and a CCD camera, which receives visible light from a bending magnet beamline. Horizontal/vertical beam emittance and coupling are calculated from the profile data. The results are displayed in 24-hour stripcharts.
The rms beam motion is calculated by a DSP processor, which collects and processes data from a set of selected BPMs at a rate of up to 1600 sample/s. Figure 2 is a plot from a recent run. Most of the peaks seen on the plot are horizontal beam orbit motion generated by insertion device gap movement, which is not fully compensated.

![Graphs showing X/Y emittance and coupling](image)

**Fig. 2: Beam Emittance and rms Motion Display**

### 3.3 Beam Orbit Display

Storage ring beam orbit is displayed with the Array Display Tool (ADT) [3]. The display has three separate panels: two show the horizontal and vertical orbit errors and one provides a zoom-in view of orbit errors in both planes and the storage ring components at the selected location.

### 3.4 Bunch Purity Monitor

Due to the imperfect phase matching and damping of the accumulator ring, a satellite bunch with about 1% of the main bunch current exists. This satellite bunch is carried through the booster to the storage ring. Some user experiments require the satellite bunches to be small and located on the leading side of the main bunches. An Avalanche Photodiode Detector and multichannel analyzer are used to obtain bunch distribution in the storage ring. Satellite bunches as small as $1 \times 10^{-6}$ of the main bunches can be resolved. The result is displayed in the Main Control Room for beam quality check.

### 4. BEAM LOSS AND BEAM MOTION ANALYSIS

#### 4.1 Beam Loss Analysis

Unintended beam losses account for most of the user beam downtime. Identifying the source of beam losses helps diagnose and eliminate faulty equipment and improve beam availability. Beam loss happens about once a day at APS. It can be caused by a tripped rf system, a glitch of a magnet power supply, a tripped interlock system, etc. If the fault is latched or the fault condition persists after the beam loss, the cause of the beam loss can be readily found. Sometimes the faulty system glitches and then returns to normal state. Furthermore, some systems, such as rf, BPM and MPS, may change or trip in reaction to a beam loss. This makes the task of finding the initial cause more difficult.

The MPS DumpData Review, with its turn-by-turn BPM histories, can provide information about orbit movement prior to the trip, the plane in which the beam orbit moves, and how fast the beam motion is, etc. From this, one can draw some partial conclusions. A slow orbit drift in one plane may
indicate a corrector problem, a drift in both planes or an orbit oscillation may indicate a quadrupole problem (see Fig. 3). A fast movement of a few ms before the beam loss may indicate a fast orbit feedback corrector problem. A sudden inward movement of the horizontal beam orbit may indicate an rf problem, etc.

![Fig. 3: BPM history of a quadrupole trip](image)

The Glitch Data Review displays beam orbit immediately before the beam loss. The source analysis can often resolve the source location to a few magnets. Figure 4 is a plot of orbit glitch captured two seconds before the beam loss; it shows a large vertical orbit error. Figure 5 is the source analysis printout, which indicates the source is a vertical corrector around sector 33.

![Fig. 4: Glitch Data Review output of a beam loss](image)
If the Glitch Data Review shows an inward dispersion function like horizontal orbit, the beam loss may be caused by an rf system fault.

The Alarm Logger provides the time relation between beam loss and certain equipment alarms. If a magnet power supply alarms within a few seconds of the trip, and if the magnet is not part of the orbit correction or fast orbit feedback systems, it may be the cause of the beam loss.

Figure 6 is a partial printout of the Alarm Review for the same beam loss, in which the vertical corrector magnet S34A:V3 alarmed around the beam loss time.

There are cases where the cause of a beam loss can not be found with all the available information. This is either due to the limited time resolution or insufficient data. For these cases, we can still use the analysis to narrow the causes down to two or three possibilities, and the results of the MPS Dump Review, the Glitch Data Review, and Alarm Review can be used as a ‘trace’ to characterize different cases for further study.

Some upgrades are planned to improve the time resolution, including a 100-Hz glitch detect software tool in the power supply controls, and a BPM movie in the fast orbit feedback system.

4.2 Beam Orbit Motion Analysis

By reviewing rms beam motion data, one can find the time, duration, and direction of beam orbit motions. For fast orbit spikes, if the orbit errors are over the trigger limit, glitch data are captured. The Glitch Data Review can be used to identify the approximate location of the source, and the Alarm Data
Review can help to narrow the source down to a particular magnet supply. For slow beam orbit motion, Data Logger review can be used to discover the character of the orbit variation and its correlation with possible noise sources.

With this approach, we are able to identify sources of most beam orbit motions, including glitching or noisy magnet power supplies, and unreliable beam position monitors in the fast orbit feedback or slow orbit correction systems.

5. CONCLUSION

The application of beam monitoring and review tools to APS beam operation analyses has helped to improve beam availability and beam quality. These tools have proved to be effective in determining causes of beam losses and excessive beam motions.

References


6. ACKNOWLEDGEMENTS

The software tools and beam monitoring displays were developed by the APS Operations Analysis Group, Control Group, and Operations Group. Many APS individuals have spent their time and contributed new ideas and suggestions to beam operation analysis. In particular, I would like to thank L. Emery, M. Borland, J. Carwardine, F. Lenkszus, A. Nassiri, R. Gerig, G. Decker, and the operations crew for their continuous efforts to improve the software tools and their active participation in the analysis of beam loss and beam orbit motion. This work was supported by the U.S. Department of Energy, Office of Basic Energy Sciences under contract No. W-31-109-ENG-38.
THE REFILL WIZARD - IMPROVING EFFICIENCY AT DARESBURY LABORATORY’S SYNCHROTRON RADIATION SOURCE

C.L. Hodgkinson and J.A. Clarke
CLRC, Daresbury Laboratory, UK

Abstract
The SRS at Daresbury Laboratory is a 2 GeV 2nd generation synchrotron radiation source. The SRS is scheduled to operate almost 6000 hours per year for users. This places significant demands on the efficiency and reliability of all accelerator components and systems. Although the SRS operates with only one refill per day, each taking about an hour, with such a demanding user schedule the length of time taken to refill can be significant when calculating the annual performance statistics. The duty operations team leader traditionally determined the refill sequence at the SRS without following a strict procedure. In December 1997, a very narrow aperture vacuum vessel was installed. Following this, if the correct refill sequence was not followed the potential for major component damage during injection was significant. The Refill Wizard, a series of tcl script programmes, was introduced to guide the operations team through the correct procedure at every refill in a step-by-step manner. The introduction of this operations software has led to increased efficiencies by making the refill process repeatable and predictable. This paper will discuss the significant advantages of such a system and will also highlight the unexpected disadvantages encountered during daily operations using the Refill Wizard.

1. INTRODUCTION
The SRS is a 2 GeV, 2nd generation synchrotron light source operating in the UK. It was designed to use the main dipole magnets as a primary source of radiation, however during its lifetime there have been several major upgrades to install insertion devices in the straight sections, these devices have relatively large apertures.

In 1997 a project was funded to install two 2 Tesla Multipole Wigglers (MPWs) in the SRS. The MPWs were designed to provide high flux at 10 keV, therefore the vertical aperture was carefully assessed to determine an optimum gap with respect to lifetime. It was concluded that the internal beam stay clear region in the straight sections could be reduced from 36 mm to 15 mm with a reduction in lifetime of approximately 15% [1]. In December 1997, a prototype MPW vessel was installed in the SRS to gain operational experience refilling the machine with such a small aperture. At the end of 1998, the two MPWs and vessels were installed in the SRS and have been in routine operation since the start of 1999.

With the introduction of the two narrow aperture vessels the potential for major component damage during injection was significant. In order to prevent damage the correct refill sequence had to be followed. This paper describes how the SRS was traditionally refilled, the solution employed to prevent damage to the narrow gap vessels and its subsequent effects on SRS operations.
2. SRS OPERATIONS

The facility produces synchrotron radiation for users and is scheduled to operate almost 6000 hours per year. This places significant demands on the efficiency and reliability of accelerator components and systems. In addition to the number of user hours scheduled, the SRS is subject to Service Level Agreements (SLAs) with our funding bodies. The overall reliability of the source must be in excess of 90% for dipoles and MPWs and 85% for the superconducting wiggler sources. An allowance of 1 hour is given for each multibunch refill.

Due to the excellent lifetimes at the SRS, the facility can operate with only one fill per day. However, with such stringent requirements placed on the reliability of the source and the limited time allowable for refills, it is critical that each refill is completed quickly and efficiently. Unless Beam Studies time is scheduled the duty operations team leader is responsible for conducting all SRS refills.

The Main Control Room (MCR) is manned continuously by 3 shifts, each with 2 operators. A duty operations team leader and a deputy operate the SRS on a day-to-day basis. Each team leader works with the same deputy, increasing team working and efficiency. There are 6 operations teams in total. The additional cover enables annual leave and sick leave to be covered easily. In addition each member of the team can carry out project work.

3. REFILL OF THE SRS PRIOR TO THE INTRODUCTION OF THE WIZARD

Prior to the introduction of the narrow gap vessels each team leader had complete autonomy and carried out refills to suit their own personal style. This method of refill produced very different procedures and refill times varied from one operations team to another. However, provided that the time taken was within that allowable in the SLAs there was very little drive to standardise the system.

![Multibunch Refills in 1997](chart.png)

**Fig. 1:** Multibunch Refills in 1997

The graph shows the refill statistics for multibunch operations in 1997. Total time spent refilling per month is shown on the left and the average time per fill for each month shown on the right.

The average time taken for a multibunch refill in 1997 was 58 minutes.
4. THE INTRODUCTION OF THE WIZARD

In December 1997 the first narrow gap vessel was installed into the SRS storage ring. During the design phase of the project it became apparent that the possibility for major component damage during refill was significant due to very high power levels in the photon beam and various vessel protection systems were put in place. However, this did not eliminate the possibility of human error and it became necessary to ensure the correct refill sequence was followed. A system was required which allowed the operations team to refill the SRS in a step-by-step manner. The solution employed was The Sequence Manager, more commonly known as ‘The Wizard’.

4.1 The Wizard

The Wizard is a programme, which can read and execute a text file in a particular order. The file the wizard uses is the SRS Refill file, which is just a text file that contains a list of executable Tool Command Language (tcl) programmes. Tcl is a general purpose, robust command language that can be easily integrated into new applications. Tcl programmes are scripts consisting of tcl commands, which are processed by an interpreter.

The complete SRS Refill text file is given in Appendix 1. As the wizard reads each line of the text file in order the associated tcl programme is executed. An example is shown below:

The SRS Refill text file final line is:

    Run Goodbeam,2,GoodBeam.tcl

Run Goodbeam appears in the wizard window. Goodbeam.tcl is the name of the programme to be executed. The number 2 indicates a level of priority. The wizard runs at level 5, therefore those lines that have a number less than 5 must complete successfully to allow the next line in the file to be executed. If a line fails to complete there is the option to run the script again or to debug. The debug function allows the operator to move on to the next line even though the previous tcl script has not been completed correctly. This function is useful where the fault is likely to be communications problem, rather than a real fault. All lines in the SRS Refill file are at level 2, except one, the line reads ‘Cycle OCEMs,6,CycleOcems.tcl’. As this number is higher than level 5, at which the wizard operates, the sequence will continue even if this tcl script does not execute properly. This particular script runs a degauss cycle on the magnet power supplies. Communications between the magnet power supplies and the control system is carried out using RS232, which is relatively slow and an error message was generated regularly. The debug command allowed the operator to continue with the refill in these circumstances, however the fault occurred often and caused unnecessary delays in refill. By changing its priority to 6 the wizard ignores the error message and continues with the sequence, eliminating the unnecessary delays. Before using this technique the implications of the script not running must be carefully considered. In this case the implications are minor if the degauss sequence does not run and injection into the storage ring is not achieved, some time is lost fault finding and rerunning the sequence from the degauss cycle.

Since it is a text file based it is easy to edit and add new tcl scripts. Several scripts have been written by the Accelerator Physics group rather than relying on specialist controls programmes. An example of a tcl script Goodbeam.tcl is shown in Appendix 2

5. THE EFFECT OF THE WIZARD ON OPERATIONS

The wizard was introduced as a safety feature to prevent significant damage to the two narrow gap vessels and flexibility has been deliberately reduced, this caused considerable concern in the operations group. It was perceived that the reduction in flexibility would reduce efficiency by preventing the duty operations team leader from intervening at particular points during the refill. However, flexibility can still be maintained, by understanding what each of the tcl scripts are doing. Scripts can be modified and run individually or arranged in a text file in a particular sequence for the wizard to execute.
In addition to its safety role the wizard has provided some significant benefits. Since the installation of the two new narrow gap vessels during December 1998, there have been two full years of refill statistics using the wizard. The two graphs below show multibunch refills in 1999 and 2000.

Fig. 2: Multibunch Refills in 1999

Fig. 3: Multibunch Refills in 2000

The average time taken to refill the SRS in 1999 and 2000 was 48 minutes and 47 minutes respectively. The refill times for 2000 include a significantly longer superconducting wiggler ramp (approximately 5 minutes longer), due to control system changes. The figure for 2000 also includes the high average refill time in October due to problems with the RF system.
The reduction in refill times has been achieved by allowing the precise timing and order of events to be modified in a systematic manner. The wizard locates and executes all of the small programmes that the operations team had to search around for, prior to its introduction. By using a single wizard in this way the interaction between the various front end controls systems and the operations team has been simplified. A significant benefit has been the ease with which the operations team can change between various operating conditions. A selection box appears at the launch of the wizard, at which point the operations team can select which insertion devices are available, the wizard then selects the appropriate scripts for that particular refill. This can save a significant amount of setting up time, when an insertion device has to be withdrawn unexpectedly due to a fault.

Another benefit is that there is no confusion over file names. For instance, the latest steering file is already applied as are the best settings for obtaining injection. Occasionally in the past incorrect files were used because of poor communication, this is no longer an issue.

In addition to the reduction in refill times, the overall reliability of the source for users has been improved by correct sequencing. For example soft starts on particular power supplies have been routinely introduced to prevent overload trips. In another case, a line has been added to the wizard, which checks the MPWs can wind out before allowing beam dump. This improves efficiency by keeping the stored beam until the correct technical groups have been contacted and are ready to correct any fault immediately on beam dump. Beam stability has also been improved by keeping the magnets on for the maximum amount of time prior to refill, ensuring optimum thermal stability.

The introduction of a step-by-step refill sequence has made the training of new operations staff much easier. In addition, as all operations team leaders now refill in the same way, when a member of the operations team is on leave, to replace that member with a stand-by causes much less disruption to the two man team.

Although the wizard has been proved to provide significant benefits to the operation of the SRS, there have been some unexpected disadvantages. All of these disadvantages are associated with the lack of flexibility and also the operators are now divorced from the procedures happening in the background.

The operations staff who operated the SRS prior to the wizard gained significant understanding of the accelerators. This knowledge was necessary to refill the machine. The refill wizard has simplified the refill to the extent that this knowledge is no longer necessary during routine operations. Although the wizard has made it easier to train new operations staff, the length of time taken to acquire the same knowledge of the accelerators and controls systems is much longer, as there is no longer a requirement for it on a day-to-day basis. This reduction in expertise is noticeable when serious problems arise with the operation of the accelerators.

Due to the sequential nature of the wizard there are cases where the wizard has actually increased the refill time. The wizard has been developed to refill the SRS from the beginning; therefore these situations usually arise when a fault condition has occurred at some point during the refill. A significant part of the sequence may need to be repeated increasing the time taken to re-establish injection. This is due to conditions written into the scripts, which assume refill from a controlled beam dump.

If the refill fails continually, it is more likely that a member of the Accelerator Physics Group is required to solve the fault. Fault finding and correction now relies upon the understanding of what each of the tcl scripts do, where each of them are located and the interaction between tcls and other files. However, it is usually clear where the fault lies and so solving such problems is usually faster than in the past.
6. CONCLUSION

The refill wizard was developed and introduced as a safety feature. It has fulfilled its role of protecting the narrow gap vessels from damage for the last 3 years. Although received sceptically at first, due to the deliberately reduced flexibility during refill, the wizard has performed well and provided some additional benefits. The refill wizard is an excellent memory aid and minimises most of the repetitive tasks. It almost eliminates the possibility of operator error, particularly during busy periods in the MCR.

As a result of using the wizard, refill times have reduced by approximately 10 minutes (17%) even though more actions are taken by the operations team due to the introduction of 2 additional insertion devices. The user community have benefited from increased reliability of components and beam stability due to correct sequencing during refill. However, the reduction in flexibility does inevitably cause some frustration to the operations teams, particularly when the beam is lost part way through a fill and the time taken to recover is much longer due to the sequential nature of the wizard. The wizard simplifies the refill to the extent that new operators are able to refill the SRS very quickly. However, the detailed knowledge that was required to refill the machine is no longer required on a day-to-day basis, which could prove to be a disadvantage in the long term.

Since the introduction of the wizard the benefits to operations have far outweighed the minor disadvantages. The SRS Refill Wizard has proved to be a major improvement to the safety, efficiency and reliability of the SRS.

7. ACKNOWLEDGEMENTS

The authors of this paper would like to thank the members of the SRS Operations Team for their insights into daily operations using the wizard and for their contributions to this paper. Controls group for developing the software.

References

APPENDIX 1 – SRS REFILL TEXT FILE

Check MPW6 is OK,2,MPW6Check.tcl
Check MPW14 is OK,2,MPW14Check.tcl
Open MPW14 Gap,2,OpenMPW14Gap.tcl
Unlock MPW6,2,MPW6Unlock.tcl
Open MPW6 Gap,2,OpenMPW6Gap.tcl
Switch off servos,2,ServosOff.tcl
Dump The Beam Using the RF,2,BeamDump.tcl
Set Wigglers to zero,2,WigDown.tcl
Run Injection sequence,2,OpsSequence.tcl
Check DISP,2,CheckDisp.tcl
*** Open Undulator Gap,2,OpenUndulatorGap.tcl
Show refilling,2,ShowRefilling.tcl
Reset Steering,2,ResetSteering.tcl
Set-up Transfer Path,2,TransferPathSetup.tcl
Cycle OCEMs,6,CycleOcems.tcl
Set Injection Steering,2,InjectionSteering.tcl
*** Set Timing mode,2,SetTiming.tcl
Check cavity impedance calibration,2,ImpedanceCal.tcl
Switch on RF,2,RFOn.tcl
Set OCEMs/RF for Injection,2,InjectionSetup.tcl
*** Start Stacking,2,StartStacking.tcl
*** Store Beam,2,StoreBeam.tcl
Start Ramp steering system,2,RampSteerOn.tcl
Arm Vessel Protection system,2,VesselProtection.tcl
Start Orbit Trip,2,OrbitTripOn.tcl
Start Ramp,2,StartRampRF.tcl
Switch Off DSHN,2,DSHNOff.tcl
Initialise MPW14,2,SendMPW14TrakMap.tcl
Close MPW14 Gap,2,SetMPW14Gap.tcl
Initialise MPW6,2,SendMPW6TrakMap.tcl
Close MPW6 Gap,2,SetMPW6Gap.tcl
*** Ramp Wigglers,2,RampWigglers.tcl
Stop Ramp Steering system,2,RampSteerOff.tcl
Apply User Steering,2,UserSteering.tcl
*** Check H Orbit,2,HOrbit.tcl
*** Steer Line 5U,2,SteerLine5.tcl
*** Steer All TVMs,2,Steer.tcl
*** Run Global Servos,2,GlobalServos.tcl
Show User Beam,2,UserBeam.tcl
*** Record Fill Structure,2,RecordFillStructure.tcl
Run Goodbeam,2,GoodBeam.tcl
# Goodbeam.tcl
# ---------------------
# # This file runs the injector down
# # Revision history:
# # ---------------------
# # 25th Nov 1998 BGM Script rewritten for MPW upgrade
# # 8th Feb 2000 BGM Added SI parameters
# # 20th Mar 2000 SFH Corrected error - SL.HTRBs now switch OFF

package require Sequence

sequence::init true
sequence::completion 1 "Script interrupted"

sequence::heading "GOODBEAM SEQUENCE \n\n"

catch { sequence::setProp BM.ACPI.01 CCV 0.0}
catch { sequence::setProp BM.DCPI.01 CCV 0.0}
catch { sequence::setStatus BR.RFON.01 OFF}
catch { sequence::setStatus {FR.PULS.01 FR.PULS.02 FR.HTV.01} OFF}
catch { sequence::setStatus {BL.HTRB.01 BL.HTRB.02 BL.SEPT.01} OFF}
catch { sequence::setStatus {BE.HTRB.01 BE.HTRB.02 BE.HTRB.03} OFF}
catch { sequence::setStatus BE.BUMP.01 OFF}
sequence::remark "nBooster magnets running down. Please wait 60 seconds...\n"
sequence::wait 60000

catch { sequence::setStatus {BM.ACPI.01 BM.DCPI.01} OFF}
catch { sequence::setStatus {LG.HTV.01 LG.RFHT.01} OFF}
catch { sequence::setStatus LR.KHTV.01 OFF}
catch { sequence::setStatus LR.HTRB.01 OFF}
catch { sequence::setStatus LR.DHR.01 OFF}
catch { sequence::setStatus TM.DIP.02 OFF}
sequence::remark "nLinac Off and Booster magnets Off\n"
sequence::wait 2000

catch { sequence::setStatus SI.POSN.01 ON}
catch { sequence::setProp SI.POSN.01 CCV 0.0}
catch { sequence::setStatus {SL.HTRB.01 SI.HTRB.02 SI.HTRB.03 SI.HTRB.04} OFF}
sequence::remark "nSeptum retracted and Heaters off\n"
sequence::wait 2000

sequence::completion 0 "OK"
exit
SUMMARY OF SESSION 3
HOW SHOULD ACCELERATOR OPERATIONS BE ORGANIZED?

Rick Bloemhard and Mike Stanek
TRIUMF & SLAC

1. INTRODUCTION

The underlying structure and organization of a group strongly influences its effectiveness and efficiency. An operations group may develop a ‘persistence of form’ that prevents it from responding to changes in responsibilities and technology. Even if a group has been in existence for a long time, it is a good idea to re-evaluate its structure periodically. An organization can possess an aesthetic quality related to how simple and transparent its functions appear to users and other outsiders. Information and tasks should flow freely without undue impedance. In this session we examined the issue of group design from a variety of perspectives including both large and small labs, commercial operations and that of an ‘expert’ consultant.

2. ENGINEERING PROCESS MONITORING FOR CONTROL ROOM OPERATION

Mario Batz (CERN) told us how an existing operations group at a large established accelerator lab could change their conduct of operation by looking at their organization from a different perspective. The Technical Control Room operations group monitors and controls the conventional facilities, such as cooling water, vacuum equipment, fire alarms, cryogenics, and electric power, for the entire CERN site. The control room was characterized as a high stress environment, with many system alarms and user requests coming in simultaneously, especially during service outages. The group turnover rate was as high as 20% per year.

By first agreeing on the process objective (i.e. to maximize up time for the CERN Accelerators), and then identifying the key processes, systems and resources needed to reach that objective, they can organize their group to more effectively reach their goal. They can make decisions on how they will respond to crises, and conduct operations with this structure as a guide. This leads to decisions for Alarm and Status Engineering, Procedures for Crisis Management, and Operator Training, to name but a few.

This structured approach to the design of an operations group can be generalized to future projects. This method of organizing TCR operations with a production goal in mind has many parallels with commercial cyclotron operation, as we learned in the next talk.

3. THE ORGANIZATIONAL STRUCTURE OF OPERATIONS GROUPS IN A COMMERCIAL ACCELERATOR FACILITY

Nigel Stevenson (Theragenics Corporation) talked about some differences between experimental and commercial facilities:

<table>
<thead>
<tr>
<th>Commercial</th>
<th>Laboratory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product focused</td>
<td>R &amp; D focused</td>
</tr>
<tr>
<td>Industrial commercially available equipment</td>
<td>Specialized equipment (home built)</td>
</tr>
<tr>
<td>Non-academic staff</td>
<td>Academic staff</td>
</tr>
<tr>
<td>Pragmatic attitude</td>
<td>Perfectionism</td>
</tr>
<tr>
<td>Long term stable mode of operation</td>
<td>Dynamic / changing modes of operation</td>
</tr>
<tr>
<td>‘For Profit’</td>
<td>Government funded</td>
</tr>
<tr>
<td>Motivation: quantity &amp; ‘Status-Quo’</td>
<td>Motivation: quality &amp; new challenges</td>
</tr>
</tbody>
</table>
It is also generally true that operations group members are of two general types:

1) Jack of all trades. Typically found in smaller linear organizations.
2) Specialized roles. Often found in extended or parallel organizations.

Commercial operations usually fall into the first category, but as they grow they may evolve into the second type. The (inter)national labs often operate in the second mode. Each type of organization can benefit from examining the strengths of the other.

4. COMPLEXITY MANAGEMENT THROUGH INFORMATION TECHNOLOGY AT THE ALS

The needs of the ALS users drives the requirement for a highly stable orbit. Jan Pusina described the hardware and software architecture that allows the ALS to fulfill these requirements. Jan also described the operations group structure that has evolved at the ALS. One of the features of the way they do business is the adoption of a fixed owl shift crew. This point generated a few comments at the end of this talk. While claiming the advantage of having a stable staff, Jan concedes that the owl shift crew tends to get out of touch. The ALS uses the web to access standard procedures and training.

5. BUILDING AN OPERATIONS GROUP

Pierre Bricault gave us a look at how an accelerator operations organization to run the new ISAC Radioactive Ion Beam Facility at TRIUMF was built. ISAC was faced with a new accelerator at the end of its commissioning phase, ready for physics users. The first question was: Who can operate it? One possible answer was to have some existing group take over. Perhaps the users could run it themselves, like ISOLDE at CERN. For several reasons this was not acceptable. Another possibility was the existing Cyclotron Operations group at TRIUMF. But this, too, was not acceptable. So ISAC began the task of building its own small group. In answer to the question, “At minimum what do we need?”

1) A Group Leader, to set policy and goals, and to interact with management and the experimenters.
2) A Coordinator, to handle training and documentation.
3) Operators

To fill the operator positions, ISAC looked for people with characteristics such as curiosity, creativity, insight, perspective, common sense, consistency, good work habits, ability to learn from mistakes, and in general, someone with a diversity of skills.

Now, what type of standards would be set for training the operators? ISAC was faced with recent decisions by the Canadian government and the Nuclear Safety Commission which mandated that nuclear facility standards be applied to particle accelerators. This forced ISAC to design and implement a formal training program. The mandated ‘Systems Approach to Training’ includes:

- Training Analysis
- Evaluation of the program
- Training Design
- Conduct of Training & Evaluation
- Validation of Training
6. STRESS AND SHIFT WORK

Mina Michal presented a talk about the intense biological stress of working shifts. Understanding the physiological basis of such stress can help us develop coping strategies. These stresses and strategies represent some important input into the organizational design process. Those of us that attended WAO'96 may remember broad similarity in the advice offered by Ms. Michal and the earlier workshop's talk on sleep deprivation. The experts seem to agree on the nature of the problems and the best ways to minimize them.

7. SESSION CONCLUSIONS

Even though the title question of this session may not be easily answered, it seems that we should periodically ask it. The optimal structure for each group depends heavily on that group's size, resources & goals. Some of the newer factors to consider may include the desire to implement on-line logbooks & pressure to adopt systematic and documented training programs.

We hope that this session, especially the hallway and dinner conversations that may have been sparked inspire you to re-examine how your group is organized.
ENGINEERING PROCESS MONITORING FOR CONTROL ROOM OPERATION

Mario Batz
European Organisation for Nuclear Research (CERN), Geneva, Switzerland

Abstract
A major challenge in process operation is to reduce costs and increase system efficiency whereas the complexity of automated process engineering, control and monitoring systems increases continuously. To cope with this challenge the design, implementation and operation of process monitoring systems for control room operation have to be treated as an ensemble. This is only possible if the engineering of the monitoring information is focused on the production objective, and is lead in close collaboration with control room teams, exploitation personnel and process specialists. In this paper some principles for the engineering of monitoring information for control room operation are developed using the example of the exploitation of a particle accelerator at the European Laboratory for Nuclear Research (CERN).

1. INTRODUCTION

Many similarities exist between CERN and production industries concerning the processes, process control and control room operation. CERN's main production objective is related to particle beams and luminosity, for which various traditional industrial processes are necessary, such as water-cooling and electrical systems. Still today production processes cannot be automated completely. The remote monitoring from a control room is an essential element of the total effectiveness in meeting the production objective. The process information that is available for control room operators determines, amongst other things, the correctness and speed of their decisions and actions.

In preparation for the LHC operation, the SPS/LHC accelerator control room (PCR) and the Technical Control Room (TCR) have launched a project to study the recovery of the Super Proton Synchrotron (SPS) after major system breakdowns. The activities of both the control rooms shall be focused on the main production objective. The documentation of operation activities, as well as the specification of process monitoring tools, and the needs of operator training will be established to minimise the down time of the SPS.

The monitoring information presented to the control room operators has to be defined through close collaboration between control room teams, exploitation personnel and process specialists. Although the basic principles and requirements are identical for many processes, a method shall be available to rationalise the engineering of the monitoring information that will be applicable to the future LHC operation and other CERN accelerators.

2. SITUATION TODAY

During the engineering of the TCR monitoring information the particle beam production has not been considered systematically and the design approach has been different for different processes. In the same way, the monitoring of the technical infrastructure has not sufficiently influenced the monitoring information of the PCR [1].

65
In the PCR and the TCR the workload, knowledge and background of the operators are different and the operation teams are hosted in different control rooms. Even more importantly the work objectives after major control room incidents are not identical:

- **For the TCR:** the restart of the technical infrastructure for the whole laboratory where the accelerators do not have exclusive priority
- **For the PCR:** the restart of the accelerator equipment and finally the particle beam

The monitoring of the technical infrastructure of CERN's accelerators by the TCR is based on alarm list displays, synoptic diagrams and trend curves of process values. The processes under control are:

- electrical distribution and supply,
- ventilation and air-conditioning,
- water distribution and cooling, demineralised water production and distribution,
- beam vacuum and compressed air,
- monitoring and control system infrastructure,
- fire and gas detection equipment,
- communication equipment, such as telephones and intercom.

The state of the main process elements (pumps, valves, switches, analogue values etc.) are represented on synoptic diagrams for each individual system. From a general process overview the operator can navigate to the details of sub-processes. Alarms are transmitted in parallel to the synoptic diagrams and to an alarm list display, where the operator has an overview of all the alarms active in any of the monitored systems. A simple indication of the consumers on the accelerator site exists on the synoptic diagrams.

The monitoring applications for each process are independent, so that navigation between synoptic diagrams of dependent processes is difficult. The alarm list display does not show group alarms of the same or different processes together, nor does it apply any filter criteria. Thus, the control room operators need a lot of background information to exploit the monitoring information and to quickly assess failures. Furthermore, complementary information has to be looked up in operation instructions, which are not part of the monitoring system.

The TCR and the PCR share the same data logging tools and the PCR uses some of the TCR process synoptic diagrams. However, the operators do not have enough background information to efficiently use the monitoring tools that are technically available in both the control rooms.

3. **MONITORING INFORMATION ENGINEERING**

The engineering of the monitoring information shall be based on a proper identification of the production objective, the production processes and sub-processes, see figure 1.

To meet the main production objective, the different processes of the main systems, such as electricity, cooling, vacuum, have to be identified. The processes will consist of sub-processes, such as cooling towers, water demineralisation, which in turn can be split into operations, such as pressure control, temperature control. Any of these elements has time dependencies and dependencies with other sub-processes or operations. The combination of those dependencies determines the critical paths for any restart operation [2].

All the information has to be available for the control room operators in the form of visualisation diagrams for the critical paths, process diagrams and alarm list displays; although not to forget the operation instruction, see figure 2.

66
In order to have a complete picture of all the influences and constraints, the exploitation personnel and process specialists have to contribute their know-how during the engineering phase [3]. This exercise has to be done for different phases in the production process such as start-up, process studies, production optimisation, physics, maintenance (stand-by) etc.

4. RECOMMENDATIONS

The work objectives of the PCR and the TCR after a major incident have to be identical: it has to exclusively serve the main production objective. Major incidents have to be treated from the managerial point of view as a crisis. Thus, the information concerning faults and failures has to be as transparent as possible for both the control rooms, as far as the main production process is concerned. Details of each
of the processes have still to be adapted to the particular needs of each control room. The engineering of the monitoring information has to be optimised for the restart of the main production process and not for the restart of each individual system process.

The control room operators have to be enabled to find the best restart strategy based on process dependencies, process functions and nominal operation values. The following information shall be available, so that decisions and actions can be taken rapidly:

- availability of the main production process and the main system processes,
- state of the critical paths and the dependencies,
- unavailability of process equipment and causes (fault states),
- actions to be taken to re-establish the availability of the processes,
- detailed information on the process equipment to verify the correctness and coherence of process information, to verify the correctness of the standard restart procedure and to establish alternative procedures, if necessary,
- trend information of process operations that are part of the critical paths,
- nominal process values and process limitations.

Depending on the type of information, the representation method and the degree of availability of this information can be determined. As far as possible this information shall be delivered ‘in real-time’ via a computerised monitoring system. Navigation to the information shall be orientated towards the control room operator’s tasks. Navigation between trend displays, synoptic diagrams, visualisation diagrams and alarm lists shall thus be seamless.

Furthermore, the distribution of control actions between an automatic system and the control room operators has to be documented in a transparent way, especially when several control rooms are in charge of different processes, the faults, failures and the advancement of the restart of processes will be transparent. Field operators as well as crisis teams have to be kept up to date in the best possible way too.

5. CONCLUSION

The key to the realisation of process monitoring by control room operators is the focus of monitoring information engineering to the main production objective. The proper analysis of the processes and activities needed to keep the availability of the production, leads to a task oriented design of the monitoring tools. In addition, increasing the clarity of information that is exploitable, without too much background information, is important to improve communication and information flow after major breakdowns. The management of such crises will profit from this and the reduction of down time becomes easier.

This paper has shown the major principles that shall be applied using the example of the SPS exploitation by the TCR and PCR. However, this analysis is still on-going. The final results will be published later and shall be applied to the engineering of monitoring information and systems for the LHC.

References


THE ORGANISATIONAL STRUCTURE OF OPERATIONS GROUPS IN A COMMERCIAL ACCELERATOR FACILITY

Nigel R. Stevenson
Theragenics Corporation, 5203 Bristol Industrial Way, Buford, GA 30518, USA

Abstract
The number and the complexity of commercial accelerator facilities have grown dramatically over the past few decades. The challenges of operating such facilities within a business environment often include demands on efficiency, flexibility and meeting stringent product delivery schedules. The organisation of an accelerator (usually cyclotron) operations group to handle these demands is somewhat different from that typically set up in research accelerator laboratories. However, similarities are present and much can be learned from past examples of successes and failures at commercial accelerator facilities. Research facilities are themselves experiencing changes towards increasing resource demands, restrictive budgeting scenarios, and reduced staffing levels. As this change occurs, they may have to move into an operations mode that is indeed closer to that typically seen at commercial facilities. This talk will look at staffing, maintenance, development and training, radiation dose issues, shift-work and other aspects of running a commercial accelerator facility.

1. COMMERCIAL ACCELERATOR FACILITIES
Commercial accelerator facilities include radioisotope production cyclotrons, LINACS for therapy, commercial positron emission tomography units, elemental analysis technology, etc. In contrast, experimental (national, university, etc.) laboratory accelerators tend to be more unique in nature. The philosophy and mode of operation of these two types of facilities is exemplified in Table 1. Having said this, it must be recognised that factors such as reduced government budgeting are, by necessity, bringing the operational modes of many accelerator laboratories increasingly into the ‘commercial’ realm.

<table>
<thead>
<tr>
<th>Commercial</th>
<th>Laboratory</th>
</tr>
</thead>
<tbody>
<tr>
<td>'For Profit'</td>
<td>Government Funded</td>
</tr>
<tr>
<td>Product Focused</td>
<td>R. &amp; D. Focused</td>
</tr>
<tr>
<td>Industrial/Commercially Available Equipment</td>
<td>Specialised Equipment (Home-Built)</td>
</tr>
<tr>
<td>Non-Academics</td>
<td>Academic Staff</td>
</tr>
<tr>
<td>Pragmatic Attitude</td>
<td>Perfectionism</td>
</tr>
<tr>
<td>Long-Term/Stable Mode of Operation</td>
<td>Dynamic/Changing Modes of Operation</td>
</tr>
<tr>
<td>Motivation:</td>
<td>Motivation:</td>
</tr>
<tr>
<td>• Quantity</td>
<td>• Quality</td>
</tr>
<tr>
<td>• Status-Quo’</td>
<td>• New Challenges</td>
</tr>
</tbody>
</table>

When setting up or evaluating a commercial accelerator facility some items to consider are:
- Increase/Retain/Reduce Staff Levels?
- Operations only? Development?
• Complexity of Operations -
  • (medical) LINAC (<1 Operator/Machine)
  • CYCLOTRON (> 1 Operator/Machine)
  • Size of Operations (# Accelerators)

We will now explore one of the most common examples of a commercial accelerator facility – radioisotope production cyclotrons.

2. ORGANISING COMMERCIAL CYCLOTRON FACILITIES

Two modes of organising the operations staff are commonly employed:

1. Jack-Of-All-Trades’:
   - Staff perform all activities
   - Suitable for smaller facilities
   - Multi-skilled individuals
   - Flexible operations
   - Potential for burnout?

2. Specialised Roles:
   - Staff perform specialised functions
   - Suitable for larger facilities
   - Specialists
   - Not as flexible (needs cross-training)
   - Less stressful

The first mode of operation in which all employees perform all of the tasks is often run as a linear organisation as depicted in Figure 1.

Larger cyclotron facilities more often move into a parallel mode of operation in which cyclotron operation and cyclotron support functions are separated as specialised tasks, as shown in Figure 2. If the facility has R&D and/or other project responsibilities then this organisation may need to be extended, typically as displayed in Figure 3.

![Figure 1: Linear organisation](image-url)
3. OPERATING COMMERCIAL CYCLOTRON FACILITIES

Typical characteristics and challenges for the two main groups within a parallel organisation are:

1. Operations:
   E-M Technologists
   Trouble-Shooting Skills
   Production Scheduling
   Shifts?
   Radiation/Hazardous Environment?

2. Technical Support:
   E-M Technologists/Engineers
   Trouble-Shooting Skills
   Technical Planning (Preventative Maintenance)
   Radiation/Hazardous Environment?
   In-House Inventory Control, Document Control, Machining, etc.
One of the major disadvantages that typically comes with larger facilities and operating in a parallel mode (specialised assignments) is achieving comprehensive (“round-the-clock”) expertise for trouble-shooting and routine maintenance activities. This can be handled by setting up a comprehensive listing of specific assignments, showing primary and back-up responsibilities, as typified in Table 2.

<table>
<thead>
<tr>
<th>Task</th>
<th>Primary</th>
<th>Secondary</th>
<th>Tertiary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion Source Replacement</td>
<td>Operator A</td>
<td>Technologist 2</td>
<td>Operator B</td>
</tr>
<tr>
<td>Mech. Pumps - P.M.</td>
<td>Technologist 1</td>
<td>Operator A</td>
<td>Technologist 3</td>
</tr>
<tr>
<td>Target System - Retrieval</td>
<td>Operator B</td>
<td>Technologist 3</td>
<td>Technologist 1</td>
</tr>
<tr>
<td>Nucl. Vent.- Filter Change</td>
<td>Technologist 2</td>
<td>Technologist 4</td>
<td>Operator C</td>
</tr>
</tbody>
</table>

Table 2: A method for task and skill assignments

4. OPERATIONS AND STAFFING ISSUES

With increasing demands on cyclotron staff, alternative opportunities, limited budgets, etc. it becomes imperative that we make these facilities challenging, enjoyable, etc. Some final points to consider when setting up and running commercial accelerator facilities are:

- Allocation of Staff According to Skills
- Provide Ongoing Education – Technical and Management (if appropriate)
- Personnel Development Planning
- Opportunities to Change Career Paths
- Limited Autonomy
- Make Work Enjoyable
- Provide Employment Security

Running commercial accelerator facilities has challenges and rewards that are somewhat different from those experienced within a laboratory environment. However, the skills and mechanisms employed to successfully operate such an organisation has many aspects that are also transferable into the laboratory realm. This is especially so with increasing budgetary pressures and the emphasis now being placed on laboratories for researching industrial applications and participating in the technology transfer process. By necessity, laboratories are evolving and adapting to these circumstances and the mechanisms described in this presentation are also increasingly applicable to this environment.
COMPLEXITY MANAGEMENT THROUGH INFORMATION TECHNOLOGY AT ALS

Jan Pusina
LBNL, Berkeley, California, U.S.A.

Abstract
This paper addresses management of the Advanced Light Source accelerator systems through computer hardware and software. It also examines the overall design of the accelerator Operations Group, including training and safety. Accelerator physics at the ALS moves toward control of ever-shrinking spatial and time dimensionality, driven by the needs of end-station users (atomic, surface, biological, and nano scientists, to name a few). For smooth operations, data accessibility and processing must be fast, flexible and highly organized. Fine control and monitoring of beam and equipment parameters necessitates systems whose complexity is out of proportion to previously existing systems. With the addition of functions such as longitudinal and transverse feedback systems and higher harmonic cavities, the orbit must be stable on the scale of a few micrometers. To be discussed are design of control room computer applications and networks, and automated operational procedures to cope with the needs cited above.

1. THE MACHINE

The Advanced Light Source is a third generation synchrotron accelerator, which delivers high brightness radiation in the energy range of infrared to soft X-rays, to approximately 27 beamlines. The accelerator complex consists of an electron gun (120 KeV), linac (50 MeV), booster synchrotron ring (1.5 GeV), and a storage ring which ramps down to 1.3 GeV or up to 1.9 GeV. A typical run cycle consists in filling and ramping (15 min.), and providing light to users (six hours). The storage ring has a capacity for 328 buckets, with 276 typically filled, leaving a dark space for users doing time-of-flight experiments. In some cases a single high intensity bunch is injected in the dark space (a 'spike' or 'camshaft') to provide a trigger for teams looking at time-dependent x-ray phenomena, either with solids or gases (beamline 5.3.1). Every six months, for two weeks the machine is run in a two-bunch mode.

The storage ring lattice has the capability of three bend magnet ports in each of the 12 sectors, and an insertion device in ten of the straight sections, the other two straight sections being reserved for injection devices and RF cavities. In actuality we have two bend magnet ports in most of the sectors, and 7 insertion device beamlines. Many beamlines have multiple branchlines.

2. SYNCHROTRON RADIATION AVAILABLE TO USERS

Users' light energy is in the range of 0.5 out to 12.4 KeV photons, in 30-pS bunches. The radiation is used for a variety of scientific disciplines, including atomic physics, biology (protein crystallography), chemical dynamics, materials and surface science, and X-ray microscopy.

3. ALS OPERATIONS

There are typically two operators and two electronics maintenance technicians present on each shift. Operators may serve as beamline coordinators when not actually running the machine, especially on off shifts. The technicians can look forward to career growth as electronics coordinators, while
operators may move to associate scientists on beamlines. The ALS has a strong training program, consisting of a dedicated Procedure Center, with online access to all ALS procedures. The maintenance schedule consists typically of 5 shifts per month dedicated to maintenance and installation, with longer periods for major installations. The ALS uses operators actively, e.g., for troubleshooting, rather than simply to make adjustments. Operators are seen on the floor as well as in the control room, in a directorial capacity.

Day-to-day safety issues are met by operations coordinators and beamline scientists. On off shifts the emphasis for safety is on use of operators and electronics maintenance personnel. There are periodic Safety Circle meetings coordinated by an industrial hygienist, who reports to Environmental Safety and Health.

The owl shift crew schedule is fixed, with respect to personnel, the other members of the crew rotating between day and swing shift. We find this yields a stable operations staff with relatively low turnover. On the other hand, keeping one crew constantly on owl shift tends to cause them to lose touch with machine developments. However, the increased stability it lends to operations outweighs any disadvantages, as proven in 30 years of practice at the Bevatron and ALS.

4. PROGRESS 1990-2001

There were several significant events that served as milestones in the development of the ALS. Because of the severity of the challenges they posed, the administrative, engineering, and scientific strengths necessary in overcoming them provided opportunities for growth. First there was the commissioning of the ALS itself. During construction, the various groups (electronics, mechanical, etc.) worked well as independent groups, but when operation began it was discovered that they needed much more interfacing among one another than before. In a sense, group building had to take place.

Another significant historic event was damage caused to one of the flexbands, a series of thin metal strips designed to provide a smooth RF surface inside the vacuum chamber. The event was precipitated by the use of an unusual fill pattern with many single bunches, causing fatal heating due to the peak beam power. The machine was down 17 days while the physics and operations groups struggled to find the cause of the damage. Finally, an operator found a way of threading beam around the obstacle, thereby identifying its location and allowing for a fix.

The Birgeneau report, a DOE mandated review of four synchrotron facilities, provided the incentive for rearrangement of the coordination staff, in which beamline coordinators were moved functionally closer to operators, and the creation of a new LBNL division, the ALS Division. The latter process reduced the administrative distance between the lab director and the ALS Facility.

In the spring of 2001 we look forward to the installation of three super bend magnets, and to their attendant cryogenic issues.

5. DEVELOPMENT OF INFORMATION TECHNOLOGY AROUND MACHINE ISSUES

The ALS controls system was designed around the end of the 80’s, in preparation for the start of ALS commissioning. Some early software tools still in use are CTLPlay, Toolbook and DBChan, the latter being a ‘primitive’ Windows application that lists the entire machine database, through filtered searches. These programs are all still in use, although the first two are slated for replacement. In fact, the control system is currently involved in an upgrade, in order to address these and other issues, including a system capable of making kilohertz readouts of BPMs available in the control room.

A long-standing problem with storage ring beam is the unevenness of the amount of charge bucket-to-bucket. This unevenness contributes to beam instabilities and loss of lifetime, and is caused, in part, by unequal intensities of gun bunches injected into the booster ring, probably due in turn to uneven energy in the linac from pulse to pulse. I am currently developing a program for fill optimization to address this issue (see below).
In 1994 the first undulator was installed, and six more have since followed, necessitating feedforward routines for precise orbital correction. In 1997 the longitudinal and transverse feedback systems were added. Together, they reduce the transverse beam size from \(~300\) to \(~60\) microns. After an extensive period of commissioning by SLAC and ALS personnel, these programs have continued to be developed at the ALS. Until recently they have been among of the most frequent causes of downtime.

6. INFORMATION TECHNOLOGY AS OPERATIONAL TOOL

6.1 The Software Suite that Manages the Complexity of the ALS Storage Ring

It should be considered a strength of ALS Operations and Controls Groups, that operators’ contributions to programming are encouraged. At least two operators have contributed significant quantities of software to machine control and monitoring since 1991. This is facilitated by the fact that object-oriented and Windows-oriented programming environments and libraries specific to the ALS control have been provided to operators inclined to programming. Program SRInject, written by the author, [Fig. 1] is used to create new fill patterns and, at each storage ring refill, to start and stop the fill. It is slated for improvement in two ways: to include a fill enhancement routine which will equalize the charge in the SR buckets, and, if deemed feasible, provide automation of the entire fill procedure, including the insertion of the camshaft bucket.

The hardware used to connect the control room to the machine is implemented in two ways: 1) Using a database system, networked PC’s are processed through the display micromodule (DMM) and collector micromodule (CMM), and connected by fiberoptics to intelligent local controllers (ILC’s) at specific machine sites. Each ILC is equipped with 4 channels of ADC and DAC, and 4 boolean channels to exchange data with devices. 2) Workstations are connected directly to input-output controllers (IOC’s) using ethernet links. Newer installations are implemented in IOC architecture.

The software ensemble that runs the storage ring during user beam time consists of slow orbit feedback (SOFB), longitudinal and Transverse Feedback (LFB and TFB), RF Phase Control, Feedforward (FF), and Higher Harmonic Cavities (HHC).

- SOFB: A continuous orbit correction program. Regulates to within 5 microns, as measured in straight sections.
- LFB: Designed jointly at Stanford Linear Accelerator Complex and ALS, uses a digital signal processor farm and a quadrature phased shift keying system to damp synchrotron oscillations
- TFB: Damps horizontal and vertical bunch oscillations.
- RF phase control: Matches the phase of the RF power to beam phase. This was necessitated by problems with stability of the LFB system.
- FF: Compensates for beam misalignments caused by movement of insertion devices.
- HHCs: Enhances 3rd RF harmonic in the beam as it moves through passive cavities, thereby increasing beam lifetime by 50%. The cavities may be continuously tuned by this program to regulate the coupled power. Currently, it is in ‘stretch mode’ to improve lifetime.

These six programs run simultaneously and provide complete, automated control of stored beam parameters. Several of them (LFB – TFB – HHC) interact with one another, requiring detailed tuning in order to coexist. However when the machine is running well, which is increasingly the case, it may not be adjusted for days.

7. CONCLUSION

The use of information technology in daily life has introduced a host of problems along with its promise of a faster, more varied lifestyle. However, A vision of an appropriate application of IT might lie in its usefulness in governing the activities of large, complex machines. Running a large accelerator
like the ALS is not a unique situation worldwide. The ALS uses only one subset of software that COULD be used to run an accelerator anywhere. The software suite described here is not only a fine example, but also an exemplary one. According to social philosopher Nick Lee, without a solution to complexity, time seems to move faster, causing the ultimate goal of a project - whether driven by convenience or curiosity - to recede precariously into future inaccessibility, and preventing a proper fixing of attention on it.

* * * * *

BUILDING AN OPERATIONS GROUP

Pierre Bricault
TRIUMF, Canada

Abstract
The construction of the first phase of the ISAC Radioactive Ion Beam (RIB) Facility is completed. The facility uses the Isotopic Separation on-line (ISOL) method to produce the RIB. The ISAC facility at TRIUMF includes: a new building, a new beam line with adequate shielding to transport up to 100 μA of proton at 500 MeV from the existing H- cyclotron to two target stations, remote handling facility, a high resolution mass separator, a linear accelerator and experimental facilities.

The ISAC facility operation group was formed completely separated from the main cyclotron operation since it was recognized that during the commissioning of ISAC, operation of the new systems could be a distraction for the ongoing cyclotron operation. The new operation group is composed of nine persons: the head of ISAC operations, a training and documentation coordinator and seven shift operators. Because TRIUMF/ISAC is considered by the new Canadian Nuclear Safety Commission (CNSC) as a class 1 nuclear facility - and treated similar to nuclear power stations, the training approach of the new operators is somewhat different than in the past. The coordinator is in charge of putting a new training program in place. This training program is based on the ‘Systems Approach to Training’ developed by the ‘Public Service Commission of Canada’ that was adopted by the CNSC.
STRESS AND SHIFT WORK

Mina Michal
Leadership 2000, Geneva, Switzerland

Abstract
Understanding the fundamental aspects of stress and the biological and physiological effects of shift working is an important step toward developing coping strategies. This presentation was designed to give the participants a better awareness of these aspects and propose several practical strategies designed to sustain the performance of shift workers whilst maintaining their health and quality of life.

The first part of the presentation was devoted to defining stress, describing its biological effects and the difference between positive and negative stress. Whilst positive stress results in optimal levels of energy, vitality, physical stamina and mental alertness, excessive stress induces negative stress which results in fatigue, irritability, lack of concentration and errors in discernment accompanied by physical symptoms which vary from one individual to another. The second part focused on describing the link between circadian rhythms, our biological clock and the alternating phenomena of catabolism and anabolism. The last part described typical problems related to shift work and several solutions.

The nature of shift work causes additional stress for the shift worker who has to constantly adjust to variations in natural circadian rhythms. The practical implications of carrying out activities, which do not necessarily correspond to peaks and troughs of the natural biological cycles, induces additional stress which has to be kept under control. In this respect, it is vital for shift workers to eliminate or reduce other sources of stress and to maintain their health and well being at optimal levels.

The solutions proposed and discussed include the following: managing the physical environment, optimal nutrition, physical exercise, relaxation exercises, frequent health checks, physical training facilities at work, avoidance of overload, development of teamwork, and longer holidays for better recuperation.

It is highly recommended that shift workers follow a special training program in order to cope optimally with the demands of the nature of shift working. Such a program would be designed to increase their knowledge of the physiological and psychological implications of shift working, show them how to identify sources of stress and how to eliminate or reduce them, motivate them to adopt an optimal lifestyle based on effective nutrition, physical exercise and relaxation, elevate and maintain their energy levels and performance, and lead them to an overall improvement of their quality of life both at work and at home. This preventive approach would be significantly beneficial to the individuals, their teams and the organization. It would motivate shift workers, responsibilize them for adopting an effective lifestyle, reduce errors of judgment and accidents, prevent illness, enhance communication / teamwork and reduce conflict, amongst other advantages.
SUMMARY OF SESSION 4
HOW DO WE MONITOR BEAM QUALITY?

Emanuel Karantzoulis
ELETTRA, Trieste, Italy

Up to the end of the 80's beam quality was mainly believed to be connected only to the intensity i.e. beam quantity. However, with the new colliders already functioning or programmed, new and more (also in safety) demanding production machines (e.g. isotope) and the many new 3rd generation synchrotron radiation sources that accommodate many experimental lines, the beam quality (BQ) issue has to be re-examined, re-evaluated and re-defined.

Accelerator Operations and the Management have also realized that accelerators are built to serve the experiments by providing beam and as in any 'commercial' business quality is an important factor. Different experiments however have different beam needs and tolerances thus BQ demands and definitions differ.

It would be desirable to define beam quality from the accelerator point of view; firstly for the experimenters needs and secondly for the simple reason that at experimental positions (detectors, beam lines) many things can go wrong, which may lead to a mis-interpretation of the beam.

In general BQ can be seen as the contribution from three main factors:

- Beam availability (uptime)
- Beam monitoring (to verify or improve quality)
- Communication (meetings, messages, displays, info to the users)

Some of the aspects of good beam quality are that it eases the problems with the experimentalists, attracts more users and thus makes more money available. In some cases like Jefferson Lab. or ELETTRA, beam quality is strictly connected to the lab performance and production bonus.

1. BEAM AVAILABILITY

The beam availability or Uptime has been defined as the usable beam delivered according to the schedule (even if it is not actually used for a certain period by the experiments). The uptime depends heavily on the organization of operations, automatism used, money available for maintenance/ interventions, the number of pre-accelerators and it is ranging from 60-95%. To improve on uptime one needs also archiving of the machine (e.g. magnet settings) and frequent 'operations meetings' where problems of the machine are discussed and responsibilities are defined. It is recommended that a cost-effective evaluation be performed for the desired uptime level just like for the safety issues. To increase the uptime performance one can think of:

- Redundancy of equipment
- Non interruptable mains
- Universal Power Supply spares
- Preventive maintenance
- Operations team that can troubleshoot and repair
2. BEAM MONITORING

In general parameters and methods depend on the specific machine. The users, however, are usually interested to know the following:

- Energy
- Intensity
- Intensity decay (lifetime)
- Luminosity-brightness-brilliance
- Stability

In order to get the necessary information the following beam parameters are involved (or displayed):

- Global/local orbit
- Beam dimensions – spot size
  - Transverse: pinhole imaging of Synchrotron radiation, wire scanners, residual gas monitors, quadrupolar pick ups, OTR screens
  - Longitudinal: streak cameras, topography methods that also reveal the longitudinal bunch shape in phase space.
- Emittance-coupling-tunes
- Momentum and momentum spread (OTR, synchrotron radiation spectra)
- Polarization
- Spectral quality on dedicated synchrotron radiation line
- Radiation losses
- Collimators position
- Bunch purity
- Transfer functions
- Intensity stability (top-up, lasers on the gun)
- Beam bunch stability control (rf plungers/HOM shifters, rf cavity temp. tuning, super conducting cavities, feedback)
- Magnet cycle-beam destination

It is also recommended to have some supporting software available like an Alarm handler, Process log and beam parameter archiving.

3. COMMUNICATION AND PROCEDURES

All agreed on the following strategy towards experimentalists:

- Display messages from the Control Room
- Display relevant machine parameters
- Allow archive searching since also experiments need machine/beam data

From the tactics point of view one should:

- Anticipate the problem – inform of a bad quality beam
• Communicate with transparency
• Carefully hear any complains and be honest
• Only a careful selection of messages and alarms should be available (not alarming unnecessarily the users, might not be interested, not blaming equipment groups)
• Intra-division meetings (at the most once per run)

From the organization point of view the following roles were mentioned for contacts with the experimentalists:

• Operations liaison (operations person that is directly communicating with a certain experiment)
• User support or run or experiment or floor coordinator (a user representative that brings the user's demands to the control room, preferably the only user allowed to phone to the control room)
• X-ray beam line position expert (for light sources). A machine division person who verifies the good functioning of these monitors in case of complains.

As available tools for communicating with users were mentioned: the TV screens, telephones, loudspeakers and Internet. Especially about Internet there is a great interest that all communications and displays go also via this way.

4. IN CONCLUSION

Beam Quality applies to all accelerator facilities - small and large.

A single parameter may be sufficient to characterize the BQ for a certain experiment. However, there are usually many experiments and that single parameter may depend on many others (e.g. luminosity). Thus in practice many parameters are defined.

It is possible to connect these parameters in a weighted way to a single fictitious quality indicator that continuously ranges the beam quality from 0-100% (blue line on the right) as it is done at ELETTRA (Fig. 1).

![Beam Quality Controller](image)

Fig. 1: Beam Quality Controller
One must not forget that ‘clients’ may well be always right but on beam quality issues only 10% of the complaints are due to a bad beam. However this needs to be proved by beam quality monitoring and the following presentations will give us a more detailed account on how this is done.

Finally it is the wrong tactic to ask the opinion of users on the quality of the beam they are using. One should first define it according to their needs and then monitor it independently.
OPERATION OF THE ANKA SYNCHROTRON RADIATION SOURCE UNDER A STANDARD QUALITY MANAGEMENT SYSTEM

M. Hagelstein and V. Saile
Angströmquelle Karlsruhe GmbH, Hermann-von-Helmholtz-Platz 1, D-76344 Karlsruhe

Abstract
ANKA (Angströmquelle Karlsruhe) is a state-of-the-art synchrotron radiation facility at the Forschungszentrum Karlsruhe (FZK). Based on a 2.5 GeV electron storage ring it delivers photons from the infrared to the X-ray range. Five straight sections are available to accommodate insertion devices. The facility will be operated by a for-profit company, ANKA GmbH. In compliance with its mission, commercial services to customers will represent the majority of the overall activity, complemented by providing beam time to research users. Nine beamlines have been installed, eight will be operated by ANKA GmbH, one by the Max-Planck-Institute for Metals Research, Stuttgart. Three lithography beamlines for X-ray based production of microstructures will be jointly operated by ANKA GmbH and FZK’s Institute for Microstructure Technology IMT, which is certified under ISO 9001. Current plans for the application of standard quality management procedures are presented.

1. INTRODUCTION
The synchrotron radiation (SR) source ANKA is located inside the premises of Forschungszentrum Karlsruhe (FZK), a member of the Helmholtz Society. Construction and commissioning of the accelerators and beamlines is under the responsibility of a special project group of FZK and will be completed in 2001 and finally, ownership of the entire facility will be transferred to ANKA GmbH in April 2001. This company is organised as a for-profit, commercial entity and will operate the facility for private-sector customers. Access to academic institutions will be co-ordinated by the Research Group Synchrotron Radiation (Forschungsgruppe Synchrotronstrahlung, FGS), a newly established organisation within FZK.

2. THE SYNCHROTRON RADIATION SOURCE
The main technical parameters of the synchrotron radiation source ANKA are summarised in Table 1 [1]. Nine beamlines have been installed, eight will be owned and operated by the ANKA GmbH and one by the Max-Planck-Institute for Metals Research in Stuttgart (see Fig. 1). In addition, two front-end beamlines serve for beam diagnostics. Three beamlines for X-ray based production are jointly operated by ANKA GmbH and the Institute for Microstructure Technology, IMT at FZK. IMT is certified under a strict ISO 9001 Quality Management System (QMS) and will also apply this system to these three beamlines housed in a clean-room, including scanners and ancillary equipment.
Table 1: Technical parameters characterising the synchrotron radiation source ANKA

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection energy</td>
<td>0.5 GeV</td>
</tr>
<tr>
<td>End energy</td>
<td>2.5 GeV</td>
</tr>
<tr>
<td>Max. electron beam current</td>
<td>400 mA</td>
</tr>
<tr>
<td>Storage ring circumference</td>
<td>110.4 m</td>
</tr>
<tr>
<td>Horizontal emittance (DX=0.5)</td>
<td>46 nmrad</td>
</tr>
<tr>
<td>Bending magnet deflection radius</td>
<td>5.559 m</td>
</tr>
<tr>
<td>Bending magnet magnetic field</td>
<td>1.5 T</td>
</tr>
</tbody>
</table>

Fig. 1: Schematic view of the facility with beamlines for LIGA-based production and SR-based physical and chemical analysis.

3. QUALITY MANAGEMENT SYSTEM AT THE INSTITUTE FOR MICRO-STRUCTURE TECHNOLOGY AT FORSCHUNGSZENTRUM KARLSRUHE

The institute for microstructure technology IMT, conducts applied research and development in the field of micro-structure technology, compliant with the rules and goals of the FZK. It is operated under a DIN EN ISO 9001 and 9004 certified quality management system (QMS) since 2000 [2]. The tasks of IMT span the large range from conception and design of new devices and systems to the development of series production of components. The micro-structured components and technologies may be transferred to industrial or public customers including fabrication of samples and manufacturing of components in pilot production. IMT is organised into seven divisions, three for research and development, one for micro-systems production, one for marketing, sales, and administration and finally one for quality assurance. The quality management rules are summarised in the Quality Management Handbook (QMH), which is
authorised by the institute director. The QMH is complemented by a large set of additional documents describing procedures, processes, tasks, specifications, plans, etc. The responsibilities of the leading staff and of the divisions are defined in the QMH. Compliance with the quality management rules is compulsory for all IMT personnel.

4. QUALITY MANAGEMENT SYSTEM FOR ANKA GMBH

Synchrotron radiation laboratories have reached a degree of maturity, where stability of the electron source, quality of the photon beam, predictability of the schedule, service, and cost-efficient operation are mandatory requirements for long term success. In particular, facilities like ANKA GmbH serving paying customers must embrace well-proven concepts such as 'customer satisfaction'. Producing goods or providing services that satisfy the specifications of a customer provides a definition for quality. In the private sector, quality is of overwhelming importance and has led to standard quality management systems such as DIN EN ISO 900X. Nowadays companies manufacturing goods or providing services must be certified for compliance with such a norm in order to stay credible and competitive. With the widespread success of quality management systems in industries it is a straightforward idea to implement such a system also at a synchrotron radiation facility.

The management of ANKA GmbH has decided to develop a QMS for the facility by 2002. The final objective is certification of ANKA GmbH. More important, however, is establishing the system as such, as well as implementing and applying it. The success of this effort will critically depend on the acceptance of the QMS by ANKA’s employees. ANKA GmbH will strongly benefit from the experience at IMT over the past 3 years with establishing ISO 9001 at the institute, which is one of the main partners of ANKA. Furthermore, the documentation for the technical systems of ANKA will focus up-front on QMS requirements. Continuous education and training of the ANKA GmbH employees will allow for efficient and reliable operation. Clear and well-documented procedures and responsibilities will be the basis for the ANKA GmbH organisation. The QMS will be implemented step-by-step, starting with the three beamlines for X-ray lithography. Ultimately, it will cover all procedures conducted at ANKA. The goals are customer satisfaction, in particular:

- Delivery of a beam of perfect quality with high reliability (beam availability, spectral quality, position accuracy, beam stability)
- Safety management, high safety standards for personnel, customers and academic users, evaluation of failure modes
- Environmental management, define, implement, operate, control, publish
- Conduction of production processes with tight tolerances under auditing control
- Conduction of analytical services, transparent and traceable for the customers
- On-time delivery
- Cost-effective operation

As far as radiation safety is concerned, strict procedures had to be followed since commencing operation of the accelerators and beamlines. The operation rules are defined in legal texts and radiation safety instructions. An officer responsible for radiation safety and the interaction with the local governmental bodies assures compliance.

5. CONCLUSIONS

The implementation of a standard quality management system at the synchrotron radiation source ANKA is driven by the main goal of supplying high-quality services to customers from industries and to academic users. A company culture with well educated and highly motivated employees is a major
prerequisite for reaching this goal. The very positive experience gained at the Institute for Microstructure Technology of FZK encouraged us to continue along this route.

References


Bibliography


MONITORING BEAM QUALITY IN THE PS COMPLEX DURING THE LIIC ERA

M. Benedikt, G. Cyvoc, S. Hancock, A. Jansson, M. Lindroos, G. Metral, PS operations team
PS Division, CERN, Switzerland

Abstract
Continuous monitoring of beam intensity and beam losses is provided today at the PS complex with beam current transformers and beam loss monitors. The beam intensity is continuously displayed over a video network, together with relevant information concerning the machine status. In the future, during the LHC era, further important beam quality parameters will be brightness, bunch length and momentum spread.

For maximum beam brightness, any increase of emittance must be avoided, and its value should be monitored continuously. Transverse coherent beam position oscillations, due to injection steering errors, can be measured with conventional pickups. A new system, using two quadrupole pickups, will allow continuous monitoring of both position oscillations and beam size oscillations, the latter caused by injection matching errors. Beam size, after smear-out consequent to any injection errors, is measured with fast wire-scanners on a daily basis. The possibility of monitoring it non-invasively and continuously using the signals from the quadrupole pickups will be explored.

A longitudinal phase space plot can be created on-line by applying phase space tomography to bunch shape data from a longitudinal pick-up. This allows many important longitudinal parameters - among them emittance and momentum distribution - to be deduced with unprecedented precision.

We discuss the problems associated with i) automating all these measurements, ii) the limits of the different systems and iii) how the results can be used for on-line beam quality monitoring.

1. INTRODUCTION
The PS Division is responsible for the operation of seven accelerators which deliver beams of protons, antiprotons, lead ions and electrons either directly to the users, or to the SPS for further acceleration. Four areas are fed with beam directly: the East Hall where there is an experiment (DIRAC) and numerous tests of experimental equipment, the ISOLDE facility, the new AD area and the LEA and SLF areas where tests of detector and vacuum components take place. During 2001, the Division took over responsibility for operating the ISOLDE facility. The breadth of the CERN physics programme requires that normally several of the different particle beams operate simultaneously, which requires pulse-to-pulse modulation of the machines and a complicated interweaving of different machine cycles in a supercycle. The accelerators operate for close to 6500 hours per year, which requires the reliable operation of all the component parts of all the machines for extended periods. In general the many different users have high requirements on beam quality, but with different emphasis on particular beam characteristics. In this paper the monitoring of the future LHC beam will be discussed. In particular, the issue of providing on-line beam quality data for the subsequent machine in the injector chain will be addressed.
2. **ON-LINE BEAM MONITORING FOR THE PS USERS**

At present a display showing the actual magnetic cycle in the PS, the ejected beam intensity and the beam destination is broadcast over a video network to experiments and subsequent machines (the Users). Measurements of transverse and longitudinal beam characteristics are done on a daily basis at all machines by the PS operation crew, by some experiments and at injection into the next machine in the chain. The PS operators correct for all irregularities and work on improving general aspects of the beam quality. Such general aspects can be a poor beam profile or a undesired beam halo. Irregularities observed by the Users which cannot be verified or understood by the operation crew are discussed in specially arranged meetings. Weekly meetings are also held to inform the Users about the machine programme and status, and the work in progress.

3. **THE LHC BEAM**

The emphasis at the PS division has historically been on high-intensity beams. Major investments have been made to increase the intensity over the years with impressive results. The LHC beam is of low intensity but high brightness. This translates into a small emittance beam with a high longitudinal and transverse particle density. To enable the control and observation of such a beam, a project was launched in 1993 to adapt the machine hardware, the longitudinal and transverse beam control, and the instrumentation of the PS machines forming part of the LHC injector chain.

4. **MONITORING TRANSVERSE LHC BEAM CHARACTERISTICS**

In order to verify that the beam emittance is not blown up by bad matching between machines, a new measurement system has been developed to monitor PS injection (since the Booster uses multturn injection, matching is not as much of an issue there). This system is currently being installed and consists of two quadrupole pick-ups positioned in consecutive straight sections of the machine. A quadrupole pick-up is a non-intercepting device that measures, apart from the beam position, the quadrupole moment of the beam. The PS pick-ups [1] have been designed [1] so that \( \kappa \) can be measured on a turn-by-turn basis for each bunch separately (see Fig. 1).

\[
\kappa = \sigma_x^2 - \sigma_y^2 = \varepsilon_x \beta_x - \varepsilon_y \beta_y + \sigma_z^2 D_z^2
\]  
(1)

Any oscillatory part of \( \kappa \) as a function of machine turn is due to mismatch. If the lattice dispersion is non-zero (as in the PS case), beam size oscillations due to injection errors in \( \beta_x \) and \( D_z \) develop differently as a function of turn. Consequently, it is possible to separate these two effects in the horizontal plane. The vertical dispersion mismatch cannot, however, be easily distinguished from a vertical betatron mismatch, but it is expected to be very small.

Since the ratio of \( \beta \) values (horizontal to vertical) are different at the the two pick-up locations, the system of equations given by Eq. (1) for the measured \( \kappa \) values can be solved for the emittances. This requires a knowledge of the \( \beta \)'s, which may be oscillating due to mismatch. However, by using the values of \( \beta \) and \( \kappa \) averaged over many turns, the filamented emittance can be calculated. This is theoretically very straightforward, but has yet to be demonstrated experimentally. Since \( \sigma \) is the rms beam size, the result is the true rms emittance, independent of distribution.

The momentum spread, which is needed to quantify the dispersion part of the signals, is calculated from the cavity voltage and the bunch length. The latter can also be determined from the pick-up data. Thus, the measurement system is self-contained in the sense that it will not require any additional input of measured beam parameters by the user. Therefore, it can employ a very simple user interface, or even run continuously in the background as an emittance watchdog, alerting the operator when correction is needed. The application program for this system will be integrated with the ABS (Automatic Beam Steering and shaping) one developed for the PS Complex [2], allowing the simple correction of detected injection errors.
Since the quadrupole pick-up system was developed primarily with injection studies in mind, some of its components (hybrids and amplifiers) are bandwidth-limited to about 30 MHz. This means that it is not possible with the present configuration to make single-bunch measurements in the very last part of the cycle, when multiple splitting has significantly shortened the bunch length to fit the SPS requirements. An increase of the bandwidth is possible if required, but the emittance at PS ejection will anyway be monitored using the Optical Transition Radiation (OTR) screens [3] in the transfer line towards the SPS.

![Graph](image)

Fig. 1: Quadrupole moment of a proton bunch in the PS measured with a quadrupole pick-up over several machine turns.

Apart from the on-line monitoring of the injection using the quadrupole pick-ups, it is foreseen that the operators measure the emittances at different times in the cycle on a daily basis using the wire scanners [4]. This will provide a valuable cross-check of the on-line results, verify the beam profile that cannot be studied with the pick-ups, and provide day-by-day emittance statistics.

5. MONITORING OF LONGITUDINAL LHC BEAM CHARACTERISTICS

The main longitudinal beam characteristics can be determined from a measurement of the longitudinal bunch shape. The longitudinal pick-ups in the PS and the PS Booster can be read with a digitizing oscilloscope and the resulting image can be displayed for one entire turn. It is also possible to acquire turn-by-turn data with an oscilloscope triggered by a revolution train synchronous with the bunch, or bunches, in the accelerator. The software for the first system permits the operator to save reference images, which can be compared to the present image yielding information on the phase and bunch shape. This is particularly important for the LHC beam where there is a second bunch-to-bucket transfer which must be synchronised at the energy of the first batch waiting in the PS. The on-line software for the turn-by-turn system includes a tomographic reconstruction algorithm [5] which permits the measurement of longitudinal phase space density (see Fig. 2). Additional input of some machine parameters, e.g. the RF voltage and the magnetic field, is necessary for the reconstruction. The longitudinal rms emittance together with the momentum distribution can easily be deduced from the resulting tomograms. Our tomography algorithm has proved extremely robust for errors in the input data [6]. An example of the on-line display is shown in Fig. 3 where the Booster beam was captured at the wrong frequency.
Fig. 2: A tomographic reconstruction of an unusual bunch distribution. Without tomography it would not be trivial to visualize the longitudinal phase space distribution from the turn-by-turn data.

Fig. 3: A small error in the RF capture frequency at injection caused this phase space distribution. From the profile data alone it would not be possible to diagnose this fault.
6. CONCLUSIONS

The LHC beam is more sensitive to a deterioration of the beam quality than the present beams. The new instrumentation developed for this beam will, as we have shown, yield reliable on-line data for the beam characteristics. This can be used for on-line alerts (and correction) but it can also be directly broadcast to the subsequent machine. This would enable the crew at that machine to monitor and even store the initial beam conditions and relate that to observed abnormalities in their accelerator. This would require a different form of broadcast compared to today, which will need a common control structure (under study). It would also differ from the present situation due to the type of data that is being monitored and broadcast e.g. longitudinal and transverse beam emittance, beam shape and longitudinal phase shift (compared to a given reference). Maybe the most important difference is that, with this new type of monitoring, the operator of the subsequent machine would not have to rely on a manual intervention to have important beam characteristic data at hand.

Longitudinal tomography not only yields emittance data, but it could also serve as a powerful visual aid to see small longitudinal beam perturbations. The present style of video screens with a summary of the most important machine data will probably continue to be broadcast over the existing, or an improved, video network. The tomograms are visually attractive and would form a natural focus on such a screen. The present progress in computing power should permit us to compute on-line tomograms for every machine cycle at the LHC start-up in 2006.

References


[3] New Methods to Derive the Optical and Beam Parameters in Transport Channels, G. Arduini, M. Giovannozzi, K. Hanke, D. Manglunki, M. Martini, Accepted for publication in Nuclear Instruments and Methods in Physics research A


MONITORING BEAM QUALITY AT HERA

M. Bieler
DESY, Hamburg, Germany

Abstract
At Hera (a lepton proton collider), the amount of the data taken by the experiments is determined by two factors: the operational efficiency of the accelerator and the beam induced background rates of the experiments. As both Hera and the booster, used for injection (Petra), are slow cycling machines, about 17% of the scheduled operation time of the machines are spent filling both beams and bringing them to collision energies. The time required for this procedure depends very much on the reliability of the hardware, the degree of automatisation of the procedure and last but not least, on the skills of the operators. Another 26% of scheduled operation time is lost due to hardware failures. Weak components and reasons for failure are trying to be identified. During the remaining 57% of scheduled operation time beams are colliding and the experiments are taking data. The quality of the data depends on the beam quality; for example on the beam emittance, the amount of unbunched (coasting) beam, the amount of parasitic bunches, beam lifetime and so on. All these parameters are not only monitored by the Hera control room, but also shared with the experiments through a site wide data exchange system.

1. HERA
HERA, the ‘Hadronen Elektronen Ring Anlage’, is an electron proton collider for high-energy physics. Two rings are placed in one tunnel of 6.3 km circumference. The superconducting proton ring has an injection energy of 40 GeV and a flat top energy of 920 GeV. Typically 100 mA are stored in 180 bunches. In the electron ring, (12 – 27.5 GeV) typically 50 mA of either electrons or positrons are stored in 189 bunches with a characteristic spin polarisation of 60%.

In the four straight sections of the HERA ring four experiments make use of the HERA beams: Both H1 and ZEUS use colliding beams used to probe the structure of the proton. Hermes uses the polarised electron beam and a polarised gas target to investigate the proton spin. HERA-B uses a thin wire target in the halo of the proton beam to look for c-p violation.

2. WHAT IS ‘BEAM QUALITY’ AT HERA?
For the HERA experiments the figure of merit is the integrated luminosity on tape. The integrated luminosity is determined by parameters like the operational efficiency of HERA, the beam currents and beam sizes. The luminosity on tape depends also on the amount of background and on the detector efficiency.

3. OPERATIONAL EFFICIENCY
The average operational efficiency of HERA in the year 2000 was 57%. Here operational efficiency is defined as ‘time during which luminosity is delivered, divided by total scheduled operation time’. The number is low compared to other machines, but this is mainly due to the fact that both HERA and its pre-accelerator PETRA are slow cycling machines. Figure 1 shows a plot from the HERA archive. The parameters displayed here are proton energy (black), proton current (red), electron energy (blue),

92
electron current (green) and integrated luminosity (black). On the horizontal axis time is displayed in hours.

![Graph showing data from HERA archive](image)

**Fig. 1:** Data from the HERA archive, showing a refill of the machine from beam dump to luminosity in 2 hours.

In figure 1 it can be seen that it takes about two hours to dump the beam, cycle the proton magnets, fill the proton machine, ramp the protons to full energy, cycle the electron magnets, fill the electron machine, ramp the electrons to full energy and bring both beams to collision.

![Pie chart showing HERA efficiency 2000](image)

**Fig. 2:** Operational efficiency of HERA in the year 2000

Figure 2 shows how the scheduled operation time for HERA was used in the year 2000. Apart from the time it takes to inject both beams and bring them to collision (17%) there are two categories of downtime: 'Fault' (18%) means a broken component in HERA, 'Idle' (8%) means that HERA has to
wait for either a pre-accelerator or one of the experiments to become ready. During the remaining 57% of the operation time HERA did deliver luminosity.

These data for these statistics are taken from an electronic logbook, which is written by the run co-ordinator. This logbook also contains the cause of each fault and allows one to produce statistics about the reliability of all technical components of HERA. These data are for internal use only and are not made public.

4. BEAM CURRENTS

While the electron current in HERA is mainly determined by the available rf power, the proton current in HERA depends on the beam current and transfer efficiencies of all the pre-accelerators. Protons can only be accumulated in the synchrotron for a limited number of turns after passing a stripping foil in the transfer line from the H-linac. From here on the final beam current in Hera depends on the loss rates in the synchrotron, in the transfer line to PETRA, in PETRA, in the transfer line to HERA and last but not least on the loss rate during the energy ramp in HERA.

5. BEAM SIZE AND COUPLING

A synchrotron radiation monitor measures the beam size of the electron beam in HERA. Synchrotron radiation from a bending dipole is focussed on a CCD camera. A frame grabber is used to display the beam spot and to calculate the beam size. The electron spot size in the interaction regions can also be determined by the photon detectors of the luminosity monitors. These spot sizes are also displayed in the HERA control room.

The pictures of the electron spot size can be used to determine the coupling of the transverse betatron oscillations. If the beam ellipse is not flat, the coupling has to be corrected. This helps both for luminosity and for spin polarisation.

The proton beam size is measured either by wire scanners or by rest gas ionisation monitors. The wire scanners move a thin wire through the beam and measure the amount of scattered particles with respect to the wire position by means of photomultipliers, which are located downstream from the wire scanners. This method is quite accurate, but creates a lot of background and would therefore trip the high voltage of the central detectors of H1 and ZEUS, if used during a luminosity run. The second method, using a rest gas ionisation monitor to determine the proton beam size, can be used all the time, but is not as accurate as the wire scanners. The rest gas monitor is located in a warm straight section of the proton ring. Here the residual gas pressure is sufficiently high so that enough residual gas molecules can be ionised by the proton beam. The electrons liberated through this process are accelerated by an electric field perpendicular to the proton beam. Through a multicannel plate the electrons create an image of the beam on a video camera.

The coupling of the transverse betatron oscillations of the proton beam can be monitored on the betatron tune spectra. If the coupling is well compensated, the tune spectrum shows one single peak for each plane. If the coupling is not well compensated, the horizontal peak appears on the vertical spectrum and vice versa.

6. BACKGROUNDS

The data taking efficiency of the experiments is mainly determined by the dead time caused by beam induced background. The most important background trigger rates from the experiments are displayed online in the HERA control room.

Proton induced background can be caused by bad betatron tunes, coupling or chromaticity (all visible on the tune spectrum), bad collimator positions (collimator loss rates), huge beam emittance (wire scanner or rest gas monitor), particles in the wrong rf bucket (fast current monitors), particles
outside the rf buckets (beam current monitors: \(I_{DC} - I_{Bunch}\)), bad orbit (beam position monitors) and many other reasons.

Electron related background can be caused by a bad orbit (visible through the beam position monitors), misteared synchrotron radiation (collimator positions), off energy particles (collimator positions) and many other reasons.

7. LUMINOSITY

The best parameter to measure beam quality is luminosity. Luminosity is displayed online by the experiments Zeus and H1. Luminosity and specific luminosity are displayed on a five minutes scale (update 1 second) to see effects of manipulations, and on a one hour scale to see slow drifts. At the beginning of a luminosity run the luminosity has to be checked every five minutes (changes due to temperature drifts), later every fifteen to twenty minutes. There is no 'luminosity auto pilot'.

8. ELECTRON/POSITRON SPIN POLARISATION

A good parameter to measure electron beam quality is spin polarisation. Polarisation is displayed online by the experiment Hermes. Polarisation is displayed every minute (to see effects of manipulations) and with a five minute average (for fine tuning). Good polarisation requires (among other parameters) a flat vertical orbit (rms ~ 1mm) and a flat beam (small coupling of betatron tunes).

9. CONTACT WITH THE CUSTOMERS

The status of HERA is published on the WWW and on TV screens all over the DESY site. Figure 3 shows one day of HERA operation.

Fig. 3: The status of HERA as it is displayed on the WWW and on TV screens all over DESY.

The HERA experiments do have online access to selected displays of the HERA control system (like collimator positions,…). This requires a Windows-NT PC.

There is a site wide data exchange system (Machine Experiments Data Exchange NETMEX) between machine and experiments, providing online machine data (beam currents, energies,…) and experiment data (luminosity, background,…). The system is platform independent.

The direct telephone contact between the HERA operators and the experiments is supposed to go through the co-ordinating experiment (which changes weekly between the experiments). This was introduced to minimise the number of telephone calls after a beam loss.
10. ACKNOWLEDGEMENTS

This paper reflects the work of many people over a long period of time. Instead of a very long list of references I would like to thank all the people from the diagnostics and instrumentation’s group for all the information they contributed to this paper. References about the instrumentation of HERA can be found on the webpage of this group: http://desyntwww.desy.de/md/
BEAM QUALITY CHARACTERISATION AT THE ESRF

L. Hardy
ESRF, 6 rue Jules Horowitz, BP220, 38043 Grenoble, France

Abstract
The high level of sophistication of many experiments is a first motivating factor for accelerator physicists to improve intrinsic beam parameters. In order to process data and understand results, Users need to be actively informed of such parameters.

At the ESRF, demand for beam time is three times greater than is available. It is this aspect, among others, that spurs accelerator engineers to do their utmost to improve beam time availability in order to best satisfy the User community. This is also part of the so-called beam quality. Beam uptime has now reached such high figures in many centres that Users tend to forget that there is an accelerator behind the wall ... until it fails! This is why maintaining a good level of communication with Users is crucial: explaining what we are doing and listening to their needs are our two major interests.

The manner in which this business is managed at the ESRF will be detailed in this paper.

1. INTRODUCTION
The European Synchrotron Radiation Facility (ESRF) is an X-ray source of the third generation. The accelerator complex is composed of a Linear accelerator (e- 200 MeV), a synchrotron (300 meters – 6 GeV) and a Storage Ring (844 meters). The ESRF accelerators have been in full routine operation for over six years. The source delivers 5600 hours of X-ray beam to nearly 40 beam lines simultaneously. Our first goal is to ensure good availability of the Machine as well as a satisfactory Mean Time Between Failures (MTBF) all of which under safe conditions.

2. INTRINSIC BEAM PARAMETERS AND BEAM QUALITY
2.1 Why is it important for the Users?
For fundamental research as well as for applications (including medical treatments) using particle accelerators, the knowledge of intrinsic beam parameters is essential. Almost all experiments are fitted for dedicated beam characteristics (beam size at the location of the sample for LIGA techniques, beam stability for cancer treatment, etc). Experimental devices, such as monochromators, targets, detectors, will be especially designed for given beam parameters and scientists will generally exploit beam characteristics so as to develop new ideas for experiments (time-structured beam for storage of hard X-ray photons in a crystal cavity, bunch length for biochemists, etc). Then, for the processing of obtained data, these parameters will again be of prime importance in order to analyse and understand results and to finally validate models.

2.2 What is monitored online in the ESRF Control Room?
One computer screen displays the main beam parameters online (intensity, lifetime, rms orbit values, tunes, emittance). It is located at a central location in the Control Room so that it is permanently visible to the Operator. For all these parameters, a tolerance range has been predefined. Should the value be in this range, the value will appear on a green coloured background. Otherwise the background colour
turns to orange so as to catch the attention of the Operator. Some of these parameters (such as the orbit value) are even linked to a voice synthesiser audio alarm.

Whilst the beam is running, several important beam parameters are monitored online:

- The betatron tunes: should this parameter be wrongly tuned, this will have an impact on the lifetime. The Operator has the possibility of changing the tunes.

- Information about orbit values. A plot of the orbit seen by the 224 Beam Position Monitors (BPM) is displayed. Rms values and peak values are then automatically computed. The Operator can retrieve good orbit values by applying a SVD correction process. However, in the case of abnormal behaviour of a steerer, the orbit plot can be used as an input in a simulation code, which will determine the faulty steerer (which can then be invalidated by the Operator).

- Furthermore, three beam lines require particularly good beam stability. They are equipped with local feedbacks (making local corrections at a rate of 4.4 kHz). A graph in the frequency or in the time domain is permanently monitored for these 3 beam lines.

- Viewed by a pinhole camera located in the Storage Ring, the X-ray beam spot is displayed online. This gives a considerable amount of information. When the beam displays optimal conditions, a Region of Interest (ROI) is defined on the screen. Beam drift or jumps outside this ROI will indicate orbit anomalies. When inside this ROI, the emittance is permanently computed in both planes. Horizontal deformation will indicate the presence of High Order Modes. Vertical palpitations will indicate a lack of chromaticity. A tilted spot will indicate that a skew resonance is badly corrected, etc.

- When delivering a time-structured mode (such as the single bunch), Users need a perfectly cleaned bunch, i.e., no parasitic electrons besides the main bunch (a ratio below $10^{-7}$ is paramount. Again, the bunch purity is monitored online thanks to an APD diode located in the Storage Ring. However, when the Operator is sure that the bunch is pure enough, the diode is extracted in order not to degrade it unnecessarily.

- Hundreds of others signals can be accessed and monitored online through a common application. However, this is done only with special goals in mind and not during the normal Users delivery.

2.3 Which information can be accessed by the Users?

In order to open/close their Front End, the Users are obliged to go through an application in which, basic beam parameters are automatically updated online, such as intensity, lifetime and the messages sent from the Control Room to all beam lines.

In addition, the Users, as well as the Control Room, can access the archived data of about 1500 signals. For each signal, the time scale can be chosen between the present time and 1 year ago. This is of interest to them since, to give but 1 example, the X-ray beam position in their Front End can be displayed. However, it has been noticed that Users rarely use that possibility and prefer raising the questions directly with the Control Room. Most of their questions concern beam stability. The Operators will generally be able to answer all their questions. However, in tricky cases, Users have the possibility of sending e-mail to position@esrf.fr which groups a few Machine experts. An answer is usually provided within a few hours maximum.

Moreover, all online Machine information may be viewed by the ESRF personnel via videos and scrolling screens installed in most major corridors of all the ESRF buildings (including the Users Guesthouse).

As yet, no WEB tools have been developed to archive and retrieve data.
3. RELIABILITY OF THE BEAM DELIVERY

Having perfect beam characteristics would be useless if good beam delivery reliability was unobtainable. Beam time availability and the Mean Time Between Failures (MTBF) constitute the 2 basic figures of importance (the MTBF being of prime importance for the Users). This must be taken into account in the definition of ‘beam quality’.

At the ESRF, the starting point is a hand-written sheet filled in by the crew on shift. Amongst other information, this sheet contains: the real delivery time, the average intensity and the failures (equipment description + time and duration of event). This information is regularly extracted and summarised in order to produce periodic statistics such as the figures mentioned above. All the failures and their characteristics (time, duration, description, etc) will be compiled in a spreadsheet, which includes every failure since the beam is delivered to Users at the ESRF 6.5 years ago. This spreadsheet can be exploited in many different ways, the most interesting one consists probably in displaying the evolution of the MTBF per piece of equipment along the years, which will trigger preventive maintenance actions. This spreadsheet will give information about the origin of the repetitive failures and the long failures (respectively spoiling the MTBF and the beam availability). It is worth noticing that the definition of the availability at the ESRF is 100% - dead time for the refills (~1% in 2000) – time interruption due to failures (~2.5% in 2000) – time interruption in the case of the Control system crash preventing the Users from working (even if the beam is running) – the time between 2 failures IF 2 failures occur within 1 hour. Our goal, which is adhered to for 3 years, is to stay above 95%. Several examples of this achievement can be found in ref. [1].

4. COMMUNICATION TOWARDS AND FROM THE USERS

Now, what to do with a high quality beam and perfect delivery conditions if it does not fit User’s requirements? This shows the usefulness of two-way communication: firstly, in order to communicate to the Users our scheduled improvements or our problems and secondly, to listen to their requirements.

In short, the first step is to anticipate the problems. To do that, once a week, a meeting is held within the accelerator’s Division and chaired by Operation Managers. All the accelerators’ physicists, engineers and technicians are invited to this meeting. The beam delivery of the last week is reviewed in detail. All interruptions, failures and problems are discussed in depth. The main goal is to make sure that all problems are understood and above all, that experts have undertaken actions to solve them! Finally, the results of the Machine Physics Studies of the week (one day per week) are reviewed.

Then, once per Machine run (i.e., every two months), another meeting takes place where a larger audience is invited: Directors, Users, Machine experts, and any other persons interested. This is called the Inter Division meeting. The beam delivery of the run in progress is summarised (10 minutes). The Machine Physics results which have a direct impact on the Users are also summarised. This meeting is a good opportunity to propose medium to long term strategies to the Users (new filling modes, better beam stability) AND to listen to their feedback, complaints, and requirements.

At every meeting one User presents scientific results obtained on his/her beam line. Whenever possible, they are asked to give focus on results, which were obtained thanks to a given particularity of the beam characteristics, for example a perfectly cleaned single bunch or a given time-structured beam. This kind of meeting is of real interest to both communities.

5. CONCLUSION

We have seen that, at the ESRF, the so-called ‘beam quality’ is the result of three indissociable approaches: having good intrinsic beam parameters, maintaining a good level of beam delivery reliability, two-way communication with the Users. For each of these points, a positive approach must be taken: a complaint may be the first hint and is a good starting point in order to improve the accelerator’s performance hence leading to better scientific results.
References

BEAM QUALITY AT JEFFERSON LAB

M.F. Spata
Thomas Jefferson National Accelerator Facility, Virginia, USA

Abstract
The Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Lab is a $600M CW electron accelerator in Newport News, Virginia. The machine is a recirculating, superconducting 5-pass linac initially commissioned for 4 GeV with a maximum beam power of 1 MW. With improvements in our RF cavity performance and an upgrade to magnet power supplies we are now capable of reliable operations at up to 5.7 GeV. We employ a three-laser photocathode gun to provide a CW electron beam with 80% polarisation to three experimental endstations in currents ranging from 100 pA to 200 mA. Establishing clear criteria for beam quality and developing the means to verify and maintain beam quality is essential to a successful physics program.

1. INTRODUCTION
Beam quality criteria are developed early in the life cycle of an experiment and are realised through a co-ordinated effort between the various departments within the Physics and Accelerator Divisions. I'll discuss the overall experiment approval process, in the context of the identification of beam quality specifications, and the realisation and maintenance of these criteria through the development and implementation of diagnostics, feedback systems and communication mechanisms.

2. EXPERIMENT APPROVAL PROCESS
Experiments are awarded beam time as a result of a careful review of overall scientific merit, technical feasibility, and manpower requirements. All experiment proposals come under the review of the Program Advisory Committee (PAC). The PAC is an advisory group to the Lab Director. It consists of members external to Jefferson Lab appointed by the Director, plus the current Chair of the User Group Board of Directors.

The PAC solicits input from the Technical Advisory Committee (TAC). The TAC reviews an experimental proposal from the perspective of challenging technical issues, unusual demands on Jefferson Lab resources, and unusual Environmental Health and Safety issues. Specific beam quality criteria are contained in the body of the proposal and the TAC evaluates these on the basis of the present capabilities of the accelerator and decides if additional hardware or diagnostics are required to meet the beam quality specifications.

When technical challenges are evident for an approved experiment the effort is managed by the Accelerator Division Experiment Co-ordinator. A much broader audience is now exposed to the experiments needs and meetings are scheduled with members of Mechanical Installation, Electrical Installation, Cryogenics, Diagnostics, Radiation Control, Personnel Safety, Survey and Alignment, Software, Accelerator Electronics Support, and Operations Groups as necessary.

A key step in the process of communicating beam quality specifications to the Operations Group is the assignment of an Operations Experiment Liaison. The liaison is either a crew chief or operator who is responsible for facilitating information exchange between the experimenter and Operations staff during an experiment as well as during the planning stages. The liaison works closely with the
Accelerator Division Experiment Co-ordinator in streamlining the flow of information between the Operations Group and the Experimental Collaboration. Standard forms have been developed as tools to aid in the information exchange.

- **Physics/MCC Experiment Planner Form** – This form is completed by the Accelerator Division Experiment Co-ordinator (this is a full-time position that should not to be confused with the Experiment Liaison, which is a temporary responsibility). The form provides a brief description of the experiment, contact names and information, beam quality requirements, run times, and any special concerns related to the Machine Protection System (MPS) or the Personnel Safety System (PSS).

- **Experiment Liaison Check List** – This form is completed by the Accelerator Division Experiment Co-ordinator prior to the start of an assigned experiment. The form consists of a list of questions that help identify areas of special concern (e.g., additional procedures, new MPS interlocks, additional magnets...).

- **Experiment Liaison Binder** – The binder is located in the MCC control room and includes a specific section for each upcoming experiment. The Experiment Liaison is responsible for adding the completed Physics/MCC Experiment Planner Form, the Experiment Liaison Check List, and any other important experiment-specific information to the binder, prior to the start of the experiment.

Having clearly defined the flow of information to Operations staff regarding beam quality specifications, we then need to focus on mechanisms for maintaining beam quality and overall facility efficiency. This is accomplished through implementation of diagnostics, software, communications feedback mechanisms, and time accounting systems.

3. **BEAM TIME ACCOUNTING**

JLAB is operated by the Southeastern Universities Research Association (SURA) under a performance-based contract with the Department of Energy (DOE). The DOE employs a 1000-point system to rate our performance in the following key areas for overall success.

- Science and Technology Peer Review 300
- Reliable Operations (Simultaneous Availability) 250
- Production of Scientific Manpower 75
- Corporate/Community Citizenship 75
- Environmental Heath and Safety Peer Review 100
- Fiscal Responsibility Peer Review 100
- Institutional Management Peer Review 100

1000

The category for Reliable Operations specifically addresses our accountability with regards to maintaining the highest level of beam quality and efficiency of operations and counts for 25% of our overall assessment. A system of time accounting has been developed to keep us apprised of the overall facility efficiency, and helps us utilise our resources wisely when it comes to improving machine availability and beam quality.
3.1 Accelerator/End Station Status Definitions

The time accounting system is defined by the following categories:

- Acceptable Beam in Use (ABU) – Both the accelerator and experimental end station are meeting program requirements.
- Beam Available but Not in Use (BANU) – The accelerator is considered to be able to meet program requirements, but the experiment is not in an Experiment Ready status and therefore cannot make productive use of the beam.
- Beam Not Available or Unacceptable (BNA) – The accelerator is unable to meet program requirements which may include beam quality issues.
- Accelerator Configuration Change (ACC) – The accelerator is making a planned configuration change in the beam(s) being delivered.
- Experiment Ready (ER) – The experimental equipment is meeting program requirements or is considered capable of meeting program requirements if the Accelerator is in a BNA status.
- Planned Configuration Change (PCC) – The experimental end station is making a planned change to the software or hardware configuration, and this activity interrupts data taking or other activities in progress.
- Unplanned Experiment Down (UED) – The experimental equipment is unable to meet program requirements because of an unplanned system or administrative failure.

3.2 Metrics Definitions

Simple relations can be developed from these definitions to determine the overall success of the program. If $T$ is defined as the total time in the run period planned for physics activities then by definition:

$$ T = ABU + BANU + BNA + ACC $$

$$ T = ER + PCC + UED $$

The Accelerator Availability (AA), Experiment Availability (EA) and the Simultaneous Availability (SA) are then defined as follows:

$$ AA = \frac{ABU + BANU}{ABU + BANU + BNA} = \frac{ABU + BANU}{T - ACC} $$

$$ EA = \frac{ER + PCC}{ER + PCC + UED} = \frac{ER + PCC}{T} $$

$$ SA = \frac{ABU}{T - ACC} $$

The most relevant metric with regards to beam quality is Beam Not Available or Unacceptable (BNA). In most cases this means that the accelerator is unable to deliver acceptable beam to the user. This includes time required for investigating, troubleshooting, and repairing a software or hardware problem. It also includes time used for unplanned beam tuning. This is the time spent tuning the accelerator after an unexpected event, such as an equipment failure or when beam characteristics have drifted out of specification so that the beam is no longer useable. It also includes time when an accelerator configuration change takes longer than planned.

BNA events involve two major categories. The first is Downtime, which is relatively straightforward to track and is related to a hard subsystem failures or Fast Shutdown (FSD) events (beam trip). The second is Tunetime, which is related to events where nothing is apparently broken but
the accelerator is still unable to meet program requirements due to unacceptable beam quality at one or more experimental end stations.

4. **DOWNTIME AND TUNETIME TRACKING**

Our electronic logging system is used by Operations staff to record lost beam time due to Downtime and Tunetime events. These entries are automatically entered into a database designed to track such instances. The entries are also emailed to relevant system owners, the Operability Manager and the Operations Group Leader.

The Operability manager is responsible for tracking Downtime while the Operations Group Leader is responsible for tracking Tunetime. Both are reported on at the weekly scheduling meeting, which is attended by senior staff from the Physics and Accelerator Divisions as well as members of all of the associated support groups.

The Downtime report includes lost time for each system failure and indicates if there are any trends associated with the failure. Top-level categories for Downtime reporting are hardware, software, tuning, FSD, and End Stations. Major sources of downtime are specifically called out with responsible parties identified, and action items are developed to deal with improving recovery from such events and minimizing the chance of the incident reoccurring. Failure statistics are kept on a system-by-system basis and long-term trends are presented during monthly and semi-annual reports.

The Tunetime report indicates lost time due to unscheduled tuning. Events are tracked until sufficient improvement in procedures, software, hardware, or diagnostics make it unlikely that the event will reoccur. The particular problem is stated as well as proposed solutions and responsible parties for each tuning event. These incidents are usually related directly to the accelerator being unable to deliver beam to an end station according to one of the experiment’s beam quality criteria.

Both Downtime and Tunetime reporting are our primary means of ensuring that the accelerator availability remains acceptable and that we are able to maintain beam quality within specification.

5. **RUN CO-ORDINATOR WEEKLY REPORT**

Each experiment assigns the role of Run Co-ordinator to a collaboration member for a period of two weeks. This person is responsible for attending our morning summary meeting and providing a weekly beam availability report at the scheduling meeting. The Run Co-ordinator Weekly Report is used to indicate beam time accounting metrics, major causes of downtime in the hall, percentage of data collected to date, percentage of scheduled time the experiment has been running, special task results (e.g. energy measurement, spin measurement...), any potential problems related to beam quality or communications with Operations staff, as well as plans for the upcoming week.

This feedback mechanism is relatively new but has proven quite effective in bridging the gap between experimenters and Accelerator Division staff.

6. **BEAM QUALITY MONITORS**

A program of beam quality control relies heavily on diagnostic implementation, software development, feedback mechanisms, and communication. Following are some of the beam quality criteria with a description of the method used to monitor and communicate the information to the User.

6.1 **Beam Position Stability**

Beam Position Monitors (BPM’s) are used to indicate position stability in Halls A and C. These devices are strip line detectors with 4 orthogonal electrical pickups. The resolution of these BPM’s is on order 10 microns with an absolute accuracy of ±1 mm in the current range of 2 – 200 mAmps. The critical points as far as the experiment is concerned are the two BPM’s located immediately in front of the
nuclear physics target. These two are used to indicate the position and angle of the beam as it enters the target chamber.

Position stability in Hall B is indicated by the nA BPM system since their typical beam current is well below the resolution of the style of BPM's used in the accelerator and Halls A and C. There are three such devices, each of which is composed of three pillbox cavities. One cavity is used to indicate horizontal position, one is used to indicate vertical position, and the third is a current monitoring normalisation cavity. They have 10-micron position resolution and a 50 pA current resolution.

A slow feedback system is used to lock position and angle in Hall B since the response time of the nA BPM system is slow. We employ a Fast Feedback System (FFB) to keep beam position and angle stable at harmonics of 60 Hz. with an additional slow lock to keep the FFB system actuators in the centre of their range.

All three Halls have direct access to the BPM information as well as calibration factors that go into beam position calculations. The operations staff monitors beam position as well, and are alerted to errors in the relative beam orbit as they occur.

6.2 Momentum

The relative momentum error in our 9 main accelerator arcs and 2 of the experimental endstation transport arcs is provided by a model-based software application. The application reports the total energy error as well as the integral contributions from the beam orbit, correctors, and earth's field. This application is presently being redesigned with a better calculation engine and the output will be made available to the experimenter.

6.3 Momentum Stability

Momentum stability is monitored at high dispersion points in the transport arcs for Halls A and C. We use Optical Transition Radiation (OTR) monitors and pipe the image to a digitizer system to measure the width of the spot due to energy error. Halls A and C have dedicated digitizers so they can monitor the energy error online. The operations staff has access to the same information and can easily respond to errors in momentum. We use synchrotron light monitors in arcs 1 and 2 to monitor the stability of our linacs with a resolution of 1e-5 and minimum detection current of ~ 1 nA. The data from the OTR systems is readily available to the user and typically is part of their data stream. We are presently designing a synchrotron light monitor for the injection region.

The Fast Feedback System is used to suppress any power line harmonics that may be present on the beam by modulating an RF vernier system while monitoring BPM's in dispersive locations.

6.4 Emittance

At present we have no way of monitoring the beam emittance online, but we are in the midst of developing a solution. In the meantime we perform harp swipes at multiple locations in Halls A and C and calculate the emittance based on the beam aspect ratio at five locations. We also have the capability of measuring the emittance in the injection region using a similar multiple harp technique. The measurement results are posted in the electronic log and are accessible by the experimenter and all accelerator staff.

A system that monitors beam transfer functions from the injector to the experimental end-station is under development for improving optics reproducibility and monitoring at Jefferson Lab. The measurements are based on small amplitude excitation of the transverse beam motion using four correctors in the injector and subsequent observation of beam motion in Halls A and C. Using four correctors allows one to extract a full set of betatron transfer functions. Four different frequencies of less than 1 kHz are used to distinguish each of the four correctors' excitations. The excitation amplitude is far less than the beam size, so there is no beam quality deterioration. This diagnostic will utilize hardware from two existing systems – the Beam Scraping Monitor (providing excitation) and the Fast
Feedback System (providing beam position monitoring). The two systems lack inherent phase synchronisation; however, using more monitors than correctors allows one to determine the excitation's amplitudes and relative phase for each of the four frequencies. These are used in a least squares fit against the optics model, which yields the amplitude and phase of the incoming betatron motion from each of the four correctors. The output will be monitored by operations staff and provided to the experimenter.

6.5 Current Stability

Beam current is monitored with cavity based systems in the injector and Halls A and C. Hall B uses a photomultiplier based measurement to monitor beam current as well as the output from the nA BPM system. The operations staff and experimenters both have access to the data. Feedback systems are used to stabilise the beam current by adjusting the intensity of three independent lasers at the injector photocathode.

6.6 Helicity Correlated Current Stability

The Polarised Electron Source is typically configured to flip the sign of the polarisation at a 30 Hz. rate. Any changes in beam current as a function of helicity are undesirable as it adds an additional error term for the experimenter. We minimise this effect by monitoring a photomultiplier system in Hall B, which is fed back to optical elements on the Polarised Source laser table. Operations and Hall B staff monitor this error signal from their control rooms.

6.7 RMS Spot Size

The beam spot size on target is measured with Harp systems in all three experimental end stations. The measurement and correction process is invasive and slow. We are presently developing solutions to minimise the time for optimising the beam aspect ratio. We will be using an OTR system in Hall A and insertible scintillators in Halls B and C. All three monitors will be fed to digitizers with automated quadrupole adjustments to optimise the spot size. Monitoring will be part of the Emittance monitoring application. The information will be provided to both the experimenter and Operations staff.

7. AREAS OF CONCERN

While we would like to believe that we have a good handle on providing quality beam to the experimenter there is always room for improvement.

7.1 Specification Creep

A process of continuous improvement of beam stability is what we strive for. We identify as early as possible reasonable beam quality criteria. When we meet a particular specification consistently there is a tendency for the User to want to tighten the acceptable error window. Getting all parties to agree to the extent to which we tighten specifications is challenging. We could do a better job of providing a more consistent process for identifying when specifications can be changed.

7.2 Operations Liaison Program

The success of the Operations staff member as a liaison to an experiment depends on the availability of collaboration members for meetings and the operator's schedule. With a distinct person assigned to each experiment the Accelerator Division Experiment Co-ordinator winds up working with many people for a relatively short duration, which can yield inconsistent results. We have recently changed the program by assigning one Operations Liaison to each experimental end station for a one or two year term. This person will have the opportunity to develop a working relationship with the Accelerator Division Experiment Co-ordinator and will also work closely with technical staff from each experimental end station.
7.3 Visibility of Beam Quality Criteria

We could benefit from making beam quality specifications more apparent through the development of a web-based tool. This would allow easy access to the information for all staff and enable specific persons to change specifications remotely as required. This level of consistency and availability of information will ensure that the Users and Operations staff are in agreement as to what the expectations are. More timely reviews can then occur at our morning summary and weekly scheduling meetings.

This work is supported by DoE Contract No DE-AC05-84ER40150.
QUALITY CONTROL AND CUSTOMER SERVICE AT BESSY

J. Feikes and K. Holldack
BESSYII, Berlin 12489, Germany

Abstract
The Users of BESSYII are used to a small source point with a position stability in the order of some microns. This is monitored by staggered pair systems on each beamline and a high-developed beam position system. There is a constant collaboration between experimental and machine group to guarantee constant working conditions using the information of these systems.
SUMMARY OF SESSION 5
HOW SHOULD WE HANDLE SAFETY?

Markus Albert and Ghislain Roy
CERN, Geneva, Switzerland

1. INTRODUCTION

This session was originally titled ‘Safety! Who cares?’ in a fairly provocative way. A clear conclusion of this session and discussions that were held at the workshop is that there is a wide concern for safety among the people in charge of control room operations. This was shown as well by the quality of the seven talks presented in this session on subjects ranging from safety standards to a practical case of a safety incident:

- Application of Functional Safety Standards in a Particle Accelerator Environment. L. Scibile (CERN)
- Operations at CERN under INB Regulations. A. Faugier (CERN)
- Operations and Regulations at Fermi National Accelerator Laboratory. P. Carolan (DoE/FNAL) D. Johnson (FNAL)
- How does the Control Room handle Safety at ESRF? P. Duru (ESRF)
- Operations experience with the RHIC Particle Accelerator Safety System. N. Williams (BNL)

The first three presentations concentrated on design standards and regulations, in other words the methods and context of Safety in our environment. The next two presentations showed examples of Safety in Practice: from a Control Room point of view and from an Access system point of view. Finally the last presentation is a real case study and analysis of a safety incident with the lessons learned and some useful advice to everybody.

2. STANDARDS AND REGULATIONS

L. Scibile introduced the notion of Functional Safety, in the words of J-C Laprie: The notion of functional safety, or dependability, is defined as the trustworthiness of a computing system which allows reliance to be justifiably placed on the service it delivers.’ Functional safety has a two-fold objective: Guaranteeing that systems work and that they work safely.

L. Scibile then went into more details of Functional Safety Standards, a set of methods, based on international standards IEC 61508 -> 61511, aiming at providing a system which is reliable, available, maintainable and safe all along the life-cycle of the system, from specification to decommissioning. Besides the avoidance, elimination and prevention of faults functional safety standards can facilitate the application of rules and the compliance to national regulations. Extensive applications of the methods at CERN are foreseen in the fields of control systems, control room operations, and operational processes.

Some messages picked up during the presentation:

*Safety is first about people...*
*Safety objectives help answer the question: ‘How much quality is enough?’*
*‘How much safety is enough?’ is the wrong question; ‘how much money is enough to make it safe according to my objectives?’ is the right question!*

109
A. Faugier reviewed the rules and regulations enforced in some of CERN’s installations. In France a large spectrum of facilities such as nuclear reactors, waste conditioning plants, factories for the fabrication or transformation of radioactive materials, plants for storage of radioactive materials or waste, and finally particle accelerators with a beam power larger than 0.5 kW are all classified as Basic Nuclear Installations (INB or Installation Nucléaire de Base). By convention (international agreement) between CERN and France, the Super Proton Synchrotron (SPS), Large Hadron Collider and Cern Neutrino to Gran-Sasso (CNGS) facilities are now under INB rules and regulations. The implications are numerous and very similar to those stemming from the rules presented by P. Carolan of the Fermilab DoE office in his talk.

A major difference however is that the US Department of Energy has not classified its Accelerator Facilities in the category of Nuclear Facilities but is providing specific rules and regulations for the operation of accelerators. DoE establishes a contract with the organization that operates the facilities and can enforce rules and regulations through the contract and sometimes even outside the contract.

As an example P. Carolan reviewed DoE Order 232.1A, applying to all DoE facilities and titled ‘Occurrence Reporting and Processing of Operations Information’. It aims at keeping DoE and others informed of occurrences at facilities that could adversely affect security, health and safety of the public, the environment, etc. All reported occurrences are logged in a database that will soon be available to the public via the Web. P. Carolan also noted that a small percentage of occurrences involve accelerators and only a small percentage of these involve operations personnel directly; a tribute to the quality of the work performed by operations personnel in accelerator laboratories.

Most of the reported occurrences concerning accelerator operations fall under one of the following categories:

- access control procedure violations
- improper Lock-Out / Tag-Out practices
- improper response to radiation alarm
- excessive prompt radiation / shielding problems
- exceeding operational limits
- experiment safety (breakdown in hazard mitigation, and hazard communication between accelerator/support/users)

It should be noted that one occurrence in the last category lead to one experiment being cancelled.

As an application of the above, D. Johnson explained how the Operations Group of the Beams Division at FNAL have implemented a ‘Conduct of Operations’ in response to another DoE Order. The idea of having Conduct of Operations was taken originally from the Institute of Nuclear Power Operations and translated to Accelerator Operations in late 1989, although DoE owned accelerators are not classified as nuclear facilities. The Conduct of Operations is structured in 18 chapters covering all aspects of accelerator operations.
The 18 chapters of the Conduct of Operations

| Organization and Administration | Independent Verification |
| Shift Routines and Operating Practices | Logkeeping |
| Control Room Practices | Shift Turnover |
| Communications | Operations Aspects of Facility; Chemistry and Unique Processes |
| Controls of On-Shift Training | Required Reading |
| Investigation of Abnormal Events | Shift Orders |
| Notifications | Operations Procedures |
| Control of Equipment and System Status | Operator Aid Posting |
| Lockouts and Tagouts | Equipment Labeling |

D. Johnson explained how they have turned this required document into a working document to help them in their mission. In particular the following advantages were listed and are shared with other DoE laboratories represented at the workshop.

- Common operational attributes
- Do not rely solely on ‘Word of Mouth’
- Forces people to write it down
- Used to train Department/Group
- Generates understanding and new ideas
- Aids in audits and reviews

3. SAFETY IN PRACTICE

In this part of the session the first talk exposed the handling of safety aspects in the Control Room of the Electron Synchrotron Radiation Facility in Grenoble (France). P. Duru explained that their goal for the operation of the facility is ‘a good availability, a satisfactory Mean Time Between Failure (MTBF), all together in SAFE CONDITIONS’. A more appropriate formulation would put the safety aspects first and turn the goal into ‘Providing, under SAFE CONDITIONS, a good availability and satisfactory MTBF of the facility’.

The Safety Console in the control room, facing the main console, is in the back of the operators. It regroups a wide range of alarm panels: Fire detection, Flooding detection, and Red Phone. The operators are trained in First Aid and can be called on an accident. Procedures to answer any of these alarms are provided in the form of easy to read and follow flow charts. Alarms are automatically printed and Red Phone conversations are taped and broadcast in the control room.

Besides this first line responsibility during shift work, the operations group handles the scheduling and co-ordination of all work in the tunnel during technical stops; they deliver fire permits and work permits. This allows them to be aware of all activities in the machine and to give proper advice and instructions to the personnel who are to enter the ring. The Personal Safety System for access into the machine is also centralized on the Safety Console and the operators can be called to do a radiation survey of the zone where people will enter.

The range and depth of the safety responsibilities of the ESRF operations group is impressive and certainly stressful. It is however not uncommon for smaller facilities to organize themselves like this while larger laboratories tend to decouple some of the general safety aspects (Fire, Red Phone...) from beam operations for obvious reasons of size and logistics.
N. Williams, head of the Access Controls Group at Brookhaven National Laboratory, presented another side of the coin in a large accelerator facility. The Personnel Access Safety System (PASS) allows access control into the Relativistic Heavy Ion Collider (RHIC) and its experimental areas. The PASS combines the monitoring of Oxygen Deficiency Hazards (ODH), Electrical Hazards and Radiation Hazards integrated into a single system. Fire alarms and Flammable Gas alarms are also taken into account since the ventilation and air extraction from the tunnel is triggered by this system.

The Personnel Safety System employs small Programmable Logic Controllers (PLC) interconnected as two sets of peers, separated into channels ‘A’ and ‘B’. This is done to achieve a redundancy level, for the most complex part of the system, greater than that provided by the dual level achieved by other designs. The high redundancy objective also implies having separate power supply lines and UPS for the two different crates at each access point and goes as far as providing a separate development for each of the two systems: different environment and programming team to also avoid common mode failures. The more critical devices are surveyed through this double PLC system and through a relay-based system. More arcane safety aspects of the system have been taken into account by providing panelviewer consoles in place of PC based units for the access console in order to eliminate the risk of a hacker getting into and tampering with the system.

N. Williams also presented the hardware (gates and keys) used for controlling entries into the machine. Besides the classical cards and keys found in most laboratories, two specific experiments at BNL have requested the installation of biometrics devices for access control into their experimental zones: Iris Scans for one and Palm Tracks Recognition for the other. Much interest was generated by these aspects and some of the advantages of e.g. the Iris Scan techniques are worth mentioning:

- The system is totally hands free. No possibility of contamination and the handling of materials and safety clothing or masks are not a problem; eyeglasses or contact lenses do not affect the system.

- The system is fast (identification in 2 seconds), tremendously accurate and relies on a comparison of pictures of the iris being taken by an autofocus CCD camera. No laser as required by retinal scan.

- No card to carry, no password or PIN to remember, but it is a PERSONAL Identification Nevertheless!

In the summary session the question was asked whether BNL would consider a wider use of biometrics systems if they had a choice and the answer was positive; N. Williams explained that they are now considering using biometrics identification for site access as well.

4. CASE STUDY

P. Ingrassia presented a case study starting from an incident of water contamination that happened at BNL in 1997. Following a storage pool leak of 5 Ci of Tritium the water table on site was found to be contaminated beyond the allowed Drinking Water Standard although it was by no means a large contamination. The laboratory drilled a large number of wells to check this contamination and found some other locations on site with water contamination albeit from other causes. First lesson: if one starts looking for occurrences of a given problem chances are they will look hard enough and eventually find them.

Looking at the contributing causes of the second source of contamination, beam loss at a quadrupole in a beam line to a target, the main cause is found to be inattention to details all along the chain of responsibility. Beam losses in this particular case were higher than expected from design and almost all the monitoring of the beam was at the target, raising again the question of how we define beam quality. The beam loss monitors that were installed in the beam line were unreliable which is worse than not having them because they tend to be ignored even if the signal is correct. Tuning
procedures focusing on ALARA principles, although properly implemented and followed, did not help since the instrumentation was either missing or not reliable and ignored.

P. Ingrassia expanded on some of the lessons learned from this case study:

- For any beamline or accelerator it must be assumed that there will be some beam loss, and that any soil used as shielding must be covered to prevent rain leaching out contaminants. An activation study should be routinely performed following the first run of a new beam-line to confirm the beam loss assumptions that were made during design phase. The situation should be reviewed whenever operational conditions change (increased intensity or different beam parameters such as spot size...).

- Ensuring that the beam is fixed on target does not necessarily ensure that the beam is not lost on upstream components and operators must also monitor beam loss on a routine basis, with proper procedures in place, in order to limit the level of soil or material activation. Remote sensing devices (loss monitors or equivalent) must always be operational all along the beam path and procedures to respond to loss alarms must be in place. In fact the question of interlocking the beam if the beam loss monitoring system is not available was raised.

- Operator mindset needs to change to become proactive in minimizing losses and ‘Clean Records’ should be favored. An intensity record on a target is only acceptable if the losses are also well controlled; in other words beam quality needs a very careful definition. In some cases the intensity on target will clearly be limited by loss limits, not by intensity limits from the accelerator.

- Wherever the actions of the operators on the beam could have an impact on the environment the operators must be made aware and trained in Environmental Protection Issues. It was added at the summary session that this should also apply to Public Relation Issues both towards the local community and the Press.

5. CONCLUSION

This session was interesting in many respects. The subject of Safety can sometimes be perceived as rather unimportant or less important than the mere performance of the accelerator, until an incident occurs. The operators who know the machine and control the machine operation on a daily basis are best placed to play a significant role in advocating and ensuring safe operations from design to beam tuning. The level of interest for Safety matters shown at the workshop is certainly a sign that Safety is taken very seriously by Operations teams across all accelerator installations independent of the size and type of beams.
APPLICATION OF FUNCTIONAL SAFETY STANDARDS IN A
PARTICLE ACCELERATOR ENVIRONMENT

L. Scibile, S. Grau, P. Ninin
European Organisation for Nuclear Research – CERN
1211 - Geneva - 23, Switzerland

Abstract
Many systems used by the CERN accelerators and the technical infrastructure have to respect stringent requirements in terms of reliability, availability, maintainability and safety either for operation, security, or legal aspects such as the one required by French Regulatory Authority (Installations Nucléaires de Base - INB). The functional safety approach provides a structured method for achieving these requirements. In particular, the new IEC 61508 standards give guidance for system design and an effective and safe system exploitation. When designing new systems, it also sets out a generic approach for all the safety lifecycle activities: requirements, design, realisation, installation, operation, maintenance and even the decommissioning. The standards consider the functional safety from three different, but related, perspectives: technology, procedures and human interventions on the systems. This paper gives the results of the first attempts made at the CERN Technical Service division to use these standards and gives some suggestions on how to improve functional safety in a particle accelerator environment.

1. INTRODUCTION

As computer control becomes usual for many CERN accelerators and technical infrastructure applications, it becomes apparent that the failure of these systems is likely to have an impact on the operation and/or on the safety of the people and the equipment. The risk of a failure with its consequences has given rise to stringent requirements in terms of Reliability, Availability, Maintainability and Safety (RAMS). Moreover, CERN must also comply with the safety requirements set out by the French Regulatory Authority: the INB (Installations Nucléaires de Base).

To increase the RAMS performance of a particle accelerator environment is a big challenge because it involves the management of the opposite requirements of safety and flexibility. The other challenging aspect is to organise the work processes to cope with the reduction of resources, the dynamics of the new computer control technologies and the CERN outsourcing policy.

The functional safety standard for Electrical/Electronic/Programmable Electronics (E/E/PE) systems IEC 61508 [1] has been used as a management guideline to structure the work on safety-related control systems. An overview of this approach and the IEC 61508 is given in Section 2.

The benefits and the pitfalls of the practical application of this approach in the Technical Sector (ST) division are presented in Section 3.

2. FUNCTIONAL SAFETY

2.1 Description of functional safety

The definition of functional safety, or dependability, has been expressed by the J-C Laprie [2] as:
The notion of functional safety (dependability) is defined as the trustworthiness of a computing system which allows reliance to be justifiably placed on the service it delivers.

Consistent with this definition, functional safety has a two-fold objective: guaranteeing that systems work and that they work safely. Therefore, functional safety can be seen as a method for developing a system that attains the proprieties of reliability, availability, maintainability and safety. In addition, the application of an overall safety lifecycle guarantees that these proprieties are maintained from conception to decommissioning. Functional safety is based on three major axes: people, procedures and methods. And the results of a recent study by the UK Health and Safety Executive on the causes of accidents, shown in Fig. 1, support this strategy that people, procedures and methods are capital for the reduction of faults and accidents.

![Pie chart showing causes of accidents](image)

**Fig. 1: HSE statistics on causes of accidents**

In the field of computer controlled systems, the functional safety standard IEC 61508 defines a generic approach and a technical framework for dealing systematically with safety related activities. This methodology enables us to minimise system failures and optimise performance. It is particularly interesting because it defines the skills needed to deal with safety, the required procedures to be defined and carried out, as well as the kind of development methodologies to be used. The standard also provides an overall safety lifecycle that focuses the attention on the safety aspects of each phase of the development process.

### 2.2 Functional safety, quality and the standards

The functional safety approach addresses the issues of awareness, responsibility and commitment in the organisation (or a project). In this mindset, special attention is given to the understanding and the evaluation of the real needs/expectations in terms of functional and safety requirements.

The IEC 61508 provides all the processes to build the understanding of the real needs/expectations in order to meet them. In addition, the standard explicitly addresses the issue of continuous process improvement (as found in the Capability Maturity Model developed by the Software Engineering Institute [3]). This mindset, with the processes for achieving it, is the basis for a total quality in safety-related control systems. And quality is of fundamental importance to safety because it relates to the ability of a system to meet its requirements.

On the other hand, in addition to providing the answer to the question ‘how much safety is enough?’ in terms of Safety Integrity Levels (SIL), the IEC 61508 also provides a way to answering to the question ‘how much quality is enough?’ Therefore, there is a multiple result by adopting a functional safety approach: the achievement of the required RAMS and the assignment of the sufficient effort in terms of design, realisation, installation, operation and maintenance, management and quality.
3. FUNCTIONAL SAFETY IN THE ST DIVISION

3.1 Why?

In order to face the issues of quality, project management, operation & maintenance, safety and cost optimisation for the concept phase of the CERN Safety Alarm Monitoring (CSAM) [5], the ST/NO group formed a team for functional safety. After a positive experience, functional safety is being extended to other safety-related or critical control systems.

Quality: As largely explained in this paper, the issue of quality is solved by adopting the overall safety lifecycle of the IEC 61508 with the adherence to the requirements for the management of the functional safety.

Project Management: Safety-related projects must cover additional management tasks. These also include the management of the safety requirements and their allocation, functional safety assessment and functional safety audits.

Operation and Maintenance: The standards provide an organisational framework for identifying and managing the operation and maintenance of safety-related systems. These include specific procedures for reducing the risk of accidents. The application of a systematic analysis of the operational constraints during maintenance and the definition of the preventive maintenance based on the required RAMS imply a maintenance plan with an overall cost estimation.

Safety and cost optimisation: The functional safety approach brings to an overall estimation and optimisation of the total life costs of a safety-related system because it implies the justification of the proposed solutions against measurable required safety performance and the optimisation of the operation and maintenance procedures.

3.2 How?

People are an essential element in the organisation of functional safety. Therefore, special training was organised in order to increase the knowledge of the team, to raise the awareness of the risks associated to safety-related control systems, to create a common base of knowledge and to have a feedback from industrial experts.

The training objectives have been attained and the results have been applied during the preparation of the functional and safety requirements for the CSAM technical specifications [6].

The process of knowledge acquisition/sharing has continued by actively participating to specialist conferences and seminars and by making presentations at CERN working groups and workshops.

3.3 Where?

The functional safety approach is being applied in different areas and problems as described in the following paragraphs:

Overall projects: For the CSAM project [5], functional safety has been set-up from the very beginning. The IEC 61508 has been used as a canvas for the concept phase and for structuring the system lifecycle. The standards have eased the preparation of the technical specifications and the performance requirements for the CSAM invitation to tender. In particular, it has helped in the drawn up of clear and concise performance requirements for a result oriented contract; it has also been useful for the cost estimation of the system itself and of the long-term operation and maintenance services.

Re-engineering: The execution of a systematic analysis for the SPS smoke removal control system is providing an essential overall understanding of the main safety functions executed by the system. The analysis has indicated functional priority and critical elements. The first phase has provided technical recommendations to guarantee that sufficient effort is invested in these functions.
Dependability analysis: As a quality commitment to continuous improvement, a functional safety approach was used for the dependability analysis of the Technical Data Server [7]. Even in this case, the execution of a systematic analysis has uncovered potential for improvement and has also identified and quantified the weak points of the current system.

Functional safety support: To add value to a project, a functional safety engineer must be fully involved in the design team. Functional safety support was provided for the Water 2000 monitoring project. The main contributions have been an insight to the control system risks and a set of recommendations to mitigate or eliminate them.

4. CONCLUSION

This paper gives the results of the first attempts made at the CERN Technical Service division (ST) to use the IEC 61508 functional safety standards. It is shown that functional safety can be applied in different fields and under different perspectives. After an initial investment in training and coaching, the functional safety approach is producing the expected confidence in the concerned projects and systems. In particular, the collaborative effort for the CSAM project has produced robust specifications and precise cost estimations. The use of systematic and methodical analysis has also helped to identify other systems’ deficiencies and inefficiencies and has provided means to avoid or eliminate them.

5. ACKNOWLEDGEMENTS

It is a pleasure to acknowledge the support and the invaluable contributions given by all the member of the CSAM Team.

References


HOW DOES THE CONTROL ROOM HANDLE SAFETY AT THE ESRF?

Ph. Duru, L. Hardy, P. Berkvens, P. Colomp
European Synchrotron Radiation Facility, Grenoble, France

Abstract
The operation of an accelerator presents a very particular risk; exposure to radiation either directly from prompt radiation during operation or from induced radiation during tunnel access. The access to the machine tunnels is therefore fully controlled.

Moreover, all the buildings also present various risks, depending on the laboratories and other installations that they may contain and by the presence of people 24h a day. The premises are then under supervision.

In order to provide full control of all these risks, different systems of interlocks, locking, monitoring and detection have been installed at the ESRF which send all the information to the Control Room.

In collaboration with the Safety Group, specific procedures have been elaborated which help the Operators to handle any event in the best way possible.

1. INTRODUCTION
The European Synchrotron Radiation Facility (ESRF) is an X-ray source of the third generation. The accelerator complex is composed of a Linear accelerator (e- 200 MeV), a synchrotron (300 metres – 6 GeV) and a Storage Ring (844 metres).

The ESRF accelerators have been in full routine operation for more than six years. The source delivers 5600 hours of X-ray beam to nearly 40 beam lines simultaneously. Our first goal is to ensure good availability of the Machine as well as a satisfactory Mean Time Between Failures (MTBF) all together in safe conditions.

2. THE DIFFERENT ASPECTS OF SAFETY AT ESRF
2.1 Fire
Almost every room throughout the buildings is equipped with one or several detection heads. Depending on the nature of the risk, the sensor may be of anionic, thermostatic or UV type. There are about eight hundred detection heads operating at ESRF, all of which are computer controlled.

2.2 Flooding
Many pieces of equipment installed on the site are water-cooled. They are of course protected by over temperature and/or flowmeter interlocks in case of a water cooling system failure, but the bursting of a pipe or a hose may lead to major damages if the fluid is spread over equipment. It may also bring the water distribution system to a stop because of a low level in the network. A flooding detection system is installed in all the tunnels, the beam lines and in the rooms containing the main Machine dedicated equipment.

The geographic situation of the Facility, where two rivers join, and its construction altitude require also a constant watch over the ground water level.
2.3 Personal Safety

The size and the configuration of the ESRF site have made the installation of a Red Phone network mandatory ever since the construction of the Facility. The objective is simple: to be able to contact the Control Room very easily in case of any emergency need (fire, faintness, accident etc…). There are about 230 red phones located in all the buildings of the ESRF site.

2.4 Temperature overheating

All central computer resources are concentrated in one room. The equipment in this room is indispensable for the running of the ESRF; a shutdown of the network equipment or any of the server computers immediately disturbs the work of a Group, a Division or even the entire Facility. A failure of the air conditioning unit would create an increase of the ambient room temperature and may lead to a severe control system crash. Any temperature increase triggers an alarm in the Control Room.

2.5 Interventions scheduling and co-ordination

The numerous types of equipment are subject to upgrade, modification, repair or preventative maintenance. Most of these duties are undertaken during the Machine Shutdowns, planned one year in advance but may take place at anytime in case of failure or breakdown. In order to optimise the interventions in terms of safety, resources and quality during the Machine Shutdown, the Operation Group takes over the co-ordination of the tasks.

2.6 Safety related with X-ray source

The general Radiation Protection policy at the ESRF stipulates that everybody working at the ESRF is considered as a non-exposed worker. Therefore, under all conditions one must guarantee that nobody exceeds the corresponding radiation limits (1 mSv per year). This is obtained via appropriate shielding of all accelerator tunnels and of the X-ray beam lines, and via all the corresponding Personnel Safety Systems. One particular aspect is the radiation hazard created by induced activity, limited exclusively to the accelerator tunnels. For this purpose, the Operations Group co-ordinates a system of work permits. Before entering any accelerator tunnel, a radiation survey must be made of the induced activity in the area concerned. This survey is made by the Safety Group (start of main shutdown, important intervention) or by the Operators (routine intervention during Controlled Access). As a result of these surveys specific safety procedures are elaborated.

3. THE ROLE AND THE TOOLS OF THE OPERATION GROUP TO HANDLE SAFETY

3.1 Fire Detection System

Every alarm trigger, following either a real detection of smoke or a failure of the detection system, is reported to the Control Room. The message written on the screen gives the identity of the head triggered or the faulty device, the name of the building and the number of the room. An application made on a SuperCard by the Operators and installed on a computer in the Control Room enables the fast localisation of the triggered detector, by going through windows from the number of the detector to the plan of the building and the room concerned.

Different procedures, depending on the time of the day and the status of the Machine (run or shutdown), are available in the control room in a form of a flowchart. They describe the steps to follow, and give all the relevant information to the Operator on shift; from the verification of the alarm on the spot to the initiation of the proceedings for the evacuation of the building, the call to the Fire Brigade and to the on-call Safety Engineer.

A fire permit is mandatory to perform any work that may produce smoke and trigger a sensor (welding, grounding, etc…). A copy of any delivered fire permit is posted in the control room; in case of a fire alarm, the Operator can verify if it comes from the concerned works or not.
3.2 Flooding Detection System

It consists of a sensitive cable laid on the accelerator tunnel floor and linked to a controller, which permanently measures its conductivity. In the case of fluid detection on the cable, the controller triggers an alarm and, via a computer, gives an approximate distance that facilitates the localisation of the leak. In the other critical rooms, such as beam lines and main power supply cubicles for instance, the detection system is made of optical detectors.

In the case of an alarm, the Operator will enter the zone to investigate the problem. A procedure gives the Operator the steps to follow to ensure his own safety from a radiation protection and an electrical point of view and to protect the equipment. Depending on the seriousness of the failure, the Operator will carry out the repair himself or call the on-call Maintenance Technician.

3.3 Red phone System

As soon as somebody picks up any red phone anywhere on the site, or dials 10 from any other telephone set to report any kind of incident, he is automatically connected to the red phone receiver located in the control room. An on-line printer keeps track of all the emergency calls and gives precious information as to the location of the phone call. An application based on the same principle as for the fire detection system will be developed in the forthcoming months.

A checklist guides the Operator during the call to get all the relevant information from the caller. The corresponding procedure is then applied, depending on the nature of the call.

All the Operators are trained to above all to help any injured person, in the frame of his working environment; depending on the situation. The Operator on shift may decide on the spot to go and give the victim assistance, whilst waiting for the Emergency Aid Brigade.

3.4 Interventions scheduling and co-ordination

A few weeks before the shutdown, the list of the interventions foreseen by every Equipment Group Leader is sent to the Operation Group Co-ordinator. He will then elaborate a detailed schedule, listing the tasks to be undertaken, taking into account the different constraints raised by the nature of the work such as handling, bake out, alignment, electrical and fluids cut-offs etc... The proposed schedule is accessible via the internet and submitted to all concerned people. It is regularly updated before and during the shutdown.

At the start of the Machine Shutdown, the Safety Group performs a Radiation Protection survey inside all the tunnels. From the measurements taken during this inspection, a Radiation Map showing the zones containing activated equipment is drawn up by the Operation Group and posted in all the access chicanes of the Machine. Depending on the type of intervention to be performed on the equipment, their electrical power supplies may be subject to a partial or complete ‘consignation et mise à la terre’.

For any intervention planned inside the tunnels, a Work Permit Form must be filled in by the Intervention Responsible and submitted to the Operation Group and the Safety Group for approval. The permit contains the description of the intervention, the place and the names of the people in charge of the works. It provides information about safety-related actions or requirements such as shielding dismounting radiation exposure limitation or electrical insulation. A copy of the Radiation Map is attached to every work permit.

The Co-ordinator assumes the follow-up of the activities carried out during the Shutdown and reshapes the schedule in accordance with any modification. The Operator on shift or on a normal day assists the Co-ordinator during the day and carries out a safety round during the night and the weekend. He will pay particular attention to the zones where bake out is being performed.

At the end of the shutdown, once all the work permits are recovered by the Operators, a safety round is performed by the Safety Group and the Operation Group Co-ordinator in order to verify that
all the shielding parts and protective covers have been put back in position. A protocol is then filled in, signed by both parties and recorded in the Machine Operation Logbook.

3.5 PSS and Radiation Protection

The PSS (Personnel Safety System) is a hardwired, redundant system. The PSS provides the permits for the different accelerator systems, allowing different operation modes. These modes are selected on a safety key panel located in the Control Room. The tunnels are locked after the search has been made by at least two operators. Entering any zone is always possible in Controlled Access, using a system of safety keys, supervised by the Control Room.

As explained before, the main role of the Operation Group in terms of Radiation Protection, is linked to the problem of induced activity inside the accelerator tunnels. During interventions under Controlled Access, the Operators carry out the radiation measurements. For this purpose the Safety Group provides the Control Room with radiation monitors (Eberline FH-40GL survey meters) and operational dosimeters (Rados DIS-1 badges). Written safety procedures are available in the Control Room.

4. CONTROL ROOM PARTICIPATION IN A NUT SHELL

Table 1: Statistics of the last four years

<table>
<thead>
<tr>
<th>Year</th>
<th>Fire Alarm</th>
<th>Red phone</th>
<th>Water Leak</th>
<th>Lift failure</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>30 (1 fire)</td>
<td>3 (2 serious)</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1998</td>
<td>14</td>
<td>5 (5 serious)</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1999</td>
<td>22 (1 fire)</td>
<td>5 (4 serious)</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2000</td>
<td>41 (2 fires)</td>
<td>8 (4 serious)</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

5. CONCLUSION

Since all the main safety equipment is linked to the Control Room, the Operation Group is called to react and participate in all safety related events. As well as being trained to be Machine Operators, in the event of an emergency their skills and common sense will be invaluable to insure the safety of all present on the ESRF site.
FIRST YEAR EXPERIENCE WITH THE RHIC PERSONAL ACCESS SAFETY SYSTEM (PASS)

N. W. Williams
Brookhaven National Lab, Upton, NY, USA

Abstract
Review Operations first year experience with the RHIC Particle Accelerator Safety System (PASS). This includes the accelerator access controls, radiation monitoring and the oxygen deficiency hazard (ODH) monitoring systems.

1. INTRODUCTION
A single RHIC Personnel Safety System was installed to protect the Collider personnel from Radiation Hazards, Oxygen Deficiency Hazards (ODH), and Electrical Hazards and assure full compliance with regulatory requirements. In the past, ensuring personnel safety at accelerators meant an Access Control System designed to protect personnel from radiation hazards only. Integrating all personnel safety systems in RHIC is expected to result in a superior level of personnel safety and equipment protection, while providing greater operational efficiency. It is also intended that the Personnel Safety System have a closer interface with the fire protection elements installed as part of the conventional construction than has been the case in other accelerator construction.

2. DESCRIPTION
Required safety systems for Oxygen Deficiency Hazards (ODH), Electrical Hazards and Radiation Hazards are integrated into a single system. The Personnel Safety System will employ fourteen small Programmable Logic Controllers (PLC) interconnected as two sets of seven peers, channels ‘A’ and ‘B’ in Fig. 12-1, rather than a few larger units hierarchically connected to multiple remote I/O chassis. This is done to achieve a higher level of redundancy for the most complex part of the system, than that provided by the dual level designs.

2.1 Control Devices
Commercially available Programmable Controllers are configured to attain the level of redundancy necessary to achieve compliance with DOE 5480.25. A network of PLC units compensates for the complex set of failure mechanisms exhibited by individual processors compared to designs based upon relays, much as an OP-Amp compensates for component variability with gain and feedback or a bridge is supported by its interconnecting I-beams.

In order to reduce the potential for Common Cause failure events, the core PLC system will be comprised of two different brands or models of PLCs (Allen Bradley PLC 5 and SLC 5/03,4 processors) such that basic hardware and software elements will be of different origin; each PLC has its own independent UPS and line power feed. Complications introduced by physical bus limitations result in a rather complex interconnection pattern, however, a minimum of two independent channels labeled ‘A’ and ‘B’ is always maintained. The ‘A’ and ‘B’ channels are in turn connected to one of two Command and Control processors which provide supervisory control and monitoring functions. These processors are in turn redundantly connected to a Personnel Safety System-generated display located in C-AD Main Control System (MCR).
2.2 Crash, Gates and Sweep sub-system

An emergency shutdown system labeled CRASH, which uses ‘pull cord’ type switches, is installed throughout the collider enclosure. With minor exceptions, these are essentially continuous coverage on both sides of the enclosure tunnel. Because of magnet locations, coverage in supported injection areas are installed on one side only. Each unit protects 65 m (200 ft) of tunnel. The CRASH switches are not hard wired into a lockout system, but are connected in a redundant manner to a PLC in the ‘A’ channel and to another PLC in the ‘B’ channel. When a CRASH is called for, the Personnel Safety System removes power from selected critical power supplies or closes selected critical vacuum valves. In addition, the Beam Dump System will be activated. This dual approach is necessary because the Beam Dump system, while engineered and constructed to high standards, is not considered part of the Personnel Safety System.

The Gate system is comprised of thirty five (35) Gate packages and nineteen (19) Emergency Entrance and/or Exit Doors packages. Redundant interlock switches are mounted on each of these doors. Each entry and isolation gate has standardized electronics system for information, display and access purposes. This package includes TV monitoring capability in the Main Control Room (MCR). In addition, there is a card reader based entry logging system and information display at each gate. The Radiation Monitoring system uses the ‘Chipmunk’ design used at the AGS and at FERMILAB. Interlock outputs will be connected to system PLC units.

Each crash, gate and sweep switch is monitored using a constant (32 mA @ +/-10 Vdc) current source that determines their status. This scheme reduces the complex cable network that would have been required for a completely hardwired system.

2.3 Remote Hardware Interface

The PLCs use remote scanners, plug-in I/O modules and Remote I/O blocks to communicate with the field hardware. All critical devices utilize a combination of relay and R I/O hardware interface.

2.4 Radiation Monitoring

The Radiation Monitoring system employs the ‘Chipmunk’ design used at the AGS and at FERMILAB. Interlock outputs are connected to the PLC units. Of the approximately eighteen (18) units installed,
twelve (12) units for experimental area monitoring and six (6) units for RHIC injection. Dose rate data are read by VME based optically coupled SIS3803 scalars into the central control system.

2.5 Oxygen Deficiency Hazards (ODH)

The ODH system is comprised of sensing and processing electronic hardware. The sensing electronics are built around a commercially available oxygen fuel cell. The detected ODH level is sent to the PLC controller which decides if the fans and vents need to be activated. The fans and vents are not automatically activated during stores.

2.6 Flammable Gas Detection Systems

Both the STAR and PHENIX experiments have Flammable Gas Detection System (P10 gas). This system uses industrial grade fixed-point infrared detectors with visual and audible alarms. Fans and vents are used to exhaust the halls. The fans and vents are not automatically activated during stores.

2.7 Fire Alarm Interface to PASS

The RHIC tunnel fire alarm system is connected to the PASS. This allows the use of ODH fans and vents to exhaust the tunnel during a fire. As in the case of the ODH and Flammable Gas systems, fire alarms will not automatically exhaust the enclosure during stores.

2.8 PASS MCR Interface

The MCR interface to the access system consists of the Closed Circuit Television (CCTV) system and Panelviewer computer terminals. The CCTV is used to perform remote access into RHIC entry gates. This uses video multiplexers and fiber optics cables to route the signals to MCR. The video switching is done using a SLC based system.

Panelviewer terminals are used to send commands and get status information from the field peers.

3. UPGRADE TO THE AGS RELAY BASED SYSTEM

Due to the unique requirements of two experiments running at the AGS, various upgrades were done to the beam areas of the AGS access system.

3.1 NASA E951 Iris Identification

NASA experimenters required a method of identification that would require minimal use of hands since they typically carry specimens. Iris identification does not require the use of PIN numbers but allows individuals to stand at the CCD camera and be recognized by unique characteristics of the iris. Iris Identification in conjunction with Trapped Key Technology controls who can enter primary gate. Simultaneous release and video ensured MCR still had entry control. No beam is delivered by MCR until all keys are returned and trapped.

The local reader uses a secure network to log entries in MCR. An enrollment station located in MCR allows users to be checked for proper training. Once scanned the individual's iris code is downloaded via Ethernet to a processor at primary gate.
3.2 Proton Radiography E933

This experiment uses the Hand Reader technology for access at LANL and requested this setup due to prior familiarity. This was also a cost effective means to address experiment requirements. The enrollment station located in MCR allowed users to be checked for proper training. Once scanned the hand code is downloaded via Ethernet to the access hand reader at PTR house.

3.3 Advantages of Biometric System:

- Totally hands free. No contamination.
- Tremendously accurate.
- Not affected by eyeglasses or contacts.
- No laser as required by retinal scan.
- Identification happens in 2 seconds.
- CCD Camera is auto focus.
- No password or PIN to remember.

4. LESSONS LEARNED

- Micro-switches in the electric strikes were upgraded to improve the stability of the gate current loops. Gold-plated contacts provided better performance and reliability. In general, these switches are more compatible for the low current loops used in PASS.
- The MCR Panelviewer interface was re-designed to be user-friendlier. The operations staff contributed to the design.
5. UPGRADES FOR FY2001 RUN

- During shutdown each of the 14 RF stations at 1004 A will have independent reachback system to PASS. This will give more flexibility and diagnostics to monitor the RF stations.

- A network will be installed at all the RHIC entry and GI gates card readers to a central server. This will enhance our ability to keep the personnel access status up to date. The card readers will query the server for training information of a requester to enter the ring.

- Local key trees will be installed at the experiments to enhance the access into IR regions.

- Hand recognition will be used to verify training and to log entries.
6. CONCLUSION

During the first year of RHIC running, the PASS system performed well. Some changes were required to improve the User Interface. The MCR operation staff contributed greatly to the changes that were implemented to improve the system user interface.

7. ACKNOWLEDGEMENTS

I wish to thank Roy Heyder, Jonathan Reich and Tom Tallerico whom contributed to the content of the paper.

References

SAFETY ISSUES IN ACCELERATOR OPERATION: GROUNDWATER CONTAMINATION

Peter F. Ingrassa
Collider Accelerator Department, Brookhaven National Laboratory, Upton, NY 11973 USA

Abstract
The Environment, Safety, Health, and Quality (ESHQ) is an integral part of how we do business at the Collider-Accelerator Department at the Brookhaven National Laboratory. Although the department has had a good track record with regard to safety, ground water contamination was observed in 1999 due to high intensity proton operations at the AGS. This paper will examine root causes and lessons learned from our experiences.

1. INTRODUCTION
Following the discovery, in 1997, of five curies (Ci) of tritiated water contained in a plume emanating from the spent fuel rod storage pool at the High Flux Beam Reactor (HFBR), the Laboratory began an aggressive program to locate and characterize other sources of groundwater contamination. Four sources were found in the Collider Accelerator Complex. Three sources were associated with high intensity proton operation at the Alternating Gradient Synchrotron (AGS). One source was identified with the AGS internal beam dump known as the ‘E20 Catcher’. Another source was identified with chronic beam losses on one of the final quadrupoles (VQ12) in the beam transport used to bring protons from the AGS to the production target for the muon g-2 experiment. A third source was associated with the beam dump in the decommissioned neutrino beam line and will not be discussed here. The highest concentrations of tritium ($^3$H) and Sodium 22 ($^{22}$Na) in the vicinity of the E20 catcher were found to be 2 times and 1.75 times the drinking water standard respectively. The highest concentrations of $^3$H and $^{22}$Na in the vicinity of VQ12 were found to be 90 times and 0.15 times the drinking water standard respectively. The drinking water standard is 20,000 pCi/L for tritium and 400 pCi/L for $^{22}$Na. The drinking water standard limits the internal dose to 4 mRem for an individual who annually ingests water (200 gallons ~ 800 litres) contaminated at a concentration corresponding to the standard. With regard to the problems at the HFBR, it is interesting to note that self-illuminated EXIT signs that generate light by taking advantage of $^3$H decay, contain approximately 20 curies of the isotope. A Curie is a measure of the activity or concentration of a radionuclide. It is defined as $3.7 \times 10^{10}$ disintegration per second.

2. MECHANISMS
Iron, concrete, and soil are the primary shielding materials for radiological protection. Most secondary particles created by the interaction of primary protons with accelerator components will be stopped in the shielding. When a high-energy secondary interacts, a variety of radioactive nuclei are produced. The mass numbers of the atoms produced range from the mass of the target-plus-one down to a mass number of three ($^3$H). Most of the nuclei produced are short lived. The two longest-lived isotopes produced are $^3$H and $^{22}$Na with half lives of 12.3 and 2.6 years respectively.

Radioactive nuclei created in concrete and iron are, in general, not dispersible. On the other hand, radioactive nuclei created in soil may be dispersed by water. Sodium and hydrogen tend to form watersoluble compounds that tend to be dispersed. Figure 1 shows a section of the AGS tunnel, which represents a typical shielding design. The bold inner rectangle depicts the concrete tunnel. The inner trapezoidal shape shows a ‘soil cement’ shield that was added in 1989 in preparation for the
commissioning of the booster and higher intensity operation. The outer trapezoidal shape corresponds to the soil overburden. Rainwater seeping through the soil transports the radioactive materials in the soil downward to the water table. At the water table, the water flow again becomes horizontal, tending to transport the radionuclides in the direction of the laboratory boundary.

The rate of migration of the nuclides is 0.75 feet per day. Given the migration rate, the location of the source two miles from the lab boundary, and the direction of groundwater flow, it would take in the order of two years for the radionuclides to reach the site boundary. Given the time scale, the concentration of radionuclides would be reduced when they reach the laboratory boundary owing to the radioactive decay of the nuclides and the continued influx of rainwater. Wells were drilled to map the extent of the contamination. The contamination was found to be confined to narrow plumes 20-30 feet across, approximately 40 feet underground, and in the case of the VQ12 plume, 250 to 300 feet long.

3. PAST OPERATIONS INVOLVING THE SOURCES OF CONTAMINATION
The catcher, at the E20 position in the AGS ring, was used as a beam dump from 1984 through 1999 when a new device was installed. E20 is a three-meter long block of tin-lead alloy (solder) with a beam tube at its centre. The device can be translated and skewed in the horizontal plane to minimise losses at injection. It was designed to accept any and all losses through the acceleration cycle including automatic or manual aborts of the circulating beam. It was not intended as, nor was it used as, a place to continuously dump particles. Operators were instructed to reduce the intensity of the circulating beam or to cease proton injection into the AGS rather than activate the catcher unnecessarily.

The quadrupole known as VQ12, part of the final focus for the muon g-2 experiment production target, was the source of the largest groundwater contamination problem that the Collider- Accelerator department has faced. The beamline optics were such that a beam position displacement at AGS extraction, was magnified by a factor of six at the downstream position of VQ12. The fact that 'beam quality' was only routinely monitored at the production target resulted in chronic beam loss at VQ12. One reason for the lack of beam quality monitoring was that new instrumentation was under development for RHIC and although intended for use during proton operation, its installation was delayed.

4. PRESENT OPERATIONS INVOLVING THE SOURCES OF CONTAMINATION
The E20 catcher has remained in the AGS ring. It has been positioned so that it intercepts none of the circulating beam. A new 'beam scraper' has been installed at the J10 position. An engineered solution has been employed to protect the groundwater. A gunite cap was placed over the soil at E20 and J10 to prevent rainwater from leaching $^3$H and $^{22}$Na out of the soil. During high intensity proton operations,
operators review the loss pattern at E20 to verify that they are minimal. Operators prevent the deliberate dumping of more than three pulses of high intensity beam anywhere in the AGS.

VQ12 is still an integral part of the beam transport to the production target. The beam optics were re-worked in 1999 so that changes in beam position upstream do not cause losses downstream. New loss monitors were installed and four were placed in the vicinity of VQ12. Operators regularly monitor the losses in the beam transport. A gunite cap was placed over the soil around VQ12.

5. CONCLUSION - LESSONS LEARNED

Given that losses are unavoidable, and the fact that soil is routinely used for shielding, it is no surprise that the soil shield became activated. What was a surprise was the fact that the activation had spread. The root cause for the problem was inattention to detail throughout the organisation. The lack of attention to detail made the situation at E20 unavoidable in that activation was present but we were not expecting it to spread. The VQ12 situation, in my judgement, could have been averted but again the lack of attention to detail played a significant role. The initial optics in the beam transport were off the mark. The lack of working instrumentation was a mistake. The inability of the operators to identify the loss was a disappointment but not a surprise. Given the lack of instrumentation the discovery of the loss would have been difficult. Operations management was at fault too. The procedures provided for the operators had them focusing on processes rather than on positions along the beam path – hence their focus was diverted from the problem area.

A number of lessons were learned from our experiences and the lessons have had an impact on accelerator operations. Foremost in our education was the fact that operators must possess a greater awareness of the environmental impact of accelerator operation. Knowing that some beam losses are unavoidable, we learned to cover soil used as shielding wherever losses are expected in the chain of accelerators. We have learned to confirm assumptions made during the design phase regarding soil activation adjacent to new beam lines by conducting soil activation measurements.

Operators in the MCR have learned to do business differently. The Operators routine includes monitoring of beam losses at critical locations during high intensity proton operations. The routine monitoring is prescribed by formal procedures. We have learned not to rely on one instrument to determine beam quality; beam loses must be considered as part of the ‘quality equation’. 'Watchdog’ software is used to generate alarms when high losses are experienced at critical locations, or during prescribed segments of the acceleration cycles in the Booster, the AGS, and the external beam transport. Critical to many of our lessons is the changed behaviour of the Operators. They have learned to react as required and to be proactive to prevent losses where possible.

6. ACKNOWLEDGEMENTS

The author wishes to acknowledge and thank Edward T. Lessard the Associate Chairman for ESHQ in the C-A Department and Gary Schroeder of the Environmental Services Division and Bet Zimmerman the Environmental Services Division Manager at BNL for their valuable assistance in the preparation of this work.
OPERATIONS AT CERN UNDER INB REGULATIONS

André Faugier
CERN, Geneva, Switzerland

Abstract
The CERN high energy accelerators are classified as INB ('Basic Nuclear Installations') under the French legislation. The rules and regulations governing such installations will first be exposed in general terms. The consequences and constraints for accelerator operations will then be reviewed, particularly the needs for documentation in and around the control room (logbooks...), the requirements for written procedures, the operation of the access system and the possible conflicts of interest.

1. INTRODUCTION

Founded in 1954, the CERN laboratory is located across the French-Swiss border, near Geneva. About 70% of the two largest accelerators of CERN (LEP/LHC and SPS) are located on French territory.

In 1984, a convention has been signed between CERN and the French government, where by the organization agreed to take the necessary steps to guarantee the safety of the installations of the LEP machine, according to modalities submitted to the approbation and the control of the French authorities.

In July 2000, a new convention has been signed, concerning the LEP dismantling, the new LHC collider under construction in the LEP tunnel, the SPS machine and its transfer/injection lines including the future CNGS (neutrino to Gran Sasso), and their associated infrastructures, both underground and on the surface, within a perimeter precisely defined by a set of plans.

2. THE INB CONTEXT

The signature of these conventions assimilates the installations to an INB like French nuclear reactors or installations for storage of radioactive materials.

The others CERN accelerators which are located on Swiss territory are not presently concerned.

2.1 Control of the installations

The nuclear safety authority (DSIN) controls these installations. The nuclear safety authority (DSIN) itself comes under the authority of the French government environment and industry departments.

On the Swiss part of CERN installations, the control is exerted by the Federal Office of public health (OFSP).

2.2 Organization of the INB structure at CERN

A lot of important and varied studies are requested by the authorities; this in turn implies an important documentation effort. The present structure which deals with these activities includes:

- one INB coordination unit which ensures the permanent link with French authorities and coordinates all the related work (report writing and associated studies) – 1 FTE
- one ‘AQ-INB’ unit which ensures that all INB activities are in accordance with quality assurance criteria – 0.5 FTE
- a group of about 20 correspondents in the divisions, mainly from the Technical Inspection and Safety division (TIS) and the accelerator sector – ~ 8 FTE.

131
3. CONSEQUENCES AND CONSTRAINTS

3.1 Specific systems or activities of the INB

In the accelerator domain, INB regulations emphasize on specific systems or activities called important elements for safety (EIS). The accent is put on the radioprotection, on the access system, on the alarms, on the waste treatment and disposal channels, on the traceability; these activities must follow quality assurance rules and are submitted to a careful control.

3.2 Zoning

A justified a priori ‘zoning’ of the installation must be established; the entire perimeter of the INB must be decomposed in conventional and nuclear zones.

   In a nuclear zone, the materials waste produced is radioactive or susceptible to be so.

   In a conventional zone, the waste produced is conventional.

3.3 Traceability

Every equipment leaving or entering the INB perimeter must be traced as long as it exists, which implies that a somewhat heavy infrastructure has to be to set up.

4. CONSEQUENCES FOR OPERATIONS

4.1 EIS

As previously mentioned, both design, construction and operation of these systems must follow quality assurance rules. Every incident, abnormal event, modification or anomalies treatment must be clearly documented and recorded. Some of these, according to the nature or the impact (personal safety or environment) must be reported to the authorities.

4.2 Operations

Concerning machine and access operations, clear written procedures must be established. The definition of a precise zoning of the installation is generally not done by the Operations. Nevertheless, Operations is strongly involved for the following considerations:

- the nuclear zone must be precise and rather minimized because it is not presently possible to declassify a nuclear zone in a conventional one; the opposite is possible once duly justified;
- the nuclear waste disposal channels are very expensive and necessitate a very heavy work: complete inventory of the radionuclides in the radioactive waste, conditioning to minimize the cost;
- moreover, safety is prevailing on efficiency and doses to the persons involved in nuclear materials handling must be minimized (ALARA).

For these reasons, Operations has rather to think in terms of minimum beam losses, minimum induced radioactivity, localised and well explained beam losses, clean operating conditions and clean ‘intensity records’. Enough resources must be put in an efficient and reliable beam diagnostic system which includes a complete recording of detailed transmission efficiencies/losses, coast data, recording of beam loss data, loss patterns. The logbook has an important role to play here: precision of the information (time stamp), clear documentation of the events or operation mode changes.

The potential advantages of such an approach are numerous, among them can be mentioned:

- easier anomalies treatment and reporting
- easier justification of the zoning redefinition
- cheaper radioactive waste disposal
5. CONCLUSION

CERN has signed conventions with the French Government in which we agree that certain of our facilities become classified as INB.

In the convention, we have agreed to abide by the regulations and statutes concerning INB, this is to guarantee the safety of the operations of the installations through modalities submitted to the approval and the control of the French authorities.

Finally, INB rules compel us to work within a quality assurance frame and therefore ask us to do all efforts to even better master the accelerator Operations.
ASPECTS OF OPERATIONS AND DOE REGULATION OF ACCELERATORS AT FERMI NATIONAL ACCELERATOR LABORATORY

Daniel A. Johnson
Operations Department, Fermi National Accelerator Laboratory, Batavia, IL USA
Pepin T. Carolan
U.S. DOE Fermi Area Office, Chicago Operations, Batavia, IL USA

Abstract
Fermilab is a U.S. Department of Energy (DOE) high energy physics research facility, which operates under the requirements and regulations of DOE facilities. The Beams Division Operations Department is responsible for safely and efficiently operating the accelerators. As a Federal Agency with oversight responsibility, DOE issues a range of guidance, directives and regulations for its contractors to consider or follow in their operations. Operations organizations generally see such DOE regulation in the form of limits, procedures, etc., while others take responsibility for the broader interpretation and labwide implementation of DOE requirements. Over ten years ago, DOE issued Order 5480.19 titled the ‘Conduct of Operations Requirements for DOE Facilities.’ This order directly impacted the Operations Department. Its implementation led to the creation of an ‘Operations Department Conduct of Operations’ (no longer required), which is kept updated and still in use today.

We will give an overview of DOE regulation at the laboratory, as related to accelerator operations. We will also talk about the initial worries of the Conduct of Operations and describe how it was made to work at Fermilab. This will hopefully encourage other discussions and encourage the concept of taking credit for things we do ‘right.’

1. INTRODUCTION
Fermi National Accelerator Laboratory is operated under contract by Universities Research Association (URA) for the Department Of Energy (DOE). The contract governs how the facility will operate and provides performance criteria for gauging success. The performance criteria are negotiated annually, while the contract is typically maintained over a five-year time frame. The contract includes performance criteria for things like ‘number of lost work days,’ ‘hours of operation,’ ‘integrated luminosity,’ ‘collective radiation dose,’ etc. The contract also includes the set of all Environment Safety and Health (ES&H) ‘standards’ that govern both accelerator operations, and work in general at the laboratory. This set is known as the ‘Work Smart Standard’ (WSS) set and includes State, Federal and DOE regulations, and directives as well as governmental and professional consensus standards. In addition to what is in the contract, other DOE directives and guidance can be applicable to accelerator operations at the laboratory. Some of these DOE directives are geared more toward, or are analogous to, ‘nuclear’ operations and ‘nuclear’ facility requirements. A few of the DOE directives and regulations are discussed here from some accelerator operations aspects. The DOE WSS process is an approved method of selecting applicable standards and regulations via peer-review, analysis and consensus.
2. SOME REGULATIONS AND ORDERS AS SEEN BY OPERATIONS

- **DOE Order 420.2**

**Safety of Accelerator Facilities**

This order calls for identification and analysis of potential hazards and impacts, ensuring training and qualification of personnel, and adherence to written procedures to maintain safe operations. The objective is to prevent injuries and illnesses associated with accelerator operations. Used in conjunction with other ES&H requirements. [1]

Fermilab implements key elements of the Accelerator Safety order via an internal WSS standard called, ‘Planning and Review of Accelerator Facilities and Their Operations.’ The implementation of this order and guidance shows up in a number of different ways in the Operations Department. A Safety Assessment Document (SAD) and DOE approved Accelerator Safety Envelope (ASE) are required. These documents link to operations in matters like beam intensity limits/operating parameters, access conditions, radiological, occupational and life safety hazard controls, procedures, shielding requirements, training, safety system tests, and other areas. A section of the order implementation guidance deals directly with control room shift operations in the categories of: Organization and Administration, Shift Routines and Operating Practices, Control Room Activities, Communications, Operations, Conduct of Research and Development, and Status Control of Equipment and Systems. Each of these is covered in the Conduct of Operations to be discussed later. DOE 420.2 can be found at: [http://tis.eh.doe.gov/portal/policy.html](http://tis.eh.doe.gov/portal/policy.html) (select DOE Directives, Current DOE Directives, New Series Directives, 400 Series.) Additional information and guidance for Accelerator Safety can also be found at: [www.sc.doe.gov/production/er-80/er-83/accelr8r.html](http://www.sc.doe.gov/production/er-80/er-83/accelr8r.html)

- **DOE Order 232.1A**

**Occurrence Reporting and Processing of Operations Information**

Keeps DOE and others informed of occurrences at the facility that could adversely affect security, the health and safety of the public, environment, laboratory purpose, etc. [2]

The implementation of this order puts the Operations Department into two different roles, either the role of responder or data collector. Depending on the type of occurrence the operators may be able to control the device, system, accelerator, or provide support to prevent further loss, damage, or potential hazard, etc. The Operations Department may also be required to provide documentation, graphs, plots, or other information on the events leading to and status of machines/systems at the time of the occurrence. Depending on the occurrence, the analysis of the occurrence may also result in changes in practices or procedures for operations. More information on DOE Occurrence Reporting, including Public access to all final, non-sensitive occurrence reports since 1990, can be found at: [http://tis.eh.doe.gov/oear/orps.html](http://tis.eh.doe.gov/oear/orps.html)

- **10 CFR 835**

**Occupational Radiation Protection**

This is part of the Code of Federal Regulations (CFR) and sets the standards and requirements for occupational radiation protection. This document incorporates guidance from both the National Council on Radiation Protection and Measurements (NCRP) and the International Commission on Radiological Protection (ICRP). [3]

To ensure compliance with this mandatory Federal rule, a DOE-approved ‘Radiation Protection Plan’ was implemented by the laboratory Environment Safety and Health (ES&H) groups, and its implementation can also be impacted by accelerator operations. For example, the operators control the particle beam. If not properly tuned, beam losses can result in higher than necessary residual radiation in the accelerator enclosures and tunnels. This impacts the area radiological postings, protective clothing, training, and other access requirements. The operators also control access to accelerator...
enclosures and require workers to sign the appropriate Radiation Work Permits (RWP's), check verification of worker training, provide some of the required protective or other equipment, and enforce other requirements for access.

Operators must also frequently enter the areas for various reasons including search and secure, and therefore ensure their own adherence to all radiological safety requirements. More information on DOE Occupational Radiation Protection can be found at: http://tis.eh.doe.gov/whs/rhmwp/

- **DOE Order 5480.19**

**Conduct of Operations (CONOPS) Requirements for DOE Facilities**

This DOE order provides standards to improve the quality and uniformity of operations at DOE facilities. This can include any industrial, research, testing, or production activity. [4]

Sometime around 1985 the Institute of Nuclear Power Operations (INPO) released order '85-017 Guidelines for the Conduct of Operations at Nuclear Power Stations.' It was modified and updated somewhere around 1988. It was an eighteen-chapter document, where each chapter dealt with a specific aspect of operations. Late in 1989, the DOE decided to implement a Conduct of Operations program to improve the quality and uniformity of all its facilities. The INPO document was given as an example and DOE standards were expected to closely follow it. At first pass, the implications to accelerator operations looked extremely onerous. Fermilab was not a nuclear facility and didn't want to be treated as one. After the initial shock, each chapter was examined and mapped into accelerator operations. The first versions of the Conduct of Operations for Fermilab were released in late 1989 and early 1990. As it turned out, many of the guidelines were actually being followed by operations. In some cases things were already being done in practice and only needed supporting documentation. After reviewing each chapter, it made sense to put down in writing how the Operations Department does business. This proved to be useful for new employees and audits alike. A few years ago the laboratory, under 'Necessary and Sufficient' and currently under the 'Work Smart Standards' program, decided that the Conduct of Operations was no longer explicitly contractually required. However, employees found it useful. We recently updated it and asked our department employees to reread it. As you will see some of the guidelines in the Conduct of Operations also fall in line with the 'Safety of Accelerator Facilities' mentioned above. In fact, all of the above orders and regulations are tied into the Conduct of Operations. I will briefly describe each chapter and you should be able to see the importance to operations from within and outside the group. The DOE CONOPS order can be found at: http://tis.eh.doe.gov/portal/policy.html (select DOE Directives, Current DOE Directives, Old Series Directives, 5400 Series.) Additional standards and supporting guidance (largely geared toward 'nuclear' facilities) can be found at: http://tis.eh.doe.gov/techstds/standard/appframe.html (Document Number Range 1001-2000).

I – **Organization and Administration**

This chapter covers the department makeup. It describes the job description of different members of the department and their responsibilities. This chapter also includes things like policies, how to monitor performance, accountability, management training and planning for safety.

II – **Shift Routines and Operating Practices**

This chapter covers the way shifts are run and standard practices. Things like: how to get status reports, respond to status indicators, reset protective devices, and keep the control room civilized; making operator rounds/tours with inspection sheets (e.g. readings for a system that does not have a remote readback), who has the authority to control equipment and from where, and what standard safety practices are used.
III – Control Room Activities

This chapter sets the stage for acceptable control room activity, materials, and equipment control. This chapter also suggests limiting operator activities to those related to machine operation, to limit distractions caused by working on other projects while assigned to the control room.

IV – Communications

This chapter deals with good communication practices. The use of acronyms, radio/telephone communications, and transfer of instructions to the crew are covered. The proper use of emergency and public address systems are also discussed.

V – Control of On-Shift Training

One of the most pressing issues is training new operators. This chapter discusses the training program, instructor qualification, control of trainees, and assistance from trainees. Also discussed are the number of trainees per trainer, training documentation, approval, and suspension of training in certain situations.

VI – Investigation of Abnormal Events

This chapter covers the occurrence of an event from recognition through completion and trending. It also ties in the reporting requirements of DOE Order 232.1 mentioned earlier.

VII – Notifications

This chapter sets up standards for timely notification of personnel. We must ensure responsive notification of ES&H concerns. Information must be gathered and transferred in a systematic, controlled method. An example of this would be in our safety procedures. A periodically reviewed call-in list is used to make sure proper people are notified. (This chapter tells how things are set up and is not the actual call-in list.)

VIII – Control of Equipment and System Status

This chapter covers the work on equipment/systems and their return to service. The equipment/system must be verified and sometimes certified by operations in the form of a prescribed test. The importance and need for accurate status indicators is also important.

IX – Lockouts and Tagouts

This chapter covers the aspects of the laboratory lockout and tagout procedure. Lockout/tagout requires a separate training course before use is authorized.

X – Independent Verification

As mentioned earlier, equipment and systems returned to service must be verified as functional. A device may have to be in the correct configuration, value, or position. It is important to have independent verification.

XI – Logkeeping

This chapter covers the requirements of logkeeping. We currently use an electronic logbook. It provides a timestamped, legible, and easily searchable record. It cannot be easily changed, but is accessible remotely. A hardcopy is printed for use during shift change.

XII – Shift Turnover

This chapter covers the guidelines for a thorough and proper shift turnover. It identifies use of checklists, document review, and individual turnover.
XIII – Operations Aspects of Facility Chemistry and Unique Processes

This chapter does not directly apply to our operations. It mainly deals with the monitoring of plant chemistry data and parameters (e.g. failed reactor fuel systems, systems employing or storing hazardous and radio-chemicals and gases, corrosion problems, toxic waste systems). Such systems are generally not a part of accelerator control room operations, or if similar systems do exist, are not generally monitored by main control room personnel. This chapter also generally stresses the importance of monitoring, control, and good communications with the technical support groups.

XIV – Required Reading

This chapter covers the use of required reading. It includes acknowledgement of completion, review, and documentation. Procedures classified as ‘required reading’ must be read, understood, and signed. Any questions on these procedures can be directed to supervisors. The CONOPS manual would also be another example.

XV – Shift Orders

This chapter describes the way to communicate short-term information and instructions to the operating crew. It protects the crew from external requests and distractions. The format content, review, and removal of old orders are discussed. Shift orders for the weekend crews, are frequently entered into the electronic logbook by the Operations Department Head or designee. Since it is a logbook entry, it is dated, signed, reviewed at briefing, etc.

XVI – Operations Procedures

This chapter discusses the use of procedures mainly for safety-related issues during operation. The topics covered are procedure development, content, changes, review, availability, and use. We have several types of procedures: Administrative, Safety, and Emergency Response. Each may have different levels of review and approval. An example of an Emergency Response procedure would be ‘Flammable Gas Emergency Response Procedure.’ They are written in flowchart format to make them more portable and easy to read.

XVII – Operator Aid Postings

This chapter provides guidelines for the proper use of operator aids. A piece of paper taped to the console, isn’t good enough. Operator aids should be developed, reviewed, approved, and documented. Temporary directions on how to reset a unique device may be documented and displayed in the control room provided the proper format is used and approval given.

XVIII – Equipment Labeling

This chapter covers the use of devices labels. A good labeling program provides consistency and promotes better communications. Some of the important points of this topic are label information, placement, removal, and replacement.

3. CONCLUSION

Our main goal is to safely and efficiently operate our accelerators. We all have to deal with orders, rules and regulations. The degree of impact varies, but can usually be traced to a procedure, response, limit, etc. At first, some regulations/orders may look overwhelming and contradictory to the goals. As mentioned, the Conduct of Operations and its association with nuclear facilities initially caused concern. In most cases, given a chance to break down and implement them on our own terms, such orders and regulations can be turned into something useful and maintainable.
References


(select DOE Directives, Current DOE Directives, Old Series Directives, 5400 Series).
SUMMARY OF SESSION 6
WHAT IS SO SPECIAL ABOUT OPERATING BIG SUPERCONDUCTING ACCELERATORS?

K. Cornelis
CERN, Geneva, Switzerland

Abstract
Summary of session 6, held at the workshop on accelerator operations at Villars-sur-Ollon, 2001.

1. INTRODUCTION
In this session the specific problems of operating super conducting accelerators were discussed. Reports were given on four big super conducting magnet machines (RHIC, TEVATRON, HERA and LHC) and on the operation of two smaller super conducting linear accelerators (ATLAS and JAERI).

2. CRYOGENICS
Cryogenic systems are common to all these accelerators, whether it be super conducting magnet- or super conduction cavity machines. The cryogenic system is very closely linked to the performance of all these accelerators.

First of all, there is direct link between the cryogenics and the energy deposited by the beam through parasitic mode losses, beam losses, synchrotron radiation and electron cloud.

The field which, can be obtained in Pure Nb super-conducting cavities is directly related to the speed at which the cavities can be cooled down (JAERI).

The correct and fast operation of cryo systems has an important impact on the down time. The recovery from a quench takes typically (depending on the machine) 0.5 to 7 hours if everything works correctly. In the case of wrong or late reactions in the cryo system the recovery time can be days.

The same is true for the recovery after a power cut where the consequences can be even worse, depending on the length of the cut.

This means that a good and fast (direct) communication with the cryogenics operations is indispensable.

3. SAFETY
Cryostats with liquid Helium and/or liquid Nitrogen in the tunnel are potentially dangerous. Super conducting accelerators require special access procedures and adequate operator training.

4. QUENCH PREVENTION AND QUENCH PROTECTION
Magnet quenches do occur from time to time, but if possible, they have to be avoided. Not only do they create down time (0.5 to 7 hrs), but they also result in a severe mechanical shock for the magnet. Specialists are not clear about the number of quenches a magnet can have, but the number is certainly finite. An enormous amount of energy (for the LHC: the equivalent of two big jetliners flying at 900 km/hr) has to be dissipated quickly. A good quench prevention system that dumps the beam before it can provoke a quench is vital. The system has to act fast, -in the LHC the time between failure and beam hitting the magnets varies between 6 and 200 turns, depending on the equipment. All running
machines rely on a robust beam-loss monitor system. At the TEVATRON de beam position monitors are also included in the protection system.

The quench protection system itself (the system that deviates the energy once a quench is detected) has to be 100% reliable. On the other hand, it should not be too sensitive in order avoid false quench events (RHIC suffered from this problem in the early stages of ramp commissioning).

It was stressed by all the speakers, representing the super conducting magnet accelerators, that a post mortem system is mandatory. An exact timing in the post mortem is very important in order to establish the right sequence of events and in order to make the right diagnostics.

5. STABILITY AND DYNAMIC EFFECTS

The persistent currents in super conducting magnets cause quit some problems for stability and reproducibility of energy, tune and chromaticity. Reference magnets are used to measure and compensate drifts during injection. Pilot bunches have to be used frequently in order to re-trim the machine and the monitor system has to cover the dynamic range between pilot and production beam. The control system needs very good function editors.

Ramps with super conducting magnets are very slow, so that a tune and chromaticity feedback should not be to difficult to realize.

6. SUPER CONDUCTING CAVITIES

The most predominant characteristic of a supper conducting cavity is its high Q-value ($10^9$), which means a very narrow resonance line. This makes the tuning of the cavity very critical. It can also lead to mechanical vibrations (ATLAS). The mechanical stress provoked by the high field in the cavity drives it off resonance so that the field disappears. The cavity relaxes and comes back on resonance. This phenomenon creates vibrations in the order of 50 to 100 Hz. A fast feedback can help here.
OPERATIONAL EXPERIENCES DURING RHIC COMMISSIONING: FY2000

Paul W. Sampson
Brookhaven National Laboratory, Upton, New York USA

Abstract
During the period between December 1999 and August 2000, the Relativistic Heavy Ion Collider or RHIC was brought on line for the first time. RHIC is designed to accelerate Au ions to a momentum of 100 GeV/c per nucleon in two counter-rotating rings with six (6) intersection/collision regions (IRs). The following will describe Operation’s experiences by during this period. Topics will include: special methods for independent ring power supply management and control, Operational techniques for utilisation of superconducting (SC) trim and corrector magnets, techniques for crossing transition in an SC collider, techniques for steering in the (IRs) and methods for management of cryogenic and quench protection systems.

1. INTRODUCTION
The RHIC accelerator complex consists of the following components:

- **Injectors:**
  Tandem van de Graff, which accelerates Au ions to a momentum of 40 MeV/c per nucleon.
  During RHIC operation in FY 2000 it delivered a beam pulse width of 700 μsec and a current is 12 μAmps or approximately $1.5 \times 10^9$ Total Au ions per pulse.
  AGS Booster, which has a radius $\rho$ of 32 m (104 ft). It collects and accelerates $^{12}_{7}$Au ($^{32}_{17}$Au) to a momentum of 430 MeV/c per nucleon. The average intensity was $\approx 1 \times 10^9$ ions per cycle in FY 2000.
  The Alternating Gradient Synchrotron or AGS (which is nearly identical to the PS at CERN) has a radius $\rho$ of 128 m (419 ft) collects and accelerates $^{77}_{37}$Au ions in 4 bunches to 11.24 GeV/c per nucleon. Typical intensity in the AGS was $2 \times 10^9$ ions per cycle.

- **Transport lines:**
  Tandem to Booster (TTB) line: An 853 m (2800 ft) transport line. $^{12}_{7}$Au is extracted from the Tandem is stripped to $^{32}_{17}$Au for Booster injection in this line.
  Booster to AGS (BTA) transports beam between synchrotrons. It is 61 m (200 ft) long and has a stripping foil, which creates $^{77}_{37}$Au for injection into the AGS.
  The AGS to RHIC (ART) line transports beam to the X and Y arcs. It has a switching magnet that when commanded to a positive value sends beam down the X arc for Blue ring injection and when negative transports beam to the Yellow ring. There is also a stripping foil, which removes the final electrons from the Au ions for injection into RHIC.

- **ARCs**
  The X and Y arcs transport beam from the end of the ATR line into the two RHIC rings. The X arc transports to Blue and the Y to Yellow.
• RHIC

A 3.8 km (2.4 mile) circumference accelerator comprised of 2 (two) rings, Blue and Yellow, which accelerates Au$^{+79}$ beam to a momentum of 100 GeV/c per nucleon and collides the two beams at 4 active experimental sites.

![BNL Accelerator Complex](image)

**Fig. 1: Representation of Collider Accelerator Complex (not to scale)**

During the previous RHIC runs, sextant test and engineering runs, Operations' main concern was with AGS experiments. The main contribution to these runs was to keep the injector on for the RHIC Physicists, while they ran RHIC itself.

During the effort to commission RHIC, Operations was charged with gaining as much hands on experience as possible. To help achieve this, Operations personnel were utilised as 'hands' for commissioning Physicists as much as possible. In doing so, Operators became familiar with nearly all aspects of everyday operation the collider.

2. EARLY COMMISSIONING

During the early stages of the commissioning effort, Operations worked with RHIC Accelerator Physicists and set up the injectors and ATR transport line.

2.1 AGS extraction

AGS extraction was set up such that beam could be delivered to the desired RHIC ring on demand. This required the use of several triggers for AGS extraction equipment. The Blue ring and Yellow ring triggers where set up as on demand, manually activated triggers. A third trigger called 'green' was used for much ATR commissioning. This triggers extraction every AGS cycle. The AGS has one cycle approximately ever four (4) seconds. When triggering with the green trigger, the beam is transported to a beam dump at the end of ATR, upstream of the arcs.
2.2 ATR setup

Prior to injecting into RHIC, the transport line was set up and studied. Utilising the ATR dump, beam was extracted continuously from the AGS and ATR studied. The first objective was to re-establish transport to the dump (Fig. 2). This had been done previously during the sextant test and engineering run.

![Graph](image)

**Fig. 2: Beam to ATR dump**

Once transported to the dump, beam losses were minimised. Studies dedicated to cross-calibrate Beam Position Monitors (BPMs) to quad centres followed. Operators systematically varied the current for quadrupoles in the line just upstream of each BPM. This exercise was completed for a range of transverse positions incident to the quad. After several sets of data, optical centre was determined and BPM offsets were incorporated into the model for the line. Figure 3 shows a plot of ATR and the Y arc as the arc current was varied, which changes both the dipole and quadrupole strength. Moving a quadrupole in the ATR line produced similar plots.

![Graph](image)

**Fig. 3: Trajectory effect of changing the Y arc current**
2.3 First RHIC injection

Beam was injected into one ring at a time, first the Blue then Yellow. Since beam has a downward trajectory at the end of the injection arc, it must be kicked upward onto the equilibrium orbit. The first injections were single turn only and done using a corrector dipole to deliver the required diversion. The first turn trajectory was measured and corrected using several methods. The first of these was by ‘hand’. This method had an operator measuring the beam trajectory then changing individual orbit corrector magnets to minimise the divergence from the centre of the beam pipe. Although instructive, this proved to be very tedious and hard to reproduce. In order to close the orbit and circulate the beam, the injection kicker had to be set up. Figure 4 shows the current pulses for three of the four injection kicker modules for the Blue Ring as well as the beam signature on a nearby BPM.

![Fig. 4: Injection kicker and beam signals](image)

Once injection with the injection kickers was established, the magnetic field for injection was adjusted to centre the beam on the ring BPMs. The next objective was to smooth the orbit. The controls for orbit correction allow the choice of any section (local) or the whole accelerator ring (global) for correction. The ‘local’ control was later used to steer the beams onto each other at the Intersections Regions (IRs). Figure 5 top, shows the measured orbit (red) and the corrected orbit (green) for a section of the Yellow ring. Figure 5, bottom shows a detailed view, which could be used for IR steering.

When the orbit correction application produced unexpected results, polarity checks were made on the correctors and several were found to be in the wrong polarity. Several BPM were also wired backwards. Both of these problems were compensated for in the software.
3. CAPTURE AND STORAGE AT INJECTION ENERGY

With beam parameters defined and survival for several seconds achieved, the RF system was brought on and set up. RF experts synchronised the RF systems in the AGS and RHIC so that bunches from the AGS were injected into specific bunches in RHIC. At first, one AGS bunch was injected and stored in each ring. Later 4 bunches were injected then finally 56. Table 1 displays RF harmonics and beam bunches during commissioning period. 4 Booster cycles of 6 bunches each were injected into the AGS. The beam was then de-bunched and adiabatically re-bunched into 4 bunches utilising a specialised RF cavity in the AGS. At extraction in the AGS, bunches are in every 3rd of 12 bunches and extracted into four buckets in RHIC. Bunches are in every 6th bucket in RHIC. Once in routine operation RHIC was filled with 56 bunches (i.e. 14 AGS cycles).

<table>
<thead>
<tr>
<th>Machine</th>
<th>Booster</th>
<th>AGS</th>
<th>RHIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harmonic</td>
<td>6</td>
<td>12</td>
<td>360</td>
</tr>
<tr>
<td>Bunches</td>
<td>6</td>
<td>4</td>
<td>4 (56)</td>
</tr>
</tbody>
</table>

Figure 6 shows the ‘Supercycle’, which defines configuration of the injectors. The graphic shows five (5) Booster Main Magnet current cycles (four (4) with beam and 1 dummy cycle) for every AGS cycle. Each RHIC ring takes as many as 14 Supercycles to fill.
4. ACCELERATION

With beam routinely stored at injection energy, attempts to accelerate the beam were made. The first of these was done with the main magnets ramping to 20 GeV/c/n or just below transition energy (22.9 GeV/c/n). Stopping the ramps at lower energy was done to save time, since a hysteresis correction cycle was necessary after each unsuccessful acceleration attempt. Early in commissioning, resetting the magnets took several minutes (see section on magnet control).

Initial attempts to accelerate were unsuccessful. After observing that the machine was strongly coupled at injection, attempts to adjust the tune produced unexpected results. Upon investigation, a systematic wiring error was found. Several quadrupole shunt supplies were wired backwards. This was corrected, but unfortunately, acceleration continued to elude commissioners. Further investigation and debate prompted commissioning Physicists to suspect that the some of the Chromaticity Sextupoles might also be wired wrong. Investigation proved this suspicion to be correct. Beam was accelerated shortly after this wiring error was corrected.

Later, a system for executing steps necessary to accelerate routinely was developed. It was eventually formalised and incorporated into the ‘Sequencer’. The sequencer is an application designed to sequentially execute commands to control hardware and software. Steps included performing a hysteresis reset, filling the rings, activating RF beam control and activating, acceleration ramp and dumping the beam at the end of a cycle or store. The sequencer proved to be a valuable tool and is presently being expanded upon for use in FY 2001.

Figure 7 Top shows the beam current transformer profiles for the Yellow and Blue rings during an early attempt at acceleration. Beam current for the Yellow and Blue rings are orange and blue respectively. Beam Lifetimes are yellow and green. The bottom shows the radial pick up electrode signals (Blue on the top trace and Yellow on the bottom) as the beam crashed to the inside of the rings. Beam was surviving to \( \gamma = 12 \) at this point.
The machines were tuned until acceleration to transition was reproducible when the challenge became crossing a transition with a superconducting machine. This had not been done in a slow ramping superconducting machine before. Since beam is unstable at transition energy, it is desirable to cross through it as quickly as possible. This can be achieved a number of ways. One way is to gradually change the optics of the accelerator for a brief period just prior to transition, and then quickly reverse the distortion, moving the machines through transition as the distortion is removed. This is the preferred method and is achieved utilising a separate set of quadrupoles in the rings specifically designed for this task called ‘gamma jump quads’. During the commissioning efforts, the gamma jump was not available and an alternate method had to be employed. It was dubbed the ‘poor man’s jump’ due to the fact that no specialised (expensive) equipment was needed to create it. Using the poor man’s jump, the energy of the beam is changed rapidly using the RF radial control. The disadvantages of this method include that it is slower than the gamma jump, increasing the time the beam spends at transition and thus beam blow up, and that it utilises much of the beam pipe aperture, increasing the potential for losses. Figure 8 illustrates the gamma jump. The ‘poor man’s jump’ in on the left, the gamma jump on the right.

Figure 9 shows the Yellow ring beam current (blue trace) and a Main Magnet function with a maximum field at $\gamma = 30$. The Black is dipole current and the red the quadrupole current.

In FY 2000 beam final acceleration was $\gamma = 70$. RHIC is scheduled to run at design energy in FY 2001 ($\gamma = 100$).
5. **COLLISIONS**

After accelerated beam was established and stored in both rings simultaneously, the emphasis shifted to establishing collisions. In each IR, the Yellow and Blue beams must change position from the inside ring to the outside or ring RHIC (or visa versa). This is done using specialised dipole magnets, called DX magnets. These magnets are in series with the Blue main dipole bus and bend both beams, causing them to cross. During acceleration, the beams are not coincident transversely or longitudinally. When collisions are desired, i.e. at storage energy, they must be. This is done using the DX and corrector magnets for the transverse planes and by manipulating the RF longitudinally.

RHIC was designed with a Wall Current Monitor (WCM) physically located at the Intersection Point at 4 o’clock. Since the particle bunches have the same charge, they will induce opposite polarity signals on the WCM. Longitudinal bunch alignment can therefore be confirmed by observing that the
two WCM cancel (i.e. if both machines have the same current, the signals will be zero). This process was completed in two steps. The first step was to synchronise the RF systems by locking them to the same frequency. In FY 2000, both rings were locked to the Yellow Ring’s frequency. By doing this, the respective bunches ‘stand still’ relative to one another. The second step was to change the relative phase between Yellow and Blue bunches in small steps until they are on top of each other.

Figure 10 shows the process by which the beams were ‘synched and cogged’.

![Bringing beams into collision](image)

**Fig. 10:** Left: two bunches, one Blue one Yellow. Right: ‘cogged’

With beam cogged and synched, the final step towards collisions was to steer the beams onto each other transversely. There are special BPMs located around the IPs specifically designed for this task. These have both horizontal and vertical plates where as other Ring BMPs are either vertical or horizontal. As previously mentioned, there is a specialised routine in the orbit control application designed specifically for steering the beams in the IRs. Figure 11 shows a sample display of the specialised BPM outputs during tuning for collisions.

While observing the beam position on BPMs, instruments at the IPs were monitored to determine the existence of collisions. These instruments, called ‘Zero Degree Calorimeters’ (ZDCs) are tungsten sample calorimeters and are positioned at equal distances from and at zero degrees to each experimental IP. With this geometry, incidental events on either detector due to interaction with residual gasses or other obstructions can be excluded and actual collisions detected.

Figure 12 shows the ZDC coincidence rate for STAR, PHENIX, BRAHMS and PHOBOS shortly after the first collisions.

Although the steering algorithm is designed for independent control in the IRs, in practice, when steering for one IR, others were somewhat affected. Operators were careful to record collision rates and BPM positions at all IRs prior to steering anywhere. Once the desired steering was completed, an iterative process of steering and re-steering restored all of the rates.
6. MAGNET CONTROL

As mentioned, the RHIC ring is comprised of several different systems of magnets. Each of the systems are controlled and protected in various ways. The main ring magnets are controlled primarily by two applications, one called 'Ramp Editor' and one called 'Ramp Manager'.
Ramp Editor is used to create and load driving functions for the magnet power supplies. The user can define desired characteristics for the ramp and the application then calculates magnet currents using the accelerator model. When designing a ramp, the user can define the machine optics at various values for $\gamma$. Each of these segments called ‘Stones’ has editable inputs for all of the magnetic subsystems called ‘Pebbles’. Each Stone is a complete description of the machine. Stones for energies throughout the RHIC cycle are combined and fitted to create a time dependent ramp function. By employing this method the user has the option of either propagating a new setting throughout part, or all of a ramp or of having a change remain in effect for a particular Stone only. An example of a correction that might be propagated throughout a ramp is an orbit correction made at the Stone at injection. Examples of those that it may not be desirable to propagate are IR steering on the Last stone or modified tunes for Stone at transition. Figure 13 shows a sample ramp. Each horizontal line represents a Stone. The stones are fitted together to form a smooth ramp function.

<table>
<thead>
<tr>
<th>Ramp</th>
<th>Stone</th>
<th>$\gamma$</th>
<th>$\beta$</th>
<th>$\beta_2$</th>
<th>$\alpha$</th>
<th>$\alpha_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>76</td>
<td>29.35</td>
<td>29.35</td>
<td>29.35</td>
<td>29.35</td>
<td>29.35</td>
</tr>
<tr>
<td>2</td>
<td>76</td>
<td>29.35</td>
<td>29.35</td>
<td>29.35</td>
<td>29.35</td>
<td>29.35</td>
</tr>
<tr>
<td>3</td>
<td>76</td>
<td>29.35</td>
<td>29.35</td>
<td>29.35</td>
<td>29.35</td>
<td>29.35</td>
</tr>
<tr>
<td>4</td>
<td>76</td>
<td>29.35</td>
<td>29.35</td>
<td>29.35</td>
<td>29.35</td>
<td>29.35</td>
</tr>
<tr>
<td>5</td>
<td>76</td>
<td>29.35</td>
<td>29.35</td>
<td>29.35</td>
<td>29.35</td>
<td>29.35</td>
</tr>
<tr>
<td>6</td>
<td>76</td>
<td>29.35</td>
<td>29.35</td>
<td>29.35</td>
<td>29.35</td>
<td>29.35</td>
</tr>
<tr>
<td>7</td>
<td>76</td>
<td>29.35</td>
<td>29.35</td>
<td>29.35</td>
<td>29.35</td>
<td>29.35</td>
</tr>
<tr>
<td>8</td>
<td>76</td>
<td>29.35</td>
<td>29.35</td>
<td>29.35</td>
<td>29.35</td>
<td>29.35</td>
</tr>
<tr>
<td>9</td>
<td>76</td>
<td>29.35</td>
<td>29.35</td>
<td>29.35</td>
<td>29.35</td>
<td>29.35</td>
</tr>
</tbody>
</table>

**Fig. 13**: Stones and Pebbles making up a Ramp

Once a ramp is defined and loaded an application called ‘Ramp Manager’ is used to execute it. The Ramp Manager defines where to ramp to and how fast to ramp. This turned out to be critical since the rate of ramp must be such that the difference between the measured and expected main ring currents must be within tight tolerances or the Quench Protection System will shut the main ring power supplies down. Early in the commissioning effort, this rate was as slow as 2 amps per second, making a ramp to $\gamma = 70$ take 1600 seconds or 26 minutes! Ramp times were significantly reduced by the end of the commissioning period. A ramp presently takes approximately 2 minutes.

Ramp Manager was utilised to complete a hysteresis reset. It was determined that the injection field could be reproduced by ramping the magnet from near zero to a value at or above the maximum current for the next cycle, then back to near zero and finally to injection field. At first, this process was quite tedious due to slow ramp rates, but once regular stores were achieved and ramp rates increased, it became less of an issue. Figure 14 illustrates a hysteresis reset. Pilot bunches were utilised to determine if the field was in fact correct. If these pilot bunches, which are low intensity, showed that this was not the case, adjustments were made prior to full injection.

Blue ring was commissioned first because the Intersection Region magnets, which are common to both rings, are controlled by the Blue ring power supply. Because of this, the Blue ring can accelerate beam independently but the Yellow cannot. There were two ‘Ramp Managers’ early in the commissioning effort, one for Yellow and one for Blue magnet control. This allowed one group to work on the magnet power supplies while another could work with beam in the other ring. The two were combined later to form the present Ramp Manager.

Other means of power supply control are available and useful for specific tasks. All of the magnet power supply controls are available via a spreadsheet application called ‘pet’. Control via spreadsheet is most useful when an individual or small group of supplies needs to be manipulated. In practice this was very useful after power supply interlocks. All of the ATR magnets are controlled in this way. Two features designed into the spreadsheet control became useful for performing hysteresis resets for the (warm) magnets in ATR. The first of these features is that, for a given set of parameters, the user is able to associate a value for $\gamma$. An operator can change all of the ATR magnets simultaneously by changing the value for $\gamma$. When performing the hysteresis reset in ATR, operators would vary $\gamma$ to complete a
cycle similar to that of Fig. 14. Another feature was the use of Stones. To bring supplies on and reset hysteresis, operators had the option of changing ATR to a special Stone that has all zero commands. The method of changing to the 'zero Stone' in ATR was also adopted to expedite personnel access into controlled areas of ATR and RHIC. Since critical devices must to be secured prior to entry and the preferred method of turning off the power supplies is to do it with zero current command, the use of the zero Stone was a nice option.

![Main Magnet Hysteresis reset](image)

**Fig. 14:** Example of a Hysteresis reset cycle

In addition to interlock trips, other less obvious modes of failure were encountered. A tool called the Post Mortem Viewer was developed and proved very valuable for diagnosing such failures. It was designed to record magnet functions during each ramp. In the event of Quench Link Interlock, the data is saved into a file for later viewing. Otherwise, the data was overwritten during the next ramp. Figure 15 shows a sample output for the Post Mortem. A full output is comprised of over a thousand plots.

![Post Mortem View Sample graph](image)

**Fig. 15:** Post Mortem View Sample graph

Another application called ‘PSALL’ was available for use. It was similar to the ‘pet’ version in that the user has control of specific devices. It was arranged so as to be very useful for recovering from quench link interlocks and was widely used in the field by power supply engineers.
7. QUENCH PROTECTION

During the commissioning run, a major effort was put forth into setting up and understanding the Quench Protection System (QPS). As designed, the QPS monitors the magnets in the RHIC ring, all of which are super-conducting. Cryogen reserve level and flow, magnet voltage, current and temperature are monitored and must be within tight tolerances of predicted values. Early in the commissioning effort, interlocks from the QPS were very frequent, as many as 30 a day. These interlocks were almost exclusively not from actual Quenches. Many factors contributed to these interlocks.

An additional set of interlocks was actually implemented during the commissioning effort. Following a corrector magnet failure that was determined to be due to lack of coolant, lead flow indication for these and the ring sextupole magnets was incorporated in the QPS. Interlocks due to low lead flow for these magnets were separated from a main quench interlock system. They would not cause a beam abort or interlock the main ring supply (i.e. pull the Quench Link). A corrector-lead flow interlock would interlock only the supplies affected by the lead indicating low flow. Supplies with common interlocks also share common power supply alcoves in the RHIC ring enclosure. Following the recovery of flow in the lead in question, power supply recovery from a corrector-lead flow interlock was relatively simple. Affected supplies could be reset and brought up individually or in small groups via 'pet' or 'PSALL' then ramped to the desired value. Effect on the beam due to these trips varied from negligible to drastic depending on the devices that were interlocked.

Unfortunately, the majority of quench link interlocks did cause the beam to be aborted and the Main Ring Power Supply to interlock. The beam would be dumped and the main magnet supply interlocked when any one link in system of permit links (i.e. the Quench Link) failed.

Nearly all of the Quench Link failures were NOT due to actual quenches.

Several items related to the control of the magnets were found to cause interlocks. One of these was related to the Real Time Data Link (RTDL), which contains magnet command and read back information, and runs at 720 Hz. Occasionally, a bad data point on the RTDL would cause the quench link to be pulled. Power supply engineers added additional hardware and software to the systems affected by the RTDL to preserve magnet protection while keeping a single bad data point from causing the link to go down. A second source came from the Wave Form Generators (WFGs), which drive the magnet supplies. Differences between WFG command and WFG read back values often caused the Quench Link to go down. To minimise this problem, WFG software configuration was modified and power supply engineers cleaned up noise on the power supply read back outputs. All of the above mentioned problems were static, i.e. they were independent of the ramp rate. Others were not.

While investigating possible sources for frequent quench link interlocks, power supply engineers discovered that the main ring sextupoles' monitoring circuitry was different from the other elements. The voltage for the sextupoles is monitored on the (warm) power supply side of the cables, rather than the (cold) ring side, as is the case for the dipoles and quadrupoles. The calculation used for expected voltage did not take this into account. Modifying the algorithm for the sextupoles eliminated these interlocks.

Another source of trips came when attempts were made to ramp the magnets too fast. The algorithm for main monitoring the magnet was originally set up (or tuned) for a slow ramp rate. Elements to this algorithm needed to be changed (re-tuned) in order to ramp faster.

As each bug became evident and was corrected, quench events went from as many as 20 a day to about one a week. The ramp rate was also increased by more than 10 times. Figure 16 shows the pet page for the Quench Link Summary. A failure of any of these inputs will cause the link to go down.
8. RUNNING PHYSICS

By the end of the run, RHIC was routinely running for physics at all four experiments in the ring. Stores of many hours were common, some as long as 12 hours. Operations had taken over nearly all of the tasks involved in everyday running of the machine. For example, during the Sextant test, 4 RHIC Physicists were on 3 shifts a day and Operations spent most of the time working with injectors only. By the end of the commissioning run, One RHIC physicist was on during the day and evening, while Operations ran through each night. Figures 17–21 show various parameters for the FY 2000 run.

![Typical Store](image)

**Fig. 17: Beam Current in Yellow and Blue during a typical store**
Tune measurements during acceleration ramp

Blue ring
Horizontal

Blue ring
Vertical

Fig. 18: Beam tunes during the acceleration ramp

Accelerating a gold bunch in RHIC

Injection  Transition energy  Storage energy

Fig. 19: FY2000 bunch lengths
Fig. 20: Emittance vs. time in for a group of stores

Fig. 21: Specific luminosity plot during a store
9. ACKNOWLEDGEMENTS

The following illustrations were taken from the RHIC logbooks for FY 2001: Figures 2, 3, 4, 5, 7, 9, 11, 12, and 13.

The following illustrations were adapted from a presentation for Quark Matter 2001 by Dr. Thomas Roser, Brookhaven National Laboratory: Figures 8, 10 and 17–21.
TOOLS TO CONTROL LARGE SUPERCONDUCTING COLLIDERS

Bob Mau
Operations Department Head, Fermilab National Accelerator Laboratory
Batavia, Illinois, USA

Abstract
Fermilab’s Tevatron accelerator is a cryogenically cooled four-mile ring of superconducting magnets that controls a 980 GeV beam. Superconducting magnets are expensive and take time to replace. To protect the magnets, Fermilab developed Quench Protection and Abort systems. To protect the people who maintain the magnets, Fermilab implemented ODH policies. This paper discusses these problems.

1. INTRODUCTION
Fermilab is a U.S Department of Energy (DOE) research laboratory, operated under DOE contract by Universities Research Association (URA). The Fermilab accelerator complex added the Tevatron, a cryogenically cooled particle accelerator, into its chain of accelerators in 1983. The Tevatron was constructed in Fermilab’s Main Ring tunnel, a ring four miles in circumference. The accelerator is a separated function synchrotron that raised the operating energy of Fermilab from 400 GeV to ultimately 980 GeV.

2. IMPACTS
One of the first impacts we saw in operating the new accelerator was that the cycle time increased. The Main ring’s cycle time ran at 8 seconds while the Tevatron runs between 60 and 200 seconds depending on the mode of operation. This longer cycle time meant that when tuning you had a much longer wait to find out whether your change was successful. The experimenters didn’t mind the slower rep rate because the duty factor in which they received beam increased dramatically with the slower rate (1 second flat top Vs a 23 second flat top).

When tuning the Main Ring it was often quicker to intuitively adjust the tune rather than make a careful calculation of what you wanted changed. But since the Tevatron’s tuning rate was so much slower it made more sense to actually figure out how much you wanted to move the beam before making an adjustment. In addition, the sensitivity of the superconducting magnets to beam losses meant you could not use the Main Ring technique of whacking the beam back and forth.

3. CRYOGENIC MAGNETS
The second, and by far the biggest, impact to operating a cryogenic accelerator was that these magnets could easily fail if the conductor went from superconducting to non-superconducting. The Tevatron magnet coils have a cross section of approximately 12 square mm. We run 4380 amps through this conductor. If the coil remains superconducting (no electrical resistance) then everything is fine and happy. But if the coil warms up so that the conductor develops a resistance, that high current will cause the conductor to fail. This is expensive, and worse it takes a week to replace the magnet.
4. PROTECTION & ABORT SYSTEMS

To protect against these kinds of failures, the Tevatron group had to develop a quench protection system to look for magnets that are to go non-superconducting. They came up with the Quench Protection Monitoring system, QPM for short. Some of the requirements for the QPM system were as follows:

- To get rid of the beam (initiate a beam abort) in a safe manner
- To turn off the power supplies and remove the energy from the magnets before the magnet failed
- To monitor itself and ensure that it was always online and protecting the magnets
- To allow easy troubleshooting
- To quickly show what triggered the quench system. (The QPM contains a circular buffer where measurements of magnet behavior are recorded. When the QPM system senses a quench, the circular buffer is stopped, which allowed us to back up into time and figure out what caused the quench.)

Understanding what causes and, more importantly, how to avoid quenches are vital to Operations. Our biggest quench problem is caused by beam scraping. Uncontrolled beam losses, due to scraping, will warm the Tevatron magnet so that it’s no longer superconductive. In this situation, rather than waiting for a quench, it is preferable to quickly abort the beam into an external dump. Our Abort system has similar requirements to the QPM system:

- When triggered by losses or equipment failure, the abort system fires a set of single-turn kickers that remove the beam safely and quickly
- To quickly diagnose aborts. (Each Beam Position Monitor and Beam Loss Monitor talks to a circular buffer that store positions and losses through out the beam cycle. When the abort fires, all circular buffers for the BPMs and BLMs stop. This allows us to look back at the Tevatron orbit and loss patterns around the entire ring and see what they were doing in small increments before the actual abort occurred.)

5. BENEFITS

One of the positive side effects of the superconducting magnets was that successful operation prevented us from dumping vast quantities of beam on the magnets. The TeV magnets demanded better tuning, and the QPM and Abort systems dumped the beam at spots we specified. As a result, the residual losses in the Tevatron were far lower than during the days when the Main Ring was the final stage of acceleration.

6. ODH PROBLEMS

There are other problems related to superconducting magnets. They require large volumes of internal magnet cryogen. If a cryogenic relief valve opens on one or more of the magnets there is a possibility that the cryogen will displace oxygen in the tunnel, possibly creating an oxygen deficiency hazard (ODH). The whole cryogenic system is considered to be a pressure vessel. (During the Tevatron’s design stage a considerable amount of attention had to be paid to this by various safety committees.) This in turn makes accesses into these beam enclosures complicated. Fixed oxygen alarms were required throughout the Tevatron beam enclosures.

Anyone accessing the Tevatron tunnel is required to take a personal oxygen monitor that will alarm whenever the oxygen levels get below 19.5%. They also must carry a small tank that will give them 5 minutes of air for escape.

A two-man rule became mandatory for all accesses.
The cryogens also required the laboratory's medical department to certify that all workers who enter ODH enclosures are medically qualified to do so. To this end, a database had to be set up and the Operations Department required use it to check training and medical approval records for every worker before allowing tunnel access.

In addition to all this, moving heavy objects above or around cryogenic components in the tunnel required additional procedures to prevent accidental rupturing of the insulating vacuum or puncturing cryogenic supply lines.

7. OTHER PROBLEMS

1. Four miles takes too long to walk and takes too much time transporting equipment around to complete work, or to interlock, especially when everyone is waiting for beam. So operators and technicians drive the ring in electric golf carts. After a safety analysis was performed and fixed bumpers were added around vulnerable areas to prevent colliding golf carts from rupturing cryo and vacuum systems.

2. Ground faults are much harder to locate unless a cryogenic magnet ruptures its insulating vacuum line and spews its insulation around to be noticed.

3. Vacuum is much harder to leak check in cryogenic magnet systems. The Vacuum technicians need to rely more on time of flight methods for locating vacuum trouble spots. The number of vacuum connections went up a factor of five from the conventional system to the cryogenic vacuum system.

4. If cryogenic magnets warm, cryo-pumping within the vacuum chamber can release contaminates into the vacuum system. These contaminates can then block the smaller apertures in the cryo system causing flow problems. The fix requires a warm up and a decontamination cycle for that part of the ring affected, which typically causes a week down time.

5. We have more rotating equipment, in the form of compressors and expansion engines that require constant attention and higher maintenance.

6. We are more susceptible to power outages. If our cryo equipment is not started within 30 minutes of a site wide power outage or glitch, we are down for a week while we purify and recool the ring. Thunderstorms have a much bigger impact on cryogenic accelerators than conventional accelerators.

7. Control software is more complex and sophisticated due to the complexity of cryo systems, power supply systems, and beam tuning controls.

8. Our cryogenic machines use helium for cooling purposes; it is a non-renewable resource. We have developed methods of capturing gas accidentally lost due to quenches and such, but we must be regularly resupplied.

8. RESPONSIBILITIES

Operators must be trained to work with the fire department for response to any ODH emergency. This requires being medically approved to use the Self- Contained Breathing Apparatus (SCBA) provided by the Fire Department. In addition to all this, the use of cryogenics requires more training for Operations Department personnel due to its controls system.

9. CONCLUSION

Encourage the development of air temperature superconductors.
Cryogenic machines are much more temperamental than conventional machines. Our system uses helium, which is a non-renewable resource. Cryogenic machines require refrigerators, a cryogenics group for maintenance, sophisticated quench protection systems, more time to replace failed magnets, has a bigger impact on operations due to weather conditions, and a much more complex and expensive set of instrumentation is needed for efficient beam diagnoses. And finally, it takes more time to train operators to deal with cryogenic systems and procedures.
WHO OPERATES CRYOGENICS?

Philippe Gayet on behalf of CERN–LHC ACR group
CERN, Geneva, Switzerland

Abstract
Cryogenics systems are strategic components of superconducting accelerators. To ensure the requested quality of this service the organization of the cryogenic operation must be well incorporated into the global operation policy. This paper aims to define the constraints of the cryogenic operation induced by the cryogenic system itself, and by the interference to other systems. The skills of the operation crew are reviewed and some typical operation activities presented. As the operation of such large systems requires a complex organization with maintenance and cryogenic expert teams, several operational structures will be exposed showing their respective advantages and drawbacks.

1. INTRODUCTION TO A LARGE CRYOGENIC SYSTEM: LHC MAIN RING CRYOGENICS

Eight large cryoplants (Fig. 1) will produce refrigeration for the LHC ring. Each plant normally supplies a whole LHC machine sector of about 3.3 km length via a separate cryogenic distribution line (QRL), with interconnections at every basic machine cell length of 107 meters within the arc.

![Diagram of LHC cryogenic system](image)

**Fig. 1: LHC cryogenic system**

The cryogenic system is separated in four distinct entities (Fig. 1). A typical entity is made of (Fig. 1) two cryoplants linked to the distributed cryogenic load located inside the LHC tunnel via a cryogenic interconnection box (QUI) located at a LHC access point (IP).
The 4.5K and 1.8K helium refrigerators constitute a cryoplant and are the main components of the production system. They are delivered and commissioned by industry and integrated by CERN into the cryogenic system of LHC. Figure 2 presents the different components of this system and their interconnections.

Fig. 2: Typical LHC cryogenic system at one interaction point

The following sets of components constitute a refrigerator and are considered as autonomous cryogenic units: \{QSCA, QSRA, QURA\} and \{QSCB, QSRB\} for the 4.5K refrigerator A and B; \{QSCC, QURC\} for the 1.8K refrigerator; \{QUI, QSD, QSV\} are the interconnection boxes, the liquid nitrogen storage and the gaseous helium storage connected to the cryoplants.

There is a right (R) and a left (L) hand sector around each refrigeration system. A sector is composed of different sections namely a regular arc, dispersion suppressors (DS) and long straight sections (LSS) (Fig. 3). The load, per sector, is the QRL, the superconducting magnets, two electrical feed boxes (DFB) controlling the cooling of the magnet current leads, superconducting cavities (at IP4 only) and other cryogenic equipment installed in the long straight sections located near the access points.

The cryogenic equipment installed in the tunnel is fed with helium from the QRL via so-called service modules. About 70% of the cryogenic element are the 107 meters long regular machine cells consisting each of 8 superconducting magnets and their associated QRL and service module. They are 23 such cells and four smaller cells per sector.
2. HOW CRYOGENICS INTERACTS WITH OTHER SYSTEMS

2.1 Dependence on utilities (Water, Power, Air, Control)

These utilities are vital for the cryogenic system. They are developed and maintained by dedicated technical groups and a technical control team monitors them. The knowledge of the cryogenic operator about the interface and the nature of the dependence on these systems is fundamental to develop recovery procedures.

2.2 Interaction with other components of the accelerator

Despite of its status of 'service' the cryogenic system will interact strongly with other components of the LHC. These interactions are not just a binary information exchange but reciprocal physical influences (Fig. 4).

Fig. 3: LHC sector

Fig. 4: Interactions with other accelerator components
2.2.1 Vacuum system

Variations of the temperature level in the QRL or in the magnets will induce outgasing in the vacuum system either in the insulation jacket or in the beam pipe depending where the variation is located. The vacuum degradation in the insulation jacket may lead to a large increase of the thermal losses overloading the capacity of the cryogenic system, limit the maximum beam energy and in extreme cases induce a quench. Degradation of the beam vacuum will shorten the beam lifetime and increase the beam losses.

2.2.2 Magnets

The field quality in superconducting magnets depends on the stability of the temperature control in the cold mass. If the temperature drifts out of the superconducting limit 10 mK above the working point, quenches will be induced leading to a beam dump.

2.2.3 Beam

In the previous paragraphs we have seen that the cryogenic system may affect the beam through the vacuum and the magnet. Reciprocally the beams will also have large impact on the cryogenic system. The beam losses in a cold mass may locally overheat the magnet inducing quenches. In normal operation the beam heat load will vary by a factor of 10 within an inner triplet which will impose the use of feed forward loops to avoid step functions in the cryogenic system.

3. WHAT MEANS CRYOGENIC OPERATION?

To introduce the different skills developed by the cryogenic operation team, this chapter will review several aspects of typical cryogenic operation tasks.

3.1 Operation without beam

3.1.1 Cool down

This operation will follow the annual technical shutdown. Before start of the cooldown the operation team must complete a checkout of the cryogenic system in collaboration with the maintenance team. This checkout will review the applied maintenance procedure and verify weather each component (mechanical, electrical, control,...) is in operation mode.

Once the checkout completed the production system may start. Then the cooling capacity of the cryoplants can be checked as well as the cryogenic distribution line to avoid the warm up of a entire sector in case of problems.

The cooldown of LHC cryogenic components will last 11 days. During this time the operation team will closely observe the temperature trends, evaluate and correct deviations, identify malfunctions and abnormal heat losses. The operation team will also have to manage the logistics for LN2 and LHe supply delivered to the site by several lorries per day.

3.1.2 Quench recovery

Quenches are considered as normal events in a superconducting machine (1 per week at HERA during the first years of operation). Depending on the extension of a quench (from 1 to 4 cells) the recovery time will last between 3 to 10 hours. It is foreseen to have an automatic quench recovery procedure as it was the case for the LEP quadrupoles. But the operators may reduce the recovery time and the impact of such events by acting on the power capacity of the refrigerators or by giving priorities adapted to the request of the beam operation team.

In addition the cryogenics operators must closely cooperate with the beam operation team to reduce the number of quenches.
3.1.3 Recovery after utilities or cryogenic failures

These events are common in cryogenic operation (four times per cryoplant and year for LEP2). In order to improve the recovery time and the operation efficiency the cryogenic operator will have to:

- Identify the failure
- Cooperate with the utility operation to take the actions reducing the downtime to the minimum (for utility failure)
- Solve the problem by the intervention of the operator himself or requesting the intervention of the cryogenic maintenance team for major cryogenic failures
- Restart the cryogenic system as fast as possible. The cryogenic system acts as a downtime amplifier and the expected downtime for LHC will be 6 hours + 3\(x\) (time of the stop duration).
- Report all actions and important issues to prevent new occurrence of identical trouble.

In case of a main (400 kV) power cut, the eight cryoplants will be stopped. One expects that, even with a fully automatic control system, one operator per cryoplant is needed to guaranty a rapid restart. During LEP operation it was noted than after a long period of running at a stable working point such a brutal event has often consequences on minor components of a cryoplant which may impose a restart under degraded conditions.

3.2 Operation with beam

While the accelerator is working with beam, the cryogenic operation team will monitor and optimize the cooling capacity to:

- Improve the stability of the physical cold mass parameters, as a very tight temperature margin (+/-5 mK) has to be guaranteed
- Tune all control parameter to reject any perturbations.
- Check if the temperatures remain within the operational margin to detect and correct malfunctions.
- Reduce the power consumption. (5.5 MW per sector of electrical consumption at nominal)

4. WHO IS IN CHARGE OF THE CRYOGENIC OPERATION?

According to the tasks described in Chapter 4 we can summarize the skills of the operators as follow:

- Understand the cryogenic environment (utilities, control, etc.)
- Understand the interaction with other systems
- Understand the cryogenic system behavior
- Be able to monitor and correct the system with beam operation
- Work out the beam operation period
- Be able to deal with the cryogenic hardware
- Be able to cooperate with the maintenance team

It appears clearly that the creation of a cryogenic operation structure is mandatory.

4.1 The cryogenic operation structure

Figure 5 presents a possible structure for the cryogenic operation:
The cryogenic operation team will be in charge of monitoring and optimizing the cryogenic system and the operational procedures for interventions and recovery. It will be the first line intervention on failure. Finally it will coordinate the maintenance and upgrade work with the accelerator operation needs.

The cryogenic expert team is constituted of specialists for the different aspects of the cryogenic system (refrigerators, compressors, process, controls, mechanics, ...). This team will support the operation team for optimization and will develop upgrades for continuous improvement of the system. The task of this team is essential for the first years of operation.

The cryogenics maintenance & support teams constitute the second line intervention in case of major failures. They will have to manage all maintenance work with the feedback of the operation team. Moreover these teams will have to implement modifications proposed by the expert team mainly at the beginning of the operation or for later upgrades.

5. INTEGRATION SCENARIO

There are several possibilities to integrate the cryogenic operation team in the global operation policy. We consider that the cryogenic expert team and the cryogenic maintenance team shall exist in all cases. Possible solutions with their advantages and drawbacks are presented below.

5.1 Independent cryogenic operation team

The intuitive solution is to create a cryogenic operation team independent of the existing teams for accelerator operation and technical monitoring in charge of the utilities survey.

In this case the cryogenic expertise may be partly incorporated in the operation team. This team will be very efficient in developing better cryogenic operation procedures and will be able to optimize the operation in a shorter time.

The day to day organization will be easier and dedicated to cryogenics and will permit the integration of the operation of other cryogenic systems of the laboratory.

The treatment of the interaction of cryogenics with other components will, however, require a close collaboration with the accelerator operation team which may imply a certain geographical proximity of the teams.

Shift operation will probably be needed for the startup of a machine such as LHC. This will imply a large crew which has to be found in accordance with the human resource policy of the laboratory.

5.2 Integration in the accelerator operation team

In this case the operation of the cryogenic system will be done by the accelerator operation crew.

The advantage is a better coupling between the cryogenic and accelerator operation. All interaction between the cryogenic system and others are mastered by the team. This team can easily develop strategies to limit their impact on the machine behavior.

In addition, cryogenic operation and accelerator operation are sharing human resources.
As the background of the two teams is rather different, an acculturation of the accelerator team to cryogenic problems is needed. For this reason the team will request a stronger expert support during recovery and degraded operation and will mainly depend on the cryogenic expert to establish the procedure, to optimize the cryogenic system and to interact with the maintenance team.

The cryogenic operation is often scheduled out of the normal accelerator operation.

5.3 Integration in a technical monitoring team
In this case the team in charge of monitoring utilities also performs the cryogenic operation.

The first benefit of such a solution will be the good coupling with other technical services, which will imply a better coordination for intervention on utilities reducing the recovery time for such events. The operators’ skills and background are quite similar and the training to operate cryogenic systems will be straightforward. In addition, this team will be in direct contact with the accelerator which will be an asset to its motivation and the resources will be shared.

However, as the operators will have many systems to monitor, less attention will be given to the cryogenic system and some degradation may not be recognized. In this case a strong cryogenic expert support will be needed to optimize the cryogenic system. To handle the interaction with other systems, the cooperation will have to include the accelerator team and the cryogenics experts.

5.4 Outsourcing to industry
To face the shortage in human resources, cryogenic operation may be partly or totality outsourced. The problem is to decide what is strategic in the cryogenic operation and cannot be outsourced.

If the operation team is outsourced, the cryogenics will be disconnected from the other operation teams which will imply a strong cryogenics expert support, and an operation interface team which coordinates the activities. With the time the operation expertise may be lost and a strong dependence on the external subcontractor will be created.

Outsourcing should not mean hiring missing staff but procuring a service and the quality estimators of this service are very difficult to establish. Outsourcing of the maintenance is probably easier to follow, as the work can be well defined and controlled by means of a maintenance plan.

6. CONCLUSION
The integration of the cryogenic operation team into the global operational policy must be addressed with caution, and be adapted to the nature of this operation, the human resources and the financial constraints.

The operational structure may change during the lifetime of the accelerator, starting with a strong and dedicated cryogenic operation team and later-on joining other operation teams.

As Cryogenic Operation is a strategic component of a superconducting accelerator such as LHC, the outsourcing of the cryogenic operation is a managerial and political decision which has to be weighted.

7. ACKNOWLEDGEMENTS
I would like to thanks S.Claudet, Ph. Lebrun, L. Tavian, L.Serio for their contribution to this paper and the LEP2 operation crew with whom I have spent seven exciting years running the cryogenic system.
INTERLOCK AND PROTECTION SYSTEMS FOR
SUPERCONDUCTING ACCELERATORS: MACHINE PROTECTION
SYSTEM FOR THE LHC

K.H. Meß and R. Schmidt
CERN, Geneva, Switzerland

Abstract
The protection of the LHC accelerator has to work under all circumstances, with and without beam. Several sub-systems, such as beam dump systems, beam loss monitors, magnet protection, and powering systems etc. are combined coherently with some dedicated hardware as 'glue' to form the machine protection system. The structure, some aspects of the hardware, and in particular the interfaces to the other systems are described.

The impact of the machine protection to commissioning and operation of the LHC has been recently discussed in one half-day session at the LHC Workshop in Chamonix. This write-up is identical to the report by K.H.Mess that is included in the proceedings of the Chamonix workshop [1]. During the session at Chamonix Workshop seven presentations were given that are related to machine protection:

• Mechanisms for beam losses and their time constants, Oliver Brüning.
• Beam losses at HERA - is everything understood? Mark Lomperiski (DESY)
• How to use Beam Loss Monitors at the LHC? Helmut Burkhardt
• The Quench Protection System and its interface to Machine Protection, Felix Rodriguez-Mateos
• Architecture of the Machine Protection System, Karl-Hubert Mess
• Information exchange between beam dumping system and other systems, Etienne Carlier
• What data is required to understand failures during LHC operation, Robin Lauckner

The summary of the session is also included in [1].

1. INTRODUCTION
The LHC is a complex accelerator operating close to the limits, both as far as beam energy and beam densities are concerned. Major faults in the complex equipment will result in long repair times. To optimise the operational efficiency of the accelerator, accidents should be avoided and interruptions should be rare and limited to short time. Hence a system is needed that pre-vents dam-age to the magnets, the cables and the power-leads, minimises damage due to irradiation caused by beam losses, and provides the necessary tools to implement a consistent and congruent error and fault tracing, through-out the machine.

Machine protection is not an objective in itself; it is a mean to maximise operational availability by minimising time for interventions and to avoid expensive repair of equipment and irreparable
damage. The proposal, presented here, is based on work done for the Tevatron, HERA_p, RHIC and the string tests at CERN [2, 3, 4, 5]. As an evolution of the ideas presented at the Chamonix_X workshop [5] it has been discussed since with numerous colleagues from SL-BI, SL-BT, SL-PC, LHC-ICP, and ST-AA. It has been presented to the DEWG, IWG, and the AIWG working groups as well as to the SL-TC, the TCC, the MAC, and at other occasions.

The interlock and access system for personal safety does in principle not depend on the machine protection system. The two systems are, however, related.

2. THE CHALLENGE

Both, the stored magnetic energy and the energy stored in the beams are unprecedented. Moreover, both systems are coupled. Obviously, faults in the magnet system will in general often result in a beam loss, which in turn may induce quenches. The machine protection system has, however, be made to accept that at times the magnets will be powered, without beam in the machine. The opposite case is not possible.

At nominal operating current, predominately the dipole magnets store a large amount of energy. The LHC magnets are powered separately in each of the eight sectors in order to reduce the energy stored in a particular electrical circuit. Still, the energy in each sector of the LHC amounts to 1.29 GJ, sufficient to heat up and melt 1900 kg of copper [7].

During operation without beam, the large energy stored in the magnets presents the main risk. Various reasons can lead to an uncontrolled energy release. Magnets, superconducting bus bars, current leads, or cryogenic infra-structure could in such a case be destroyed. In case of a failure the magnetic energy has to be extracted. Due to the large inductance a response time in the order of 10 ms to abort the power is acceptable for most elements (such as all superconducting magnets).

Each beam stores energy of up to 0.35 GJ, equivalent to the energy for warming up and melting 515 kg of copper. A sophisticated collimating system protects the magnets from beam losses.

If the operation of the machine becomes unsafe and beam loss has already been observed by the beam loss monitors, or is imminent due to equipment failure, the beams have to be dumped as soon as possible, in order to prevent radiation damage, quenches, and downtime. However, due to the size of the LHC at least 110 μs are required on average to request a beam dump.

The large number of vital components will be a major challenge. More than 8000 superconducting magnets, including about 2000 large dipole and quadrupole magnets, and 6000 corrector magnets, are powered in about 1800 circuits. Several thousand electronic channels may, in case of failure, force a beam dump. To limit the number of superfluous aborts below one per fortnight, the mean time between failure (MTBF) must exceed 100 years for each channel!

The machine downtime depends on the type of faults and their frequency. It could be between two hours and several weeks for one incident. Major accidents may include the partial destruction of a magnet. To warm up the neighbourhood, the repair, and the cool down will require some weeks. Should no spare magnets be available, the repair may last many months.

3. ARCHITECTURE OF THE MACHINE PROTECTION SYSTEM

3.1 General aspects

Some general requirements have to be considered for the machine protection system:

• Protect the machine: In case of fault the necessary steps shall be taken to dump the beam and to discharge the energy stored in the magnets in a safe way.

• Protect the beam: The system shall not generate unnecessary beam dumps.
• Provide the evidence: The system shall help to identify the initial fault, in case of beam dump or power failure.

• Improve the operation: The status of the system must be transparent to the operator at all times.

• Enable tests: Almost all functions must be remotely testable.

This can be achieved by:

• Hardwired abort links protect the equipment (Hard Abort).

• Soft aborts, possibly via computer links, improve the operation efficiency; they may be disabled or may fail.

• The number of channels that may provoke an abort will be minimised.

• The same structure across different sub-systems in the abort chain will be used.

• All inputs can be simulated or bridged. However, in such a case ‘permits’ are also simulated and not passed to destinations outside of the system.

3.2 General Architecture

The architecture of the machine protection system is derived from the structure of the LHC and from operational requirements. It consists of a distributed, globally acting Beam Interlock System that informs the Beam Dump System if any unsafe situation is detected, and of locally acting, distributed, Power Interlock Systems. They cause a safe discharge of the energy stored in the magnet system in case of a quench, or other failures. Interfaces between the Power Interlock Systems and the Beam Interlock System ensure the dumping of the beams, if necessary. A Post Mortem System described elsewhere [8] records data from various systems to understand the cause of a fault leading to a beam dump or power abort.

3.3 Architecture of the Power Interlock

The eight sectors in the LHC consist (Version 6.2) of 44 continuous, largely independent cryostats [9], and some warm magnets. Powering of one electrical circuit is al-ways limited to one of those cryostats or half-insertions.

The powering system for each electrical circuit includes power converters, (warm) cables from power converters to the current feedthroughs, the current feedthroughs, superconducting bus bars for the current distribution, and finally the superconducting magnets.

In case of a fault in one of the cryostats the energy of some or of all electrical circuits in this cryostat has to be discharged. Each cryostat will have a local Power Interlock System. Hence, any cryostat can be powered irrespective of other cryostats. An example of the architecture between IP1 and IP8 is given in Fig. 1.

LHC contains 36 short cryostats requiring one Power Permit Controller (PPC) each, preferentially located close to the power converters. Warm magnets on either side of an interaction point (IP) are treated as if they form an additional ‘continuous cryostat’.

The eight long arc cryostats span the major part of a sector and are electrically fed from both sides. The energy extraction systems for the MQ magnets are in the even points. The MB magnets are discharged at both ends of the arc cryostat. Hence the long arc cryostats need Power Permit Controllers (PPC) on both sides and a communication link in between. The quench detection for main magnets in the arc cryostats comprises about 200 units distributed along the arc.

About 100 power converters installed in the tunnel power the orbit correctors in one sector.
In total, almost 60 Power Permit Controllers (PPC) are required. They will also be connected to the controls network and the timing system.

### 3.4 Architecture of the Beam Interlock

There will be one Beam Interlock System for the LHC. Right and left from each IP one Beam Permit Controller (BPC) will be installed (see Fig. 1). These controllers are connected to two fast, optical links (Beam Permit Loops) running at 10MHz (see Fig. 2). The two links distinguish between beam I and II. When a link is broken, the corresponding beam is extracted into the beam dump by the Beam Dump System. In addition, a computer connection to the BPC for monitoring, testing and post mortem analysis is required.

![BEAM PERMIT LOOP](image1.png)

**Fig. 1:** Power and Beam Protection System between IP1 and IP8

![BEAM DUMP CONTROLLERS](image2.png)

**Fig. 2:** General layout of the Beam Interlock System
Note that Beam Permission is a necessary but not sufficient condition for beam injection. In order to inject beam, additional conditions have to be met.

Power Permit Controllers report their state to a BPC in the vicinity.

3.5 Inventory of the Machine Protection System

The Machine Protection System consists of:

- 16 Beam Permit Controller BPC,
- global fast links between the BPC and the Beam Dump System,
- a set of 52 (v. 6.2) Power Permit Controller (PPC) for the cryostats,
- some PPC for the warm magnets
- a computer network connection to each controller.

In addition the Machine Protection System makes use of features provided by the Quench Protection System and Power Control System:

- a set of 8 arc links to collect the quench messages (Quench Loop),
- a set of 8 arc links to fire heaters (Heater Activation Link),
- and field-busses, joining the controls for quench detectors and heater power supplies and the power converters in the arc.

Some details about the Beam Interlock System (BPC and links) and the Power Interlock System (PPC and links) are described below. More information will be presented in a forthcoming report [10].

4. COMPONENTS OF THE POWER INTERLOCK SYSTEM

A Power Permit Controller monitors the powering status of one cryostat. Depending on the cryostat, it monitors the elements in a few electrical circuits for short cryostats, and of some ten electrical circuits in the long arc cryostat. Therefore a modular design is pro-posed. Similar controllers will monitor the powering of all warm magnets in one half-insertion.

An electrical circuit is connected to the PPC through a dedicated channel, identifying the type of the electrical circuit. With respect to the magnet protection, the circuits are divided into two classes:

- Main magnets: Circuits that include magnets with large stored energy. A quench is likely to affect other magnets and electrical circuits. Therefore all magnets in the cryostat will be de-excited (Cryostat Power Abort).
- Other magnets: Circuits that do not include magnets with large stored energy. Normally, a quench of an element in such circuit is contained in that element.

With respect to the impact of a magnet fault to the beams a different distinction has to be applied. Depending on the state of the accelerator, some electrical circuits may not be vital (‘critical’) for machine operation. It would be inappropriate to dump the beams, if such a circuit quits functioning. Hence, some circuits are ‘critical’, i.e. required for beam operation under all circumstances, and some are only sometimes required. Switches set this classification.

4.1 Quench of a main magnet

The electrical circuit to be monitored defines the input and output signals for a given channel. For example a main magnet circuit will have a Quench Loop.

In case of a quench, the loop is opened by the quench detector. Since a main magnet quench will cause a Cryostat Power Abort, the discharge switches extract the energy from the main circuits in this cryostat. In addition the corresponding power converters are switched off by raising the Power
Converter FAST ABORT signal and by removing the corresponding Power Converter PERMIT (constant current outputs). All other circuits of the cryostat are discharged by the PC controller or by a Discharge Switch Trigger command.

The power converter informs the PPC of a fault by dropping the PC OK signal. If the fault requires a fast discharge, the PPC sends in addition a DISCHARGE REQUEST to the PPC (by interrupting a current loop) that activates the discharge switch for this circuit.

In the unlikely and worst case that a discharge switch fails to open after a request (Switch Open Fault), a number of selected heaters will have to be fired by the PPC using the Heater Activation Link.

For the triplet cryostats, the heaters of the MQX magnets are fired in case of a discharge request, since there is no system to extract the energy and the time constants for slow ramp down are too large.

In all cases both signals to the BPC (ALL CIRCUITS OK and CRITICAL CIRCUITS OK) will be switched off.

4.2 Quench of a low energy magnet
Circuits that have little energy stored require only a Quench Loop, a PC OK link, a PC PERMIT link, and a PC ABORT link. If one of the quench detectors for the circuit indicates a quench, it breaks the Quench Loop. The controller switches the power converter off (PC PERMIT, PC ABORT). If the circuit has an extraction resistor, the energy is extracted.

In case of a power converter fault, a signal is transmitted to the controller in order to record the failure.

It is not required to discharge magnets powered in other electrical circuits. In all cases the ALL CIRCUITS OK signal to the BPC is switched off. Internal readable jumper settings determine, whether the electrical circuit in question is considered ‘critical’. If this is the case, also the CRITICAL CIRCUITS OK signal is switched off.

4.3 Interfaces to other systems
In general, the PPC has per electrical circuit the following signals/links:

- one Quench Loop,
- one PC OK input,
- one power permission link (output),
- one PC Fast Abort link (output),
- one PC Slow Abort link (output),
- one Current Low input (I< I_access).

The PPC of the long arc cryostat requires one additional I/O section for the three main magnet circuits with:

- one Quench Loop connecting the PPCs on both sides with all quench detectors for main electrical circuits, and the discharge switches,
- three PC OK inputs,
- three PC PERMIT outputs,
- three PC Fast Abort outputs,
- three PC Slow Abort outputs,
- three Current Low signals (in-put),

175
• three NO DISCHARGE requests (input),
• three Discharge Switch Open Fault (input),
• three DISCHARGE TRIGGER links. (The second MB discharge switch is operated by the second PPC.)

All electronics of the Power Interlock System is connected to the control system. Status and memory is readable at any time.

The computer connection to the control system is established via the VME bus, a suitable processor board and VME. It might be considered to employ a local display unit and a keyboard for debugging.

Electronics that is directly connected to the Power Interlock System, like quench detectors, must be connected to the control system, either via Ethernet alone or via fieldbus and Ethernet.

5. COMPONENTS OF BEAM INTERLOCK SYSTEM

The Beam Permit Controller (BPC) combines the messages from different sources to interrupt the 10 MHz pulse trains in the optical fibres of the Beam Permit Loop (BPL) in case of a fault condition. The absence of a pulse train will be interpreted as BEAM DUMP command for the corresponding beam.

The 10 MHz trains are produced in one BPC only (IP6L, set by a jumper). The setting of the jumper (master/slave) is visible at the front panel and readable from the computer. There will be three types of inputs to the BPC. The BPL input will be used to feed the BPL output, unless one of the unconditional inputs indicates a fault condition or one of the conditional inputs does so, provided it is not masked.

All input states and the output state are continuously sampled and stored into a memory as well as displayed life on the front panel.

Table 1: Input signals to the Beam Permit Controller

<table>
<thead>
<tr>
<th>Name</th>
<th>Conditional(^a)</th>
<th>Name</th>
<th>Conditional</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF system</td>
<td>Yes</td>
<td>Collimators</td>
<td>No</td>
</tr>
<tr>
<td>Loss monitors I</td>
<td>Yes</td>
<td>Access system OK</td>
<td>No</td>
</tr>
<tr>
<td>Loss monitors II</td>
<td>Yes</td>
<td>Extraction system OK</td>
<td>No</td>
</tr>
<tr>
<td>Beam excursion</td>
<td>Yes</td>
<td>Beam Injection Permit</td>
<td>No</td>
</tr>
<tr>
<td>Arc cryostat, All Circuits OK</td>
<td>Yes</td>
<td>Vacuum valves OK</td>
<td>No</td>
</tr>
<tr>
<td>triplet cryostat, All Circuits OK</td>
<td>Yes</td>
<td>spare</td>
<td>No</td>
</tr>
<tr>
<td>Q3 cryostat, All Circuits OK</td>
<td>Yes</td>
<td>arc, Critical Circuits OK</td>
<td>No</td>
</tr>
<tr>
<td>Q4 cryostat, All Circuits OK</td>
<td>Yes</td>
<td>triplet, Critical Circuits OK</td>
<td>No</td>
</tr>
<tr>
<td>Q5 cryostat, All Circuits OK</td>
<td>Yes</td>
<td>Q3, Critical Circuits OK</td>
<td>No</td>
</tr>
<tr>
<td>Q6 cryostat, All Circuits OK</td>
<td>Yes</td>
<td>Q4, Critical Circuits OK</td>
<td>No</td>
</tr>
<tr>
<td>Q4D2 cryostat, All Circuits OK</td>
<td>Yes</td>
<td>Q5, Critical Circuits OK</td>
<td>No</td>
</tr>
<tr>
<td>4 spares</td>
<td>Yes</td>
<td>Q6, Critical Circuits OK</td>
<td>No</td>
</tr>
<tr>
<td>Experiment OK</td>
<td>No</td>
<td>Q4D2, Critical Circuits OK</td>
<td>No</td>
</tr>
<tr>
<td>Loss monitors at collimators</td>
<td>No</td>
<td>Warm magnets</td>
<td>No</td>
</tr>
</tbody>
</table>

a. Preliminary assignment
The control system sets the masks, senses the memory state (frozen or life) and performs the readout. The fail-safe and reliable inputs are described below.

Each Power Permit Controller provides two signals to the BPC:

- A fault in one of the main magnets, such as dipole or quadrupole magnet, would always cause a total beam loss. After such fault the signal CRITICAL CIRCUITS OK would disappear, and both beams would be dumped.

- A fault in a corrector magnet, such as a spool piece magnet or orbit dipole corrector, might cause a beam loss. After such fault the signal ALL CIRCUITS OK will disappear. This may imply a beam dump, depending on the machine status.

In case of circulating beams, the breakdown of the BEAM DUMP SYSTEM presents a major hazard. The beams must be dumped, as long as the system is still capable to do so. The signal is unconditional.

Inputs from the LHC experiments are foreseen. The details have still to be discussed.

If the RF system does not work correctly, the beam will debunch. It will not be possible to dump the beam properly without unacceptable beam losses. A signal from the RF system is therefore required to dump the beam if a debunching is to be anticipated or if the feedback is going to fail.

There will be beam loss monitors distributed around the ring, with a set of monitors close to each quadrupole, as well as monitors close to the collimators for beam cleaning. The signature of a beam loss that should request a BEAM DUMP remains to be established.

The input to the Beam Interlock System would be via one of the BPC close to the insertion. It needs to be understood if a link from the alcoves to the BPC is required. Alternatively, the beam loss monitor system might be subdivided into eight sections. In this case one input per octant or sector might be used.

The access system for the protection of people needs to follow the legal requirements. It needs to be completely separate from the Machine Protection System. However, there is an interface between the state of the access system and the actions to be taken by the Machine Protection System. The Machine Protection System will automatically request a beam extraction in case of an access violation. For safety reasons, a separate link from the access system to the BEAM DUMP SYSTEM is required.

There will be some elements to prevent the accidental injection and circulation of a beam, such as valves in the beam tubes, collimators and some magnets in the transfer line. Such systems are activated if ACCESS to the tunnel or the galleries should be given, or if there is an ACCESS VIOLATION. Considering valves or collimators, an injection can not be allowed unless they are out of the beam.

Two Beam Permit Loops run around the entire accelerator. The signals need to be transmitted as fast as possible to the BEAM DUMP SYSTEMS. The number of access points to the link is limited to 16. Hence, a transmission using optical fibres seems appropriate. The state of these loops is available for local distribution.

All electronics of the Beam Interlock System is connected to the control system. The computer connection to the control system is established via the VME bus, a suit-able processor board and Ethernet. It might be considered to employ a local display unit and a keyboard for debugging. All electronic connected to the computer link has to have a post mortem memory to record all essential signals. The computer link can also provide the machine status and the timing information, as well as operator commands.
6. ACKNOWLEDGEMENTS

The authors thank all colleagues that contributed to the discussions and the LIIC management for their support.

References


[8] R. Lauckner, What data is required to understand failures during LHC operation, article published in Ref. [1].


OPERATIONAL CHALLENGES OF HERA'S SUPERCONDUCTING PROTON MACHINE

M. Bieler and B. Holzer
DESY, Hamburg, Germany

Abstract
Compared to its luminosity energy of 920 GeV HERA's superconducting proton machine has a rather low injection energy of 40 GeV. During the cycling procedure of the superconducting magnets eddy currents are induced in the superconducting cables. These persistent currents decay over hours during injection and ramp. The magnetic field components driven by these persistent currents are detrimental to the beam and therefore have to be measured and compensated. In this paper the methods are described to adjust the beam energy, the betatron tunes and the chromaticity both during injection and on the ramp.

1. HERA
HERA, the 'Hadron Electron Ring Accelerator' at DESY, is an electron proton collider for high energy physics. Two rings are placed in one tunnel of 6.3 km circumference. The superconducting proton ring has an injection energy of 40 GeV and a flat top energy of 920 GeV. Typically 100 mA are stored in 180 bunches. In the electron ring (12 – 27.5 GeV) typically 50 mA of either electrons or positrons are stored in 189 bunches with a typical spin polarization of 60%.

In the four straight sections of the HERA ring four experiments are making use of the HERA beams: Both H1 and ZEUS use colliding beams to probe the structure of the proton. HERMES uses the polarized electron beam and a polarized internal gas target to investigate the spin structure function of the proton. HERA-B uses a thin wire target in the halo of the stored proton beam to look for CP-violation.

2. HERA'S SUPERCONDUCTING PROTON MACHINE
Between the injection energy of HERA's proton machine and the flat top energy there is a factor of 23 in energy, and accordingly a factor of 23 in current density in the cables of the main dipoles and quadrupoles. This results in a low current density at injection, which gives much room for persistent currents in the superconducting cables. At 40 GeV the field contribution of the persistent currents to the dipole field is $5 \times 10^{-3}$. The persistent currents have decay times of the order of a few hours.

Figure 1 shows the proton energy and beam current from the end of a luminosity run to the beginning of the next run. On the horizontal axis the time is given in hours. It can be seen that it takes approximately 35 minutes to fill the proton machine. After injection energy has been reached, a few low current test injections a needed to adjust parameters like beam energy, betatron tunes, chromaticity and injection orbit. Afterwards HERA is filled with three consecutive fills of the preaccelerator PETRA. Then it takes another 25 minutes to ramp up the beam energy. During injection the field components resulting from the persistent currents are constantly changing. At the beginning of the energy ramp persistent currents are induced again.
Fig. 1: Data from the HERA archive, showing a refill of the machine from beam dump to luminosity in 2 hours

3. PERSISTENT CURRENTS

Due to the low current density at injection energy there is much room for persistent currents in the cables of the main dipole and quadrupole magnets. Every change in the current driven by the magnet power supply induces magnetic fields in the cables, which then do induce electric eddy currents in the cables. Figure 2 shows a sketch of a strand of superconducting cable with the main current IMAIN, the main magnetic field B and the induced persistent currents I_{PC}.

Fig. 2: Sketch of the electric and magnetic fields inside the superconducting cable

As the cable is superconducting, these eddy currents (or persistent currents) decay slowly with typical decay times on the order of hours. Therefore the corresponding magnetic fields (counteracting the main field) decay on the same time scale. For eddy currents perpendicular to the main current the resistance of the superconducting cable is higher than for the main current, as the cable is made up of thousands of small strands. Figure 3 shows a photograph of the cable.
Fig. 3: HERA's superconducting cable is made up of 24 wires, 1230 filaments each, with a diameter of 14 microns.

The field components driven by the persistent currents are mainly dipole and sextupole fields. The contribution of the persistent currents to the dipole field at 40 GeV is \(5 \times 10^{-3}\), the contribution of the persistent currents to the chromaticity at 40 GeV (\(\zeta_{x,PC} = -275\)) is about 5 times that of the natural chromaticity (\(\zeta_x = -44\)) [1].

At the beginning of the proton energy ramp, persistent currents are induced again, leading to nonlinear changes of some field components on the ramp. At higher energies, as the current density in the cable rises, the persistent currents become smaller, until there is no more room for persistent currents in the cables.

4. **DIPOLE AND SEXTUPOLE CORRECTION DURING INJECTION AND RAMP**

Two HERA dipole magnets (one from each production series) are installed outside the ring, but powered in series with the ring dipoles. In these reference magnets a set of hall probes, NMR probes and rotating coils are used to measure the dipole and sextupole fields during injection and on the first part of the ramp. From 150 GeV on the sextupole component in the dipole magnets becomes so small compared to the main dipole field that the measurement is no longer needed.

From the measured field components corrections are calculated and applied to the horizontal corrector coils and the sextupole magnets in the ring.

5. **ADJUSTING THE INJECTION ENERGY**

The contribution of the persistent current driven dipole field to the main dipole field at injection energy is of the order of \(5 \times 10^{-3}\) (i.e. 10\(^{-3}\)). Depending on the history of the magnet cycle and the time between the magnet cycle and the injection, the uncorrected dipole field differs from injection to injection. Therefore after each magnet cycle a low current test injection is used to measure the energy of the injected beam relative to the stored beam. If the energy of the injected beam differs from the energy given by the dipole field, the injected bunches will perform synchrotron oscillations around their nominal bunch position. The amplitude of the synchrotron oscillation is measured with a fast beam current monitor and a fast oscilloscope. If the oscilloscope is triggered with the theoretical bunch position, the difference in time between a bunch signal taken a quarter synchrotron oscillation after injection and a signal of the stored bunch is a measure of the energy difference between injected beam and the energy given by the dipole field. With a known calibration factor the dipole field can be adjusted to the energy of the injected bunches. The smallest possible steps in dipole current correspond to
relative energy changes of $10^{-4}$. In order to avoid hysteresis effects and additional persistent currents in the main dipole magnets, the integral field of all horizontal corrector magnets is used instead with a minimum step size corresponding to a relative energy change of $4 \times 10^{-6}$.

For each proton injection the beam energy is adjusted in three steps: First the sum of the field from the reference magnets plus the field from the horizontal correctors is adjusted to the last known good value. Then a test beam with low current is injected; the energy is measured and corrected. Then, as the persistent currents in the reference magnet decay, the horizontal correctors are automatically adjusted to compensate for the changes in dipole field as long as the beam is at injection energy.

6. BETATRON TUNES

As there are no major quadrupole components in the fields driven by the persistent currents, there is no online tune correction at injection. Before beam is injected, the betatron tune quadrupoles are set on the last known good value. After a low current test injection the tunes are adjusted manually. When the beam energy is ramped up, there is a threefold ‘tune controller’: The currents of the tune quadrupoles are changed linearly from file to file (for 40 GeV, 70 GeV, 150 GeV, 300 GeV, 680 GeV and 920 GeV there are files containing all magnet currents for stable operation at these energies). Deviations from the linear behavior are recorded on typical ramps and applied on the following ramps. Last but not least the operator controls the tunes manually.

7. CHROMATICITY

As the sextupole components driven by the persistent current decay during injection, there is an online chromaticity correction using the field data from the reference magnets. First, before injecting beam, the two families of sextupoles are set on the last known good values. After injection of a low current test beam, the chromaticity is adjusted to $+3 \pm 1$ by an automated procedure (change of the rf frequency, measurement of the tune deviation). Then the online sextupole correction keeps the chromaticity constant during injection. When the beam energy is ramped up, persistent currents and therefore sextupole components are reinduced. On the ramp there is a fourfold ‘chromaticity controller’: The currents in the sextupole magnets are changed linearly from file to file. From 40 GeV to 150 GeV the online correction compensates for the nonlinear field changes measured in the reference magnets. From 150 GeV on deviations from the linear behavior are recorded on typical ramps and applied on the following ramps. Last but not least the operator controls the chromaticity manually by looking at the betatron tune spectra. A flat tune peak is a sign for a chromaticity well above +3, which may course bad beam lifetime. A very sharp peak is an indication for low chromaticity approaching zero. Here the chromaticity should be increased immediately to avoid beam instabilities.

8. ACKNOWLEDGEMENT

We would like to thank C. Montag for carefully reading the manuscript.

References

OPERATING ATLAS; THE WORLD'S FIRST SUPERCONDUCTING HEAVY-ION ACCELERATOR

G.P. Zinkann
Argonne National Laboratory Argonne, Illinois 60439 USA

Abstract
ATLAS (Argonne Tandem Linear Accelerator System) has been providing heavy-ion beams for Argonne National Laboratory's Nuclear Physics Heavy-Ion Program for the past 23 years. Over time we have learned the special needs that this superconducting machine requires, such as; how to cope with power bumps, safety issues involved with cryogens, high-Q resonant cavities, and mechanical vibration. These are just a few of the challenges that must be addressed to operate this superconducting accelerator. This paper shall discuss the nuances that has made ATLAS a world-class accelerator.

1. INTRODUCTION

ATLAS is the world's first superconducting RF linear accelerator for heavy ions. First beam was accelerated through a portion of the 'booster linac' section in 1978. Today ATLAS is a National User Facility. More than 60% of the experiments performed at ATLAS are for groups outside of Argonne National Laboratory. The accelerator operates twenty-four hours a day, seven days a week. Annually ATLAS achieves approximately 6000 hours of beam on target with over 90% reliability.

Fig. 1: Layout of the ATLAS Facility
Heavy-ion beams ranging over all possible elements, from hydrogen to uranium, can be accelerated to energies as high as 17 MeV per nucleon and delivered to one of three target areas. The beams are provided by one of two 'injector' accelerators, either a 9 million volt (MV) electrostatic tandem Van de Graff, or a 12-MV Positive Ion Injector (PII) comprised of a low-velocity linac and Electron Cyclotron Resonance (ECR) ion source. The beam from one of these injectors is sent on to the 20-MV 'booster' linac, and then finally into the 20-MV 'Atlas' linac section.

The ATLAS accelerator is constructed with six different superconducting resonator designs. The PII section consists of a range of low velocity (beta = 0.009 – 0.037 c) quarter-wave resonator structures, and the Booster and Atlas sections are comprised of superconducting split-ring resonators with a beta = 0.06 c and 0.105 c. Figure 2 lists the details of each resonator class. There are sixty-four niobium superconducting resonators at ATLAS, housed in fourteen separate cryostats units.

**Fig. 2: ATLAS Resonators and their parameters**

### 2. Operation Issues

#### 2.1 Superconducting Accelerating Resonators

The heart of ATLAS is the superconducting (SC) cavity. The RF linac is based on short, high-gradient SC cavities closely interspersed with short, high field (6-8 T) superconducting solenoids. A benefit derived from a SC linac constructed in this configuration is that the rapid alternation of strong radial and short, high-gradient longitudinal fields maintains the beam quality through the machine [1]. In addition, each accelerating cavity is independently phased. The independent phasing, intrinsic to a SC cavity array, allows the velocity profile to be varied and permits acceleration of a large range of charge-to-mass ratio ions. This makes optimum use of the maximum voltage and enables higher energies for the lighter ions.

Independent phasing also provides the capability to configure the machine in such a way as to compensate for a non-functioning resonator. By having the ability to skip over a non-functioning resonator, machine reliability is greatly improved. Independently phased resonators are in essence individual accelerators. Each one has to be controlled separately, but must stay phased locked within one degree of each other. The complexity of tuning an accelerator like ATLAS would be very difficult without the use of modern computer systems. In addition, an independently phased array like ATLAS requires many more control elements. When building a control system of this intricacy there must be a high level of reliability if one wants to achieve 6000 hours of beam on target each year.

Because the RF power requirements for SC cavities are low, CW operation is cost effective. The low RF losses of SC cavities also enable large apertures and high field gradients. The accelerating field in these cavities ranges from 2.8 MV/m to as high as 5 MV/m.
Superconducting resonators have several unique characteristics that affect operations. They are vibration, multipacting barriers, and electron loading. The effects of these are discussed below.

2.2 Vibration

In all resonant cavities, ambient acoustic noise will excite mechanical vibration modes that cause fluctuations in the resonator's eigenfrequency. In room temperature resonant cavities these fluctuations are much smaller than the resonator bandwidth and do not affect the RF phase. However, due to the low RF losses in superconducting cavities the bandwidths are typically a few tenths of a hertz. In an accelerator environment it is difficult to reduce the coupled mechanical vibration below a few tens of hertz, therefore some method must be employed to compensate for the eigenfrequency fluctuation. At ATLAS an electronic 'fast tuner' is used to control the RF phase of the resonators. [2]

The fast tuner is mounted on the resonator and is coupled to the cavity's magnetic field. The circuit is based on PIN diodes that switch, at a rate of 25 kHz, between two different impedance states. The eigenfrequency of the resonator changes when the diodes switch from one impedance to the other. The values of the impedances are chosen so that the frequency shift brackets the operating clock frequency. As the resonator's eigenfrequency is driven off the clock frequency by microphonic noise, the feedback on the fast tuner drives the resonator frequency the 180 degrees out of phase with the microphonically induced shift. By switching at a fast rate, the frequency error is corrected to less than 1 degree.

From a daily operation standpoint, this means that one must be aware of where portable mechanical equipment is placed. A vacuum pump or out of balance fan may couple acoustic noise into a resonator and drive the eigenfrequency variations beyond the control of the fast tuner. Even certain modes of refrigeration operation may cause vibration problems. Once these noise sources are recognized they are eliminated and normal operation can resume.

Due to the geometry of the very low beta (.009 c) resonators, a damping device has been developed to reduce the amount of mechanical vibration, thereby reducing the control window of the fast tuner. The damper employs a weight mounted in the inner coaxial line. The pendulum motion of the inner line performs work by sliding the weight on a plate thus damping the amount of mechanical motion. The damper has been installed in three of the lowest beta resonators with the effect of reducing the mechanical vibration amplitude by a factor of six. [3]

2.3 Multipacting Barriers

When a resonator is first cooled down from room temperature, it will not immediately achieve high field gradients. Electrons liberated from the surface at low field levels, typically a few kV/m, traverse to another surface and liberate secondary electrons. It is possible to establish an 'orbit' of electrons of the right path length so to be in sync with the alternating voltages on the resonator surfaces. These multipacting barriers will inhibit achieving high field levels until emitting objects are sufficiently depleted in that region. This phenomenon is strongly related to the cavity geometry and the cleanliness of the surface. With the application of RF power, and the passage of time, eventually all of the multipacting barriers will go away. To condition the multipacting barriers, ATLAS cavities need anywhere from 1 hour to eight hours, depending on their geometry. Once gone the resonators will operate normally until it is either warmed to room temperature, or has been exposed to poor vacuum conditions. The RF control modules have been designed so that this conditioning process is just a flip of a switch.

2.4 Electron Loading

At high field gradients, the Q of the resonators decreases. Figure 3 illustrates a typical of a resonator Q curve. The high level Q can be increased by pulsing the resonator with short, high power RF. By increasing the Q, the power dissipated into helium is reduced, thereby reducing the overall load on the refrigerator. This conditioning must be repeated from time to time to maintain the lower power losses.
into the helium system. The ATLAS cryogenic system is designed for an average heat load into the helium of approximately 4 to 6 watts per resonator. Pulse conditioning of

![Graph showing the effect of electron loading and increased load into the helium system.](image)

**Fig. 3:** Typical Q Curve of a Split-ring Resonator. This illustrates the effect of electron loading and the increased load into the helium system.

### 3. LIQUID HELIUM PLANT

The liquid helium plant is one aspect unique to superconducting machines. At ATLAS, the liquid helium plant is comprised of three separate refrigerators. In total, the refrigerators supply 750 watts of liquid helium cooling. This is distributed between fifteen separate cryostat units. Each cryostat has a dewar that holds approximately 50 to 150 liters of liquid helium. Between the cryostat and the helium distribution system, there is an inventory of approximately 3000 liquid liters of helium.

Utility failure at a superconducting machine is not tolerable. Without electrical power, it is not possible to re-liquefy the boil-off gas from the liquid helium. Since the expansion ratio of liquid to gas for helium is approximately 780:1, an over-pressure situation develops rapidly causing helium to vent from pressure relief devices. Without the proper control systems on the helium plant, a short, two-second-power bump can result in the loss of liquid helium inventory.

Several measures to ensure a reliable system have been taken. The electrical sub-stations that provide power to the facility have automatic switches that will switch over to a secondary feed line in the event the primary feed goes down. This has reduced most power losses to a manageable duration of anywhere from 1 to 10 seconds. At ATLAS, we have installed Uninterruptible Power Supplies (UPS) on the refrigerator control circuits. These UPS units will allow a power loss of up to 15 to 20 seconds without any adverse affects on the refrigerator system. In addition to the UPS units a Programmable Logic Controller (PLC) system controls the sequence of power-up for the compressors. This controlled re-start is necessary because the start-up current on the compressor motors is large compared to the operating current. If all the compressors were allowed to start at the same time, the current draw would overload the substation.

Even with these measures, an operator must respond to a power bump in a swift and correct manner. There is a 'Power Bump Procedure' located at the control console, which must be followed immediately upon a power outage. The average recovery time from a short, 2 second, power loss is
from fifteen minutes to one hour. Prior to the installation of the PLC and substation modifications some extended power outages have resulted in a two week loss of operation.

Contamination of the helium system with air also poses a serious problem. Our refrigerator runs at a positive pressure. This is an advantage in that if there are small leaks in the helium system, air is not drawn in. During maintenance periods, care must be taken to maintain the integrity of the helium system. Both operator error and mechanical failures have resulted in air freezing out in the helium plumbing. This can be a very difficult problem to solve. In some cases it is nearly impossible to get enough heat to the plugged area to melt the blockage. Upon melting, other areas in the system are still cold and the contamination may migrate to the cold sections. These incidents must be dealt with on a case-by-case basis.

4. SAFETY

Most of the safety issues are the same whether the accelerator is superconducting or room temperature. However, there is a need for special safety measures due to the use of cryogens at a SC accelerator. Large quantities of liquid helium and liquid nitrogen are being transported through occupied work areas throughout the facility. A catastrophic failure of one of the cryogenic supply lines can result in both an asphyxiation hazard and an egress hazard. The egress hazard comes from condensation in the room becoming so dense that one simply cannot see the escape route through the fog. Escape lanes have been painted on the floor to assist in guidance to the exits. To address the asphyxiation issue, oxygen deficiency monitors have been installed throughout the facility. If there is an alarm on this system loud claxons and flashing lights are activated to notify personnel to evacuate the area. In addition, all accelerator personnel are required to complete a course in cryogenic safety.

5. THE FUTURE

There is currently a proposal at Argonne National Laboratory for a SC accelerator facility that will produce and accelerate unstable nuclei. The Rare Isotope Accelerator (RIA) will take advantage of the unique characteristics of SC cavities. The RIA driver accelerator will be capable of producing a 400 Mev per nucleon uranium beam at a beam power of 400 kW. In order to obtain these beam energies and power SC cavity technology is integral. To take advantage of the large acceptance of SC cavities, multiple beam states of uranium will be simultaneously accelerated through the linac. Accelerating 10^{13} uranium nuclei per second to 400 MeV/u requires two stages of stripping. If only one charge state were accepted after each stripping then the intensity at each stage would be reduced by a factor of about five. By capturing and accelerating all of the most populated charge states, the beam intensity will be maintained with only small losses at the final energies. A study has been done at ATLAS to demonstrate this proposal [4].

References


JAERI TANDEM BOOSTER AND ITS CRYOGENIC SYSTEM

T. Yoshida
Japan Atomic Energy Research Institute. Tokai Research Establishment
2-4 Shirakata shirane Tokai-mura Naka-gun Ibaraki-ken 319-1195. Japan

Abstract
The JAERI tandem booster linac has been operated for the various experimental programs since 1994. During this seven years, the booster linac worked steadily without serious trouble. However, there are some small problems on the cryogenic system. This paper describes the operational issues on the booster linac and its cryogenic system.

1. INTRODUCTION
The JAERI tandem accelerator facility has a large tandem accelerator and a superconducting booster. The tandem accelerator, of which maximum performance in terminal voltage was 20 MV, was manufactured by National Electrostatics Corporation (NEC) in U.S.A. and started operations for the experiments in 1982. In 1994, the superconducting booster was built for increasing 2 to 4 times the ion beam energy from the tandem accelerator. We have a difficulty with the tandem booster such its cryogenic system loses its stable run sometimes in a few hours after starting the operation of the booster.

2. THE TANDEM BOOSTER
The JAERI tandem booster linac consists of 40 1/4-wavelength type cavities of 130MHz in 10 cryostats, and the total acceleration voltage is 30 MV. There is a buncher with 130 MHz and 260 MHz cavities before the linac, and 60% of the continuous beam becomes available from the two-frequency buncher. A 130 MHz de-buncher is placed after the linac, which is for equalizing spread energy of the accelerated ion beam [1, 2]. Figure 1 shows the schematic diagram of the whole accelerator system, Fig. 2 and Fig. 3 show the cutaway view of the SC cavity and cavity assembled in line, respectively.

![Diagram](image)

Fig. 1: Schematic diagram of the JAERI tandem accelerator and booster linac facility
3. THE CRYOGENIC SYSTEM FOR THE TANDEM BOOSTER

The JAERI tandem booster is constituted by the accelerating cavities, cryogenic transfer lines and the refrigeration system. The cryogenic system is licensed under the refrigerator safety regulations of the high-pressure gas law in Japan. The cold-box is a model TCF-50 manufactured by Switzerland Suluzer Co. The cold-box has a refrigeration performance to cool down five cryostats (approximately 150W RF load in 20 accelerating cavities) and the thermal load of cryogenic transfer lines and quiescent loss of the whole system. The TCF-50 type cold-box was chosen by their operation records, performances, size and as at many other research institutes. Cold (80K) helium gas is also taken out from the cold-box and returned to the cold-box for cooling radiation shields. It takes three days to cool five cryostats, bunchers and cryogenic transfer lines down to the steady state with full liquid helium. Figure 4 shows the schematic diagram of cryogenic system. Figure 5 shows the He gas flow of the cryostat.

---

**Fig. 4: Schematic diagram of the cryogenic system**
4. OPERATIONAL ISSUES ON THE SUPERCONDUCTING ACCELERATOR

Here, we discuss involved in the operations of the cryogenic system and the superconducting accelerator itself

4.1 The cryogenic system

The main component of cryogenic system is cold box, which produces liquid helium from compressed gas helium. As is described above, the JAERI booster system is regulated by the high-pressure gas law for refrigerators. Under such regulations, it is not allowed to put a reservoir in the liquid helium loop. Gas flow in the cold box always changes quickly with changing thermal load. The time constant of heat exchangers is very long, because there are several large heat exchangers in the cold box. Control of cold box, which has a different time constant, is complicated, because it does not respond immediately to abrupt fluctuation. Control processes of the cold box deviate little by little from an expected series of operations, and eventually loose the stable operation. The pressure supplying liquid to the cryostats changes in such a situation to cause the cavities to deviate their oscillating frequencies. Another reason on instability lies in operation of the pneumatic valves of the cold box. They are operated by using compressed air for the sake of safety in case of a power failure, but the valve control circuits and the mechanical structure are very delicate. Therefore, some valves sometimes get out of control from the control computer. In near future, we will change the control circuits to new reliable ones.

4.2 Acceleration units

JAERI superconducting booster has been running stably during seven years, recently, however, we opened two cryostats because of helium leak from cavity adapter flanges. Indium wires for the vacuum seal were replaced. The leaks were due to frequent thermal cycles. Several thermal cycles have been repeated every year for many reasons such as the legal maintenance of the cryogenic system and the laboratory power stations. In this occasion of opening, we re-tuned the resonant frequencies of the cavities of which natural resonant frequencies had been lowered too much during the thermal cycles. The cavity Q factors have not been degraded very much. However, the Q factors of many cavities built earlier were lower than those made later. Figure 6 shows the result of each Q value. The low Q factors were due to the Q-degradation during slow cool-down through the region of temperature from 130 K to 90 K in which niobium-hydrides precipitate on the niobium cavity surface. We could improve the Q factors by a fast cool-down using a sequential cooling process. The result is shown in Fig. 6 with a different notation.
4.3 The peculiarity of superconducting linac

To maintain the good condition of the superconducting linac for a long time, we need meticulous handling and considerations of following items; a) vacuum system, b) thermal cycle, c) maintenance and d) Q degradation.

4.3.1 Vacuum system

With respect to the superconducting linac, very strong electrical fields are generated on the surfaces of the acceleration cavities. Therefore, the surface must be protected from any contamination such as micro particles as much as possible. All vacuum components are oil free, and equipped with safety interlocks. Automatic-shut-off valves are inserted between cryostat and main pump, main pump and fore line pump. The main pumps used at JAERI are a magnetically suspended 1,000 L/s turbo molecular pump.

4.3.2 Thermal cycle

Composite materials of niobium-clad copper are used in the cavities, and indium wires for the vacuum seal between flanges. Thermal cycles, then, cause strong stresses between the different materials. We have not experienced serious problems caused by material itself, although we repeated warming-up the cavities several times in a year. It worries us, however, that a big problem may happen in the future. We have to minimize the thermal cycles taking into consideration of the machine time and the power station’s maintenance time.

4.3.3 Maintenance

Opening a cryostat for maintenance has been extremely few, but there have been several times that we had to brake the vacuum until now. The vacuum break has a risk to sprinkle micro particles on the cavity surface. At the vacuum break, dry nitrogen was fed through a very fine filter into the cryostat as slow as possible, because micro-particles might cause electron field emission from the surface of the cavity. In case of opening a cryostat, we used a clean booth.
4.3.4 $Q$ degradation

How to realize and maintain a high $Q$ factor is a big theme for superconducting cavities. With respect to the JAERI's superconducting cavities, very high performances were realized after the improvements of electropolishing and rinsing technology. However, it is uncertain that we will be able to keep their present performances for a long time. If the $Q$ factors decrease, we have no good solution to recover the $Q$ factors. Therefore, the best way to keep the present condition is to protect the cavities against any contamination. Recovering $Q$ factors by a fast cool-down, on the other hand, has a risk of serious damage to the cavities.

4.4 Operations

For the operation of the JAERI tandem booster, it takes about one hour and a half to set the cavities for the beam acceleration. The electric fields of cavities, which give expected ion beam energy, are calculated before starting operation. The RF phase of each cavity is determined by getting the beam phase measured by a beam-bunch phase detector. A heater stabilizes the liquid level in the sump container of the cold box and the total thermal load to the refrigerator is kept constant. A few hours prior to the cavity start-up, the power (approximately as much as the RF power to be inputted) is fed to the liquid helium system using heaters placed in the Dewars of the cryostats. The heater power is decreased with increasing RF input power in order to keep the load to the refrigerator as constant as possible, also. A few hours later from starting the cavities, the operating condition is balanced, and the condition will continue without any handling.

5. ANOTHER TOPIC

A job of exchanging acceleration tubes of the tandem accelerator has been scheduled as an upgrade project of the tandem accelerator. The injection energy to the booster can be increased to make the matching between the tandem and its booster better for very heavy ions. In addition, rare gas ion beams (Ne, Ar, Kr, Xe) are accelerated, and utilized for the various researches. An installation program of RFQ and interdigital-H type linacs may start from the next fiscal year in order to increase species and intensities of ion beams.

6. CONCLUSION

The JAERI superconducting linac has been continued stable operation, therefore, we have some settling problems in the above mentioned. Recovering of the $Q$ factors and maintaining present performances are extremely important subjects of JAERI tandem booster system. We have to find out best solution against these problems.

References


SESSION 7
RESERVE

Roger Bailey and Guy Crockford
CERN, Geneva, Switzerland

Abstract
The reserve session was devoted to some issues that came up through the workshop, which were grouped into three main areas:

- The Global Accelerator Network
- Problems of stress and how to get organized to minimize them
- What should an operations group be responsible for?

This paper summarizes the discussions that took place.

1. THE GLOBAL ACCELERATOR NETWORK

Steve Peggs from BNL introduced the subject, which is motivated by the possibility that any major new machine will be on such a scale that it will require international and inter-laboratory collaboration not only to build it but also to operate it. This leads into the question of whether or not it is sensible to consider remote operation of a major facility, with responsibility shared between various laboratories. To address these issues, ICFA has initiated a feasibility study into such a Global Accelerator Network. The purpose of presenting it here was to get direct feedback from operations professionals and in the lively discussion the following points came out.

Accelerators do not operate 100% of the time; they are down for scheduled long periods (months) for installation, maintenance etc. and for unscheduled short stops (hours or days) for repairs. For both of these activities experienced on-site staff are needed, and for the long stops there has to be sufficient infrastructure on-site to support a large number of people and activities.

Moving on to the times when the machine is running, opinion on remote operation was mixed. So long as there are no analogue signals to accommodate, it was felt that the control room could be situated anywhere on site already today, as long as the function of the control room is only to control an accelerator. With the advances in telecommunications technology that will surely come in the next years, it should be technically possible to situate the control room far away from the machine. Remote intervention, by experts from home, is already a part of today’s operation. The question of system security was raised, and this only gets worse with greater distance between control and facility.

Present control rooms, however, cover other functions than those involved with turning knobs. Informal, spontaneous communications is an essential part of accelerator operation, as anyone who has spent time in a control room will testify. Getting in touch with an expert, or a variety of different experts, is invaluable when facing a tricky problem. If these experts are scattered around the world, it could be a problem. More generally, the control room is a communication centre; if people want to know anything about machine operation they come to or call the control room. If the control room was far from the facility or the laboratory, these kind of functions would have to be performed differently, and here we are getting into sociological matters that should not be underestimated.

It was suggested that a low cost test would be a good idea. That is, set up the remote control of an existing accelerator from another laboratory. This would provide some immediate feedback on many of the problems, both technical and sociological.
Laboratories are interested to participate in major projects, but not as side players. A laboratory or a country would be more likely to be willing to contribute hardware to a project if, after installation and commissioning, that laboratory or country continues to operate the equipment. This seems to be far more attractive than to build and donate equipment for other people to run. In fact this is the way that large, modern accelerator experiments are built and operated already today.

Finally, it was realized that if we control a facility from 3 strategically placed control centres, the machine could always be operated during daytime. The suggestion made was for 8 hour shifts consecutively in CERN, SLAC and KEK, and with this we would not have to worry any more about shiftwork and associated problems!

2. PROBLEMS OF STRESS AND HOW TO GET ORGANISED TO MINIMISE THEM

At an earlier talk (session 3) the problems related to stress were presented and discussed, but with limited time for feedback from the floor. Is it really something we should worry about? If so where does it come from? These questions were asked and it was clear that stress is felt to be an issue in 24h operations. In order to try to bring out experiences, first group leaders and then operators were asked to publicly offer their opinions.

What do the group leaders see as the sources of stress?

- Multi-tasking. Dealing with too many things at once.
- Too much pressure from clients.
- Biological effects of working night shifts.
- Sociological effects of shiftwork.
- Many responsibilities but not enough authority.
- Everything done in control room is very visible. This can be positive, but a source of stress.
- Personal problems (outside the working environment).
- Conflicts with colleagues in the group.
- Communication problems with other colleagues in the laboratory.
- Poor management.
- Too many regulations from outside agencies.

What do OP group members see as (further) sources of stress?

- Problems during night shifts.
- Fear of waking up the wrong expert when outside help required.
- Disturbance in the control room.
- Disturbance from telephone calls.
- The 8:30 in the morning effect, when the control room is invaded.
- Stressful modes of operation, such as intensive collider operation.
- Concern for safety aspects of work (fear of getting a call on the red phone).
- Shift crew leader having too much administrative work to get through.

Immediately that the question was asked about how to deal with these sources of stress, the discussion turned towards how to get organized for shiftwork. This left many of the above problems not addressed; they could be considered at a future workshop.
The various laboratories had quite different solutions to shiftwork, ranging from fast rotation of morning, afternoon and night shifts to a system where operators worked months of days, then months of afternoons then months of nights. While the array of solutions was numerous, the following was clear; allow the operators the freedom, obviously within the constraints of the laboratory, to adopt a shift system that suits them.

Whatever system is adopted, it was felt that the minimum number of people per post should not fall below 7. This directly influences the number of shifts worked per unit time, and if this number is too high this is a serious source of stress. Cases were discussed where this had led to a vicious circle of too many shifts / stress / people leave / more shifts / more stress etc. Also, make sure that there are enough people on shift to perform the multitude of tasks that operations do.

One laboratory, DESY, does not formally have an operations group. Instead, machine operation is performed by personnel drawn from the equipment groups of the laboratory. The shift load is necessarily rather low, at 7 days per month, which brings the disadvantage that operators are away from the machine for quite long periods.

Getting organized for 24h operation has been discussed at some length in the first operations workshop in 1996. However, it was felt that this area is of sufficient interest to warrant a new exchange of ideas. It was suggested that the different laboratories could make available on the web information such as machine schedules, shift schedules, group organigramme etc.

3. WHAT SHOULD AN OPERATIONS GROUP BE RESPONSIBLE FOR?

In smaller laboratories, there is one control room, from where all operational functions are performed. In these cases at least it is clear what operations are responsible for; just about everything! This is a certain source of stress, and can lead to reduced efficiency for physics.

At the larger laboratories, there are several control rooms, which distributes the responsibilities but brings problems of communication between the different groups involved. These problems are exacerbated at times of major breakdown; it is important to establish clear procedures and priorities that all groups agree upon and follow.

For equipment faults, almost all operations groups attempt simple repairs. Different laboratories allow different levels of intervention, usually determined by the equipment specialists or by safety considerations. For example, interventions on high voltage equipment are never carried out by operations personnel.

Access into the machine is a particular area of concern. If machine operations supervises the access, this could lead to a conflict of interest because the same group also wants to get the machine going again as fast as possible. Comers could be cut, and safety could be compromised. On the other hand, if machine access is supervised by a separate group, safety is better assured but the price paid is a drop in efficiency. There is clear pressure (from the laboratory management) for a high level of efficiency, while safety is more a dormant requirement until something goes wrong. While there was plenty of discussion around this point, the general feeling was that, during periods of machine operation with beam, the operations group should take overall responsibility for access into the tunnel.
ACCELERATOR OPERATION AT THE GSI HIGH CURRENT INJECTOR

W. Barth and U. Scheeler
Gesellschaft für Schwerionenkunde mbH, Darmstadt, Germany

Abstract
The operation of the new high current injector (HSI) is characterized by up to a factor of hundred higher beam intensities and the enlarged possibilities of the time sharing operation between two ion source terminals feeding the HSI and the High Charge State Injector (HLI). The increased beam power of a single Unilac pulse is now able to damage sensitive accelerator components. New operation hard- and software tools controlling the accelerator and monitoring the device settings and beam properties had to be developed and integrated in the already existing concept. Based on the beam parameters the data supply of all devices with proofed initial settings and the check of device properties are automatically done by software programs. The interlock system was advanced by the survey of transmission losses and it also reduces the beam power automatically while beam diagnostics is measuring. The paper deals with the new requirements, the ideas of solving them and the first operation experiences.

1. INTRODUCTION
GSI is the heavy ion research center in Germany operating with the linear accelerator Unilac (universal linear accelerator), the synchrotron SIS (Schwerionensynchrotron) as a circular accelerator and a storage ring ESR (experimental storage ring) on the fields of nuclear and atomic physics, plasma physics, material research and biophysics. The SIS was designed as a high intensity machine with a large magnet aperture. In contrast, the original Unilac was not dedicated as a synchrotron injector, fulfilling all requirements due to high intensities (especially for a mass number higher than 150). To serve the SIS up to the inherent space charge limit for all ion species including uranium a new High Current Injector was installed and commissioned step by step in 1999 replacing the more than 25 years old Wideröe section of the GSI Unilac. [1]

Fig. 1: Example of Three Beam Operation with four users (December 2000)
With the new injector the operation possibilities are considerably enlarged. Pulse to pulse availability of every ion source is now possible. Two ion source terminals feed the HSI: One is housing a Penning Ion Gauge (PIG) already in operation at the former Wideröe injector (for all kinds of ions at medium and low intensities) and the other one serves for the production of high intensity, heavy ion, low charge state beams. Optionally the Multi Cusp Ion Source (MUCIS) for gases or the MEtal Vapor Vacuum Arc ion source (MEVVA) for metals is installable. Afterwards the ion beams are accelerated up to 1.4 MeV/u in the new HSI, before injection into the Alvarez the modified gas stripper section provides for the essential charge state. The other 1.4 MeV/u injector, the HLI (Hochladungsinjector) fed by an Electron Cyclotron Resonance (ECR) ion source at low intensity, high charge states and high duty cycle allows Alvarez injection directly without stripping. After the upgrade of the Unilac a multipulse mode from the different injectors is possible. Figure 1 shows typical operation parameters (in the 4th beam time period 2000): the $^{12}$C$^{5+}$ ion beam to SIS for therapy (from HLI), a high intensity $^{40}$Ar$^{11+}$ beam to SIS for the fragment separator (MUCIS) and Xe (PIG) to the Unilac experimental hall were simultaneously in operation on pulse to pulse basis.

2. MACHINE DESIGN FEATURES FOR THE HIGH CURRENT OPERATION

The increased beam intensity leads to a very high pulse power of the beam up to 1.5 MW in the gas stripper section. Connected with the short stopping range of the ions at Unilac energies even a pulse of 100μs length is able to melt metal surfaces. Hence the damage of accelerator components becomes a serious problem [2].

2.1 Passive Damage Prevention

Sensitive devices are shielded by especially designed apertures and slits; the cooling of the beam stoppers was improved. By decreasing the impinging angle on the surface in design layout, the exposed area is increased while the thermal energy density decreases.

![Diagram](image)

**Fig. 2:** Online monitoring of beam position with the pick-ups at the HSI and transfer channel; the measured positions and a stored reference is represented.

2.2 Beam Diagnostics

Due to the high beam power and the short stopping range the use of non-destructive beam diagnostics reached more importance. The beam intensities are high enough to detect the beam signal with the less sensitive high current diagnostic. A damage of the measurement system due to direct impact of the ion beam is prevented [3].

200
Instead of Faraday cups now beam transformers (33 in the Unilac) measure the intensity and 24 segmented capacitive pick-ups along the linac instead of profile harps are used to qualify beam position – the pick-ups are likewise usable for an accurate determination of beam energy. Residual gas monitors deliver information about beam profiles. Because of their size (length is 250 mm) they are only used at special matching points. Beyond several expert systems are available to measure the six-dimensional phase space distribution along the Unilac.

2.3 Interlock-System

The established interlock system has been upgraded and enlarged: the beam loss along the whole machine is monitored by beam transformers to prevent the damage of components. At some key positions the difference of the charge values between two subsequent measurement points is carried out. If this value is higher than a threshold value the pulse length will be reduced with the chopper before HSI-injection. This system is also working with special beam loss data while profile measurements with grids – beside the dynamical pulse length reduction the repetition rate is also decreased.

![Diagram of beam loss control system]

**Fig. 3:** Principle of beam loss control

Routinely the status of all accelerator components is permanently monitored. If any malfunction is detected the beam is switched off by the beam choppers selectively for the corresponding users. A special software gives the operator information about the affected device and the failure.

3. OPERATION STRATEGY

The philosophy of 'prevention of a possible damage of accelerator components' impacts not only safety aspects in the technical construction, it also affects the operation of the accelerator. An unexpected vacuum leak is always connected with a longer undesired loss of beam time. To support the installed interlock system, which should guarantee the safe operation, the control software checks all actions done by the operation crew. The following basic rules have to be fulfilled without fail:

- before a beam pulse is accelerated all devices get their operation settings based on the beam parameters
- requested changes of beam parameters lead to a new calculation of the device settings based on the actual one
• the measurement of beam parameters with destructive diagnostics has to be prepared by reducing the pulse length and repetition rate
• Online monitoring of steering by capacitive pick-up probes

4. OPERATION EXPERIENCES
The installation of the high current injector enlarges the operation possibilities considerably. Quite a lot of operation work is done automatically, as preparation of an initial data set or as save procedures. That reduces the necessary time for accelerator tune up drastically, but the risk to destroy the actual machine setting by a maloperation is increased. Essential ‘current dependent settings’ were calculated before and have to be verified during operation. A few device properties lead to interference between the single beams: several dc magnets in the poststripper section, phase of bunchers and single gap resonators, limited pulse to pulse operation of HSI magnets. This fact causes mainly operation problems, which reduces availability during multi-beam-operation. The operation experiences of the last year led to many changes of the operation procedures and automatic actions in software programs. The last high current beam time with argon from the HSI was quite successful – during three weeks the Unilac served for the synchrotron without any re-tuning and without any failure, only ion source changes were regularly done. The beam time was performed while the carbon beam was delivered for the cancer therapy.

5. ACKNOWLEDGEMENTS
We wish to thank J. Klabunde and D. Wilms for their essential help, the software group for their great support and A. Plüschke for the preparation of the figures and drawings.

References

PARTNERS IN OPERATIONS: ADVANCED LIGHT SOURCE
CONTROL ROOM AND PROCEDURE CENTER

Rita Jones
ADVANCED LIGHT SOURCE PROCEDURE CENTER, Lawrence Berkeley National Laboratory,
Berkeley, California 94720 USA

Abstract
The ALS Procedure Center creates the operational procedures for the facility. The Control Room operators implement many of these procedural tasks, providing efficient and effective operation of the machine. A typical start-up day will be presented, highlighting critical areas of concern when turning on the accelerators and exemplifying the partnership of the Procedure Center and Control Room.

1. OVERVIEW
The ALS accelerator facility consists of a 50 MeV linac, a 1.5 GeV booster synchrotron, and a 1.5-1.9 GeV storage ring. The ALS Procedure Center creates the operational procedures for the facility, ensuring compliance with federal, state, and laboratory regulations. Since the most important function of procedures is to assist workers in the performance of tasks, the Procedure Center works closely with the Control Room operators to reach a collective agreement on the best way to perform these tasks. Interaction between the Center’s manager and the operators is extensive: the operators play a major role in writing, reviewing, and revising procedure drafts. Thus, ALS procedures are seen to address the needs of those who will use them and have been enthusiastically accepted.

A good example of the partnership discussed above is the intense use of procedures in the Control Room on a start-up day following a shutdown for installation and maintenance. Four procedures used to start-up the machine have been selected for discussion below. These procedures include check-off sheets or sign-off forms that are completed as the procedure is performed. Consequently, not only are the procedures seen as reducing error and documenting the best way to perform a task, but also as providing a record of the procedure’s execution. If an operator discovers an error or decides there is a more efficient way to perform a task, he can bring these items to the Procedure Center for immediate implementation — errors are corrected and new ideas are sent out for review as a revised procedure.

Lastly, the operators, as well as all ALS staff, can access the procedures they need at any time by going to the ALS Procedure Center Web site. They can be assured of always using the latest issue of a procedure and that no alterations have been made to the document, since only PDF files are posted. The Web site, now three years old, is widely used and has provided the final step in closing the loop between procedures and operations.

2. OPERATIONS PROCEDURES USED IN THE CONTROL ROOM ON START-UP DAY
The Comprehensive Accelerator Start-Up Procedure delineates the preparation activities, accelerator shielding and equipment checks, and all the parameters to be verified in the linac, booster, and storage ring. It contains the Operations Start-Up Checklist (see Fig. 1), which ensures all items are checked and documents the completion of the procedure.
<table>
<thead>
<tr>
<th>Vacuum status in logbook</th>
<th>Vacuum status in logbook</th>
</tr>
</thead>
<tbody>
<tr>
<td>Check radiation monitor alarm status</td>
<td>Check radiation monitor alarm status</td>
</tr>
<tr>
<td>Operator-in-Charge Checklist</td>
<td>Operator-in-Charge Checklist</td>
</tr>
<tr>
<td>Review logbook</td>
<td>Review logbook</td>
</tr>
<tr>
<td>Review lockout/tags</td>
<td>Review lockout/tags</td>
</tr>
<tr>
<td>Review status board</td>
<td>Review status board</td>
</tr>
<tr>
<td>Review controlled access logbook</td>
<td>Review controlled access logbook</td>
</tr>
<tr>
<td>Review shielding change binder</td>
<td>Review shielding change binder</td>
</tr>
<tr>
<td>Tour facilities Time:</td>
<td>Tour facilities Time:</td>
</tr>
<tr>
<td>Operator-in-Charge</td>
<td>Operator-in-Charge</td>
</tr>
</tbody>
</table>

**Line Search**

- High controlled temp water system on
- Electron gun enclosure secured
- Control RF gate ON and triggering
- Injector supplemental shielding as specified in OP-02-07 Appendix 3
- Linea gate functional
- Roof plugs in place (2)
- BTS system case searched and secured
- Linea searched and secured
- Radiation monitors functional, trip set checked

**Booster Search**

- Booster fuses on (2)
- Booster gates functional
- Roof plugs in place (6)
- Radiation safety interlock panels secured
- Booster searched and secured
- Radiation monitors functional, trip set checked
- Booster magnet systems on
- Booster RF cavity water heater on
- Booster RF power systems on
- Injection kicker magnet systems on
- Extraction kicker and septum magnet systems on

**Storage Ring Search**

- Storage ring fans on (3)
- SR gap functional
- Stair gates closed and radiation signs in place
- Movables shielding blocks closed (12)
- Roof plugs in place (12)
- Beamline exit window blocks in place
- Lead belty bands in place
- Front and shielding equipment status as specified in OP-03-07 Appendix 3
- Radiation safety interlock panels secured
- SR/0 area searched and secured
- SRP area searched and secured
- Radiant monitors functional, trip set checked
- Injection septa and bump magnets on
- BTS B1 and BTS B2 unlocked
- SR magnet systems on
- SR RF water and power systems on
- SR fill pattern set

**Electron Gun Turn On**

- E20 HV sector=+120KV
- Beams, red lights, audible alarms operational
- Ready for beam

**Operator-in-Charge Verification**

---

The *Operations Start-Up Checklist* provides a fundamental, detailed, step-by-step process for turning on the accelerators. The checklist determines the flow of work to start-up the machine and yet provides flexibility in allowing the Operator-in-Charge to choose the most expeditious use of the procedure by performing the steps in any appropriate order.

The *Shielding Control Procedure* provides controls for the removal and replacement, and modification of permanent shielding and the securing of temporary or additional shielding materials. It addresses shielding in the accelerators and the beamlines. The *ALS Shielding Change Form* (see Fig. 2) is maintained in a log in the Control Room and a copy is put on the Status Board to alert all operators to removed shielding and any restrictions in place.
ALS Shielding Change Form

Location of change: ____________________________

Person initiating form: ____________________________

Reason for Change: [ ] Remove beam port plug for installation of beamline penetration (see checklist below)
[ ] Remove/Replace existing shielding
[ ] Modify existing shielding (notify ALS RCT)
[ ] Add New Shielding (notify ALS RCT)

Shielding affected: ____________________________

Shielding added by: ____________________________

Start Date: ____________________________ End Date (estimated): ____________________________

1. BEAM PORT PLUGS

*ALS RCT must check the following shielding and initial before storage ring operation*

[ ] PBS installed
[ ] transition wall shielding installed
[ ] supplemental front end shielding installed

2. ACCELERATOR and FRONT-END SHIELDING

ALS content: ____________________________ Approved: (ALS Ops.) __________________ (ALS RCT)

Restriction on beam operations: __________________________________________________________________________________________

3. BEAMLINE SHIELDING (includes beam pipes and hutches)

Beamline offline: ____________________________ (BL Coordinator's name)

Restriction on beamline operations: __________________________________________________________________________________________

Beamline coordinator's Initials (Needed for Modifications and/or New Shielding):

[ ] Key-Enable Updated or [ ] Update Unnecessary

4. COMPLETE for Sections 1, 2, or 3

End Date: ____________________________ Work completed by: ____________________________ Verified by: ____________________________

ALS RCT Initials (Needed for Modifications, New Shielding, and/or Removal of Beam Port Plug):

[ ] Beamline Drawings Updated
[ ] Shielding Photos Updated
[ ] Appen. III of Search & Secure (OP 02-07) updated

Comments: __________________________________________________________________________________________

________________________________________________________________________________________

ALS RCT or Operations Group Leader Initials ____________ indicate shielding work is complete. Accelerator or beamline may operate without restriction.

File original in ALS Control Room in the Shielding Change Binder.

Fig. 2: ALS Shielding Change Form

Checking Sections 1 and 2 on the ALS Shielding Change Form in the active section of the Shielding Change Binder quickly alerts the operator that the machine cannot be started up if beam port plugs and/or accelerator and front-end shielding have been removed. If plugs are removed, the ALS Shielding Change Form indicates whether the proper shielding has been installed and checked by the ALS Radiological Control Technician before the operator starts up the machine.

The Accelerator Search and Secure Procedure enables safe operation of the accelerators and storage ring by checking equipment and clearing all personnel from the interlocked areas prior to start-up of the machine. It includes maps showing gates, search routes, and push-button/key switch boxes (see Fig. 3, Map showing Search Push-Button/Key Switch Box Locations), as well as a list of beamline components and their status.
Appendix I: Map of Injector Search Push-Button/Key Switch Box Locations

Fig. 3: The Map Showing Search Push-Button/Key Switch Box Locations assists the operator in locating the correct boxes while searching and securing the injector (another map is provided for the storage ring).

The Electron Gun Enclosure Securing Procedure (see Fig. 4) delineates the steps for preparing the enclosure for operation and securing it for shutdown. Especially important are the hazards (high voltage and ozone gas) associated with the enclosure. By following the steps in Section 5.1 of the procedure, the operator is confident the hazards are mitigated and it is safe to operate the enclosure for start up.

Figure 4 also illustrates the ALS procedure format, used for all procedures, and the APPROVED FILE COPY red stamp, indicating the procedure was issued only by the Procedure Center Manager.
Title: Electron Gun Enclosure Securing Procedures

Section where used: Accelerator Operations, Electronic Coordinators, Electronics Maintenance, and RF Sections

Prepared by: Jan Pusina
Reviewed by: Terry Byrne, Walter Barry, Jim Gregor, C. C. Lo
Approved by: Bob Miller, Mike Wolfe

Revision Log:

<table>
<thead>
<tr>
<th>Rev. No.</th>
<th>Effective Date</th>
<th>Pgs. Affected</th>
<th>Brief Description of Revision</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3/14/87</td>
<td>1-3</td>
<td>Pg. 1: Sec. 1.6 weekends changed to maintenance shifts; Pg. 2: Sec. 5.1 [a] added, [b] new.</td>
</tr>
<tr>
<td>2</td>
<td>4/4/00</td>
<td>1-4</td>
<td>Pg. 1: update signature block, Sec. 5.0: update Refs. 2, 1, 5.1: [a] new, [b] new.</td>
</tr>
</tbody>
</table>

1.0 PURPOSE

To provide a procedure for preparing the electron gun enclosure for operation and securing it for shutdown. The gun enclosure is to be left in the operational state on maintenance shifts, and in the shutdown state for longer nonoperational periods.

2.0 SCOPE

This procedure takes into consideration the following hazards associated with the electron gun enclosure: 120 kV High voltage (HV) and presence of ozone gas. Section 5.1 delineates the steps for preparing the enclosure for operation, while section 6.2 discusses securing the enclosure for shutdown between periods of operation. Only trained personnel are permitted to prepare and secure the electron gun enclosure.

Fig. 4: Electron Gun Enclosure Securing Procedure

3. ACKNOWLEDGEMENTS

This work was supported by the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.
EFFICIENT AND EFFECTIVE OPERATION OF THE APS LINAC

S. Pasky, M. Borland, J. Stein, R. Soliday, S. Christensen
Argonne National Laboratory, IL 60439, USA

Abstract
The Advanced Photon Source (APS) linear accelerator (linac) utilizes two thermionic cathode rf guns and one photocathode rf gun. The thermionic guns are primarily for APS operations while the photocathode gun is used as a free-electron laser (FEL) driver. With each gun requiring a different lattice and timing configuration, the need to change quickly between guns and maintain the required equipment protection puts great demands on the Main Control Room (MCR) operators. This paper discusses how the APS staff has learned to deal with the frequent changes required by a newly upgraded equipment safety interlock system and how they have become familiar with the automated control system called [1, 2] Procedure Execution Manager (PEM). Our linac is controlled via the Experimental Physics and Industrial Control System (EPICS), but the lessons are applicable to any control system.

1. EQUIPMENT SAFETY SYSTEM
1.1 Interlock Support
Equipment protection interlocks are mandatory for all the linac subsystems. The original interlock chassis design consisted of a metal box enclosure containing 24 VDC relays, indicator lights, and terminal blocks that served as a hard-wired junction point between field sensors and the interlock chassis. This was a very robust and reliable interlock system until changes or additional interlocks were needed.

In the past two years components have been added to the linac that required upgrades not only to the interlock systems but also to the Motif Editor and Display Manager (MEDM), which consists of control screens used by the MCR operators. The hard-wired nature of the existing interlock system made it difficult to keep pace with these changes.

It was apparent that in order to support these changes and future project upgrades in an efficient and effective way, a new linac interlock system was needed. This was done using a programmable logic controller (PLC) (see Figure 1) with the following requirements in mind.

- The control logic should be flexible to accommodate frequent changes.
- The system must be highly reliable.
- The system must be physically compact due to space limitations.
- The system must have increased capability for complex interlock conditions.
- The system must provide enhanced information to MCR operators.

208
1.2 PLC Selection

A PLC-based system is particularly suitable for applications in which the requirements listed above are important. If system requirements call for flexibility for future growth, the programmable controller brings returns that outweigh any initial cost disadvantage relative to a relay-based system. Even if neither flexibility nor future expansion is required, the PLC-based system can provide tremendous benefits as a troubleshooting and maintenance aid, as well as providing detailed information to the MCR operators via MEDM screens.

The 205 Direct Logic Controller using a DL250 CPU was found to meet or exceed all our requirements. The DL250 CPU had the best system capacity, performance, programming, and diagnostic ability, which will save many hours of programming and debugging time. The DL250 also interfaces well with EPICS.

1.3 Interlock Function and MEDM Displays

In EPICS, equipment is controlled from workstations that communicate over a network with local computers called input/output controllers (IOCs). All systems in the linac that require or use an interlock for equipment or personnel safety protection require a latching function independent of the IOCs. Once a latch has been made, operator intervention is required to reset the interlock.

A typical interlock example, shown in Figure 2, is provided by the linac rf systems. Each klystron requires a 400-watt power amplifier to provide rf input at sufficient levels to drive the klystron. Each amplifier is potentially inhibited by two signals. The first originates in the personnel safety system, known as the Access Control Interlock System (ACIS). The second signal, independent of the ACIS, is provided by the PLC Direct Logic system, which monitors the status of equipment, that must function in order to enable the klystron drive without the possibility of damaging the klystron or the equipment it powers. Examples of monitored equipment include waveguide, arc detectors, VSWR measurements, vacuum measurements, SF6 pressure, and water flow and temperature.

Using the PLC's ability to monitor each interlocked signal separately, the MEDM screen developer was able to design a thorough and robust display for operations and diagnostics. Figure 3 shows a typical MEDM screen that displays the status of interlocks for the sulfur hexafluoride (SF6) system and parts of the beam transport line. In the event of a trip, a quick glance at this screen shows the general source of the problem in an easily understood graphical fashion. Detail screens, like those shown in Figure 4, can then be consulted to determine the exact cause of the problem.
Fig. 2: Typical rf Interlock Logic

Fig. 3: Typical SF6 Interlock Logic MEDM Screen
2. LINAC AUTOMATED OPERATIONS

The APS linac comprises five modulators and klystrons; three electron guns; three dipole power supplies; 35 quadrupole power supplies; 48 steering magnet power supplies; 18 beam position monitors; 7 current monitors; and complex timing, water, and vacuum systems. There are literally thousands of controls and thousands of read-backs incorporated in a multitude of screens that control every aspect of operations. Originally, operators had to switch back and forth among many MEDM screens, performing procedures from memory or with the aid of a written document. In order to perform rapid changes in operating conditions, some Unix scripts were written to perform tasks automatically. Though the scripts worked well under ideal conditions, they could not always be counted on because equipment and operational procedure changes were often made without warning. Furthermore, these scripts were not regulated or source controlled and did not have much of an error checking ability, making them unreliable. Finally, the Unix scripts were slow and did not have a graphical user interface.

The Procedure Execution Manager (PEM) has been used at the APS for several years to control long and complex tasks. PEM procedures, when configured properly, follow the same steps an operator would take during equipment start-ups and reconfiguration between injector lattices for user operations and experimental projects. The only difference is the PEM has the ability to repeat steps faster and with less possibility of error.

When using PEM procedures, the operator no longer has to open numerous MEDM screens and work on one task at a time. Rather, the PEM is able to efficiently use multitasking to alleviate the burden on the operators in what can often be a stressful situation. The operators can read corresponding descriptions and view the steps of a PEM procedure to become familiar with it. This is not intended to reduce operator training, but it does serve as an additional source of information that may be valuable to operators.

Complex PEM procedures are constructed by combining simpler PEM procedures in a series and/or parallel fashion. The PEM interface is expandable, simple, and consistent, so operators often do not need to learn anything new in order to correctly use a new procedure. Using PEM's ability to execute steps in parallel can decrease the execution time and further enhance productivity.

The dialog screen shown in Figure 5 for power supply start-up allows the operator to select a snapshot file to be restored at the end of a magnet conditioning. A snapshot file (see Figure 6) is a
database file including all the settings necessary to reproduce the conditions existing when the snapshot was recorded. Once executed, the PEM procedure opens another display window, shown in Figure 7, that shows each step as it occurs and reports procedure status.

Prior to the use of PEM procedures for linac operation, reproducibility was difficult. Establishing and enforcing a uniform method for machine operation has resulted in a dramatic reduction in the time spent by the control room operator for accelerator tune-ups. Start-up and switch-over activities between experimental projects and daily injections have also benefited from the PEM program.

There are two principal difficulties with the PEM process. First, changes in the controls system or hardware can cause procedures to fail. This problem has been managed by the use of administrative controls and a device layer between the PEM procedures and EPICS. Second, thorough testing of these procedures requires machine time, which is in very high demand for experimental programs. This is perhaps the major factor slowing the development of these procedures.
3. CONCLUSION

The new linac interlock upgrade and the use of the PEM procedures have proven to be very reliable for switching between multiple operating modes. Without these tools, it would be difficult if not impossible to ensure equipment safety, improve reliability, and efficiently provide consistent beam. Switching between the operation modes safely with the assistance of the PEM has made the job of the control room operator much easier and has contributed to the success of experimental programs.

4. ACKNOWLEDGMENTS

The following individuals are recognized: Interlock Review Committee: Ned Arnold, Don Dohan, and Art Grelick; Hardware Installation: S. Benes and M. Douell. This work is supported by U.S. Department of Energy, Office of Basic Energy Sciences, under Contract No. W-31-109-ENG-38.

References


OPERATION OF HIMAC AND CANCER THERAPY

Chihiro Kobayashi, Hideki Fujiwara, Tomihiro Nishimura, Yoshinobu Sano, Hirotugu Ogawa
Accelerator Engineering Corporation (AEC), Chiba 263-0043, Japan
Etichi Takada
National Institute of Radiological Sciences (NIRS), Chiba 263-8555, Japan

Abstract
The operational status of HIMAC is reported.

1. INTRODUCTION
HIMAC, Heavy Ion Medical Accelerator in Chiba, has been used for cancer therapy application since June 1994. Accumulated number of treated patients is about 1,000 at present. The results of local control rate of tumor and survival rate are good.

The accelerator characteristics are summarized in Table 1. Beams of various ion species are supplied for physics and biology experiments during nights and weekends.

<table>
<thead>
<tr>
<th>Table 1: Outline of Himac</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion Source</td>
</tr>
<tr>
<td>PIG</td>
</tr>
<tr>
<td>10GHz ECR</td>
</tr>
<tr>
<td>18GHz ECR</td>
</tr>
<tr>
<td>Linac</td>
</tr>
<tr>
<td>RFQ</td>
</tr>
<tr>
<td>DTL</td>
</tr>
<tr>
<td>Synchrotron</td>
</tr>
<tr>
<td>Upper Synchrotron</td>
</tr>
<tr>
<td>Lower Synchrotron</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Treatment and Irradiation Facilities</td>
</tr>
<tr>
<td>Treatment room A (Vertical beam)</td>
</tr>
<tr>
<td>Treatment room B (Horizontal &amp; Vertical beam)</td>
</tr>
<tr>
<td>Treatment room C (Horizontal beam)</td>
</tr>
<tr>
<td>Biological experiment room</td>
</tr>
<tr>
<td>Physical-general experiment room</td>
</tr>
<tr>
<td>Secondary beam experiment room</td>
</tr>
<tr>
<td>Medium energy experiment room</td>
</tr>
</tbody>
</table>

2. SCHEDULE
HIMAC schedule for the present fiscal year is shown below. From April to early August and from September to February are the two semesters of running. Periodic maintenance, as well as installation of new devices for improvement and research, is concentrated into the shutdown period of August or March.
Also shown is a weekly schedule. Cancer treatments are performed during the daytime of Tuesday through Friday, with carbon beams, while physics and other experiments have beams during the rest. A half day preventive maintenance is scheduled bi-weekly.
### SCHEDULE FOR THE WEEK

<table>
<thead>
<tr>
<th>Day</th>
<th>Upper ring beam</th>
<th>Lower ring beam</th>
<th>6.0 MeV beam from inj.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MON</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>He230MeV/u</td>
<td>He6MeV/u</td>
<td></td>
</tr>
<tr>
<td><strong>TUE</strong></td>
<td>C 290MeV/u</td>
<td>C 350MeV/u</td>
<td>He6MeV/u</td>
</tr>
<tr>
<td></td>
<td>C 290MeV/u</td>
<td>C 400MeV/u</td>
<td>Ne230MeV/u</td>
</tr>
<tr>
<td><strong>WED</strong></td>
<td>C 290MeV/u</td>
<td>C 350MeV/u</td>
<td>C 100MeV/u</td>
</tr>
<tr>
<td></td>
<td>C 290MeV/u</td>
<td>C 400MeV/u</td>
<td>O 180MeV/u</td>
</tr>
<tr>
<td></td>
<td>C 290MeV/u</td>
<td>C 400MeV/u</td>
<td>C 6MeV/u</td>
</tr>
<tr>
<td><strong>THU</strong></td>
<td>C 290MeV/u</td>
<td>C 350MeV/u</td>
<td>Ar500MeV/u</td>
</tr>
<tr>
<td></td>
<td>C 290MeV/u</td>
<td>C 400MeV/u</td>
<td>C 400MeV/u</td>
</tr>
<tr>
<td><strong>FRI</strong></td>
<td>C 290MeV/u</td>
<td>C 350MeV/u</td>
<td>Si135MeV/u</td>
</tr>
<tr>
<td></td>
<td>C 290MeV/u</td>
<td>C 400MeV/u</td>
<td>Si490MeV/u</td>
</tr>
<tr>
<td></td>
<td>C 290MeV/u</td>
<td>C 400MeV/u</td>
<td>Si800MeV/u</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Ar6MeV/u</td>
</tr>
<tr>
<td><strong>SAT</strong></td>
<td>C 290MeV/u</td>
<td>C 350MeV/u</td>
<td>H 230MeV/u</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Ar6MeV/u</td>
</tr>
</tbody>
</table>

### 3. ORGANIZATION

The operation of HIMAC is done by AEC. AEC is a company founded at the time of HIMAC commissioning, and now has a contract from NIRS on HIMAC operation and maintenance. Accelerator operation personnel is 28 people, average 30 years old, experiencing 4 to 5 years of operation, whose backgrounds are various and usually not accelerator-related. Shift schedule is rotating with 7 teams, each consisting of three operators. About 40% of the working time is consumed with the half-day shifts, and the rest of the time is used for maintenance and improvement work by individual operators.

### 4. OPERATIONAL PERFORMANCE

The annual operation hours are about 5,500 hours, of which major part is for therapy and relevant measurements. It can be seen that carbon ion acceleration (for 290 and 400 MeV/A) prevails more than 60% of the operational time of a ring. Nevertheless, other ions are also accelerated, ranging from H to Xe.

Since April 1998, the Time-Sharing-Acceleration in the injector linac system has been in operation, and the effective beam supply time has been increased about 20%. TSA can provide three different beams to each destination, two rings and a 6 MeV/A experiment course. Ion source improvement is also effective for heavier ions such as Fe, Kr, Xe, etc.

Although the collection of data is incomplete, machine failure is controlled to a level of 1% or less. This is depicted by the fact that unscheduled down-time of more than 30 minutes accumulates about 50 hours only for each year. RF and control (including PLC, VME and other computers) system are major source of the down. The present year sees more trouble in control domain than the recent years. This is due to both initial malfunctioning of a new system and weared-out hardware of an old computer.
Accelerator operation group organization

Operation staff from AEC

Number of staff
Manager 2
Operator 26
(Ave. Age 30.6 Ave. Career 4.6)

Operator's maintenance work

Number of staff
Ion source 6
RF system 4
Vacuum 3
Power supply & Magnet 7
Beam monitor 6
Control system 7
Cooling 2

(shift to be scheduled, per day)

Operators meeting

Date Thursdays (9hr)
Participant Team-leader & Manager
Subject - Review operation of the previous week
(Beam reliability etc.)
- Follow-up machine problems
- Confirmation of the next week schedule

Shift schedule

Number of operators per shift (team) 3
Number of team 7

D : Daytime shift (8:30 - 20:30)
M : Maintenance (8:30 - 17:30)
N : Holiday

Team 1 Team 2 Team 3 Team 4 Team 5 Team 6 Team 7
MON D MM M HH
TUE D MM M HH
WED M D MM MM HH
THU M M D MM
FRI MM M D MM
SAT HH HH HH HH HH
SUN HH HH HH HH
MON MM M HH HH D
TUE D MM M HH
WED D MM M HH
THU M D MM MM
FRI M M D MM
SAT HH HH HH HH
SUN HH HH HH HH

Working Hour/week 39.0 39.0 45.0 41.0 41.0 39.5 37.5
% of time operators on shift 44.9 59.0 53.5 41.5 41.5 29.1 30.7

Annual Operation Hours and Energy of HIMAC Synchrotron

- 6MeV/u
- 7MeV/u
- 100MeV/u
- 133MeV/u
- 150MeV/u
- 160MeV/u
- 180MeV/u
- 200MeV/u
- 230MeV/u
- 290MeV/u
- 320MeV/u
- 350MeV/u
- 380MeV/u
- 380MeV/u
- 430MeV/u
- 460MeV/u
- 500MeV/u
- 600MeV/u
- 650MeV/u
- 800MeV/u

Ranking
Big Chars: 1 - 10
Medium Chars: 11 - 20
Small Chars: 20

( Lower Ring )

217
Annual Operation Hours for Various Ions

Unscheduled Down Time of HIMAC

<table>
<thead>
<tr>
<th></th>
<th>Control system</th>
<th>RF system</th>
<th>Cooling</th>
<th>Power supply &amp; Magnet</th>
<th>Ion source</th>
<th>Operation mistake</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>97.04-98.03</td>
<td>52:14</td>
<td>24</td>
<td>2:10</td>
<td>24:30</td>
<td>2</td>
<td>16:39</td>
<td>3</td>
</tr>
<tr>
<td>98.04-99.03</td>
<td>43:04</td>
<td>21</td>
<td>2:03</td>
<td>12:38</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>99.04-00.03</td>
<td>28:51</td>
<td>17</td>
<td>1:41</td>
<td>18:59</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>00.04-00.12</td>
<td>59:57</td>
<td>33</td>
<td>1:49</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5. PROBLEMS

The trouble occurrence has decreased from the initial years. This is in the line of our objective of reducing machine trouble and reducing the down-time when trouble occurs. However, trouble-shooting is a very good opportunity to train and educate operators in our case. Stable operation may end up incapable operators. Establishing the training method of operators is one of the problems we need to solve.

A phenomenon of concern is the fact that more than 20% of the operators suffer lumbago symptom. This is much higher rate of occurrence than the average of similar age-group. Although the present average age of the operators is 30 years, the symptom may show another shift-work problem, and apparently not everyone is able to continue the shift after 10 years from now.

6. ACKNOWLEDGEMENT

The authors are grateful to all the members of AEC and staffs of Accelerator Division of NIRS.
CLOSING REMARKS

Firstly I would like to start by thanking you all, the speakers for their excellent thought-provoking talks, the session chairmen for organizing and animating their sessions and keeping things both under control and reasonably on time. However, most importantly, I would to thank you all, the participants. Without your input, ideas and discussion, this workshop would not have been the success it has.

When we started, I tried to outline what I felt we were trying to do here:

- Encourage communication between facilities
- Exchange ideas and opinions on subjects of common interest
- Find out what other people are doing
- Create contacts between people

I am very happy that in the last four days we have exceeded even my most optimistic expectations in all respects, here in the meeting room, during the sessions, and outside, socially, in the restaurant, in the bar and even occasionally on the ski slopes! I hope that the contacts that have been made here will continue in the future as I am convinced that they are very useful.

We have already heard very complete summaries from the session chairmen, and I will note even try to repeat them here. Instead, I would like to share with you my personal view of the meeting.

Today particle accelerators face many challenges. We are moving from an era of ‘beam quantity’ (i.e. How much beam can we accelerate? How many particles can we put on the target?) to an era of ‘beam quality’, both in the product we deliver and in the services we provide. I was struck several times by the similarities between our operations and commercial companies. Words like quality control, customers (not users), service and product kept coming back in many of the discussions. With this in mind, I think we have to understand that our product is changing. Now we deal with many quality control issues in our control rooms, such as beam stability in SR sources, minimizing losses for radiation and safety concerns, beam brightness for LHC, minimizing refill times. In fact, one speaker was asked what is the most important factor in determining beam quality at his facility, and he replied beam size on target, even though they are in the middle of an energy upgrade!

On top of all these issues our control rooms provide many other services, as well as running accelerators to produce beam. We have heard about many of these during this week:

- Operating access systems
- Running machine safety systems
- Running large cryogenics facilities
- Providing water and electricity services for large laboratories
- Responding to fire alarms and any other emergencies
- Crisis management during incidents

With all these tasks to complete, and complete in parallel, it is not surprising that the discussion on ‘stress’ in our control rooms triggered many bells with me and many other participants.

We can summarize this by saying that an accelerator operator today has many more tasks than just pushing buttons to turn beams on and off. In this context, I believe that this issue of stress and operator environment is something that we have to take very seriously. Management, and here I include myself, cannot expect operators to complete more and more tasks on multiple machines indefinitely. We need to supply better tools to do the job, electronic logs, improved system automation etc. In addition
we also need to give operators the optimum environment in which to work, and we should remember to consult them when designing and/or changing their working environment. Because, in the end, it is relatively easy to find excellent accelerator physicists and project managers, but good accelerator operators are hard to find and even harder to keep.

On this question, I am not 100% convinced that the DESY system, where everyone does shifts is the way to go for my group, but I will definitely think about getting a few people from other groups into the control room shift rota, when I go back to CERN. This seems to have two large benefits, easing the shift load on existing operators, and improving inter-group communications and understanding.

For the idea of the ‘global operation’ of a machine, I am again unconvinced about this as a realistic method tool for everyday operation, but it may be useful to start looking at something, at least for accelerator physics experiments. Before we can envisage a test, we will need to install a console from one laboratory in another control room, and be prepared to let the second laboratory use it! Here I think that there are already big possibilities for progress inside CERN between the SPS and PS control rooms.

It is not particularly hard to imagine overcoming the technical problems behind installing a PS control console in the Fermilab control room, but supposing that we do, then Fermilab operators will need to know how it works. Therefore, maybe we will have to be prepared to exchange operators between laboratories for extended periods of time to prepare for such a test. Such exchanges are also very useful in helping to exchange ideas between different control rooms. Hopefully some of the contacts that have been made here will help to facilitate this.

I feel, along with many others, that this workshop is very useful and should continue. So I am very happy to announce that there is a proposal to hold the next WAO in 2003 at KEK in Japan. Several other laboratories in North America and Europe are also interested in organizing subsequent meetings after 2003. So the future looks very bright.

Finally, I would like to give some advice to any organizers of future workshops. ‘Get the best organizing and programme committees that you can’. I did and it is thanks to them that this meeting has been such a success.

Simon Baird
Chairman of the Local Organizing Committee