Upgrade scenarios for irradiation lines:

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UPGRADE SCENARIOS FOR IRRADIATION LINES

Upgrade of the Proton Irradiation Facility in the CERN PS EAST AREA

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Abstract:
This deliverable reports on the design and ongoing implementation of a new proton irradiation facility in the PS EAST AREA at CERN. The report is going beyond the deliverable D8.4, which contains only the design of the facility but not its implementation. As the implementation is not completed, some details about the facility might still change. They will be reported in the descriptive part of the safety file of the new facility which is intended to evolve throughout the life cycle of the installation and operation [1].
EXECUTIVE SUMMARY

A new proton irradiation facility (IRRAD) in the CERN PS East Area has been designed and is presently under construction. The document describes the beam properties and all technical infrastructure of the IRRAD facility in the areas accessible and non-accessible during beam operation. This comprises the irradiation bunker with all irradiation systems, the control room, the technical area, the storage area, the irradiation bunker, the shielding and the access chicanes. Electrical supplies, gaseous supplies, ventilation, safety and access systems are described in detail and finally a description on how the facility and the irradiation equipment in the beam area will be operated is given.
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GLOSSARY

AMF: Area Mixed Field radiation monitor
ADC: Analog to Digital Converter
AGM: Area Gamma dose rate Monitor
AU: Arrêt d'Urgence
AUL: Arrêt d'Urgence Local
ASD: Aspirating Smoke Detector
CCC: CERN Control Centre
CHARM: CERN High energy AcceleRator Mixed Feld/Facility
CFRS: CERN Fire & Rescue Service
CNRAD: CERN Neutrinos Radiation
DD: Displacement Damage
DIRAC: DImeson Relativistic Atom Complex
DUT: Device-Under-Test
H4IRRAD: Irradiation facility for LHC equipment, installed in the H4 beamline (SPS North Area)
HFM: Hand & Foot Monitor
IAM: Induced Activity Monitor
IRRAD: Proton Irradiation Facility
IRRAD1: Proton Irradiation Facility until 2012
IRRAD2: Mixed-field Irradiation Facility until 2012
PACS: PS Access Control System
PAD-MAD: Personal Access Devices-Material Access Devices
PASS: PS Access Safety System
PS: Proton Synchrotron
PPE: Personal Protection Equipment
R2E: Radiation-To-Electronics
RADFETS: Radiation-sensing Field-Effect Transistors
RADMON: Radiation Monitoring System
RAMSES: Radiation Monitoring System for the Environment and Safety
RP: Radiation Protection
SEU: Single Events Upsets
TID: Total Ionizing Dose
UPS: Uninterruptible Power Supply
VGM: Ventilation Gas Monitor
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1. SCOPE OF THE DOCUMENT

This document gives a general overview of the CERN Proton Irradiation Facility (IRRAD) and its infrastructure located in the East Area - bld. 157 (Figure 1). The East Area is located in the PS complex (Figure 2). The facility is presently under construction. It is foreseen to keep an updated version of this document following the lifecycle of the irradiation facility on the CERN EDMS server [1].

![Figure 1 - Geographic location of the PS East Area (bld. 157)](image)

The description of the East Area and its infrastructure is not treated in this document. All the safety relevant information concerning the East Area is available in the East Area Safety File [2]. The geographical scope of the IRRAD Safety File (Descriptive part) is shown in Figure 3.

![Figure 2 - Location of the East Area on the CERN accelerators layout](image)
2. GOAL & MOTIVATION

The proton irradiation facility in the PS East Area (known as IRRAD1), derived from the T7 beam line, was heavily and successfully exploited for irradiation of particle detector elements, electronics components and detector materials since 1992. The mixed-field irradiation facility (known as IRRAD2) was instead implemented behind the DIRAC experiment [3] (T8 beam line) and has been operated parasitically to DIRAC since 1998 [4]. These facilities received particle bursts - protons with momentum of 24GeV/c - delivered from the PS accelerator in “spills” of about 400ms (slow resonant extraction). In IRRAD1, the proton beam was spread out in order to produce a uniform irradiation spot of several square centimetres, while in IRRAD2 the irradiation was performed in a cavity with secondary particles produced by the primary proton beam after crossing a thick target made of carbon, iron and lead [5].

Based on previous studies carried out during the years 2007-2010 [6], the need of improved irradiation facilities at CERN based on a slow extracted proton beam was confirmed and consolidated [7]. More specifically, with the increasing demand of irradiation experiments, the old facilities located in the PS East Area suffered from a number of unpractical restrictions:

1. The space available was very limited and allowed only the irradiation of relatively small and stand-alone objects (limited services for cooling and/or electrical power). This is incompatible with the future needs of the experiments and the accelerators community which need to irradiate components in operation (e.g. powered and cooled);

2. The proton flux was limited on the one hand by the weakness of the shielding (due to lack of space for more) and, on the other hand, by the competition for proton spills with the DIRAC experiment. This is incompatible with the future needs for the high-luminosity upgrade of the LHC experiments (HL-LHC) requiring to integrate, in a reasonable time, a fluence exceeding $1 \times 10^{16}$ p/cm$^2$;
3. The access to the IRRAD1 proton facility required long cool-down time and a stop of the operation in the whole East Area for the full duration of the access since the facility was located inside the common primary beam area.

In the framework of the AIDA project [8], an overall upgrade of the East Area IRRAdiation (EA-IRRAD) facilities has been proposed. The proposal was based on the assumption that the DIRAC experiment will come to an end by the end of 2012 and that its experimental apparatus will be dismounted during the Long Shutdown 1 (LS1) scheduled for the years 2013 and 2014 [9]. The new EA-IRRAD facility would then be installed during LS1 in the area previously occupied by the DIRAC experiment.

The proposal being accepted, the construction project of the new EA-IRRAD facilities has begun in November 2012. As shown in Figure 4, the new proton irradiation facility (named IRRAD1) is built more or less at the location previously occupied by the DIRAC target and its upstream detectors, while the mixed-field facility (named CHARM2) [10] is constructed downstream of the proton facility. This solution has several advantages:

1. The access to the facility is independent of the rest of the PS East Area;
2. The layout can be optimised for exploitation as an irradiation facility, with appropriate shielding, ventilation, dedicated infrastructure and sufficient space for a proper installation and easy accessibility of the equipment;
3. In many cases, the same protons can be used for the proton IRRAD and the mixed-field CHARM facility at the same time, thus leading to a strongly improved PS cycle economy and optimal use of available protons. The beam parameters taken for the design of the proton IRRAD facility are the following:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam energy [GeV/c]</td>
<td>24</td>
</tr>
<tr>
<td>Maximum number of particles per PS spill</td>
<td>~5×10(^{11})</td>
</tr>
<tr>
<td>Maximum number of spills per super-cycle</td>
<td>6</td>
</tr>
<tr>
<td>Maximum number of particles per second</td>
<td>6.7×10(^{10})</td>
</tr>
<tr>
<td>Super-cycle length [sec]</td>
<td>45.6</td>
</tr>
<tr>
<td>Maximum number of days per year</td>
<td>200</td>
</tr>
</tbody>
</table>

More information on the beam properties is available in [11]. A detailed description of the modifications carried out in the East Area during LS1 is available in Ref. [12].

While the IRRAD proton facility will continue to be mainly devoted to study the radiation hardness of detectors, electronics components, systems and materials for the experimental community (PH department), the CHARM mixed-field facility will mainly host irradiation experiments for the CERN accelerator & technology sector (R2E project - EN department). The CHARM facility therefore replaces “ad-hoc” irradiation

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1  [www.cern.ch/irradiation](http://www.cern.ch/irradiation)

2  [www.cern.ch/charm](http://www.cern.ch/charm)
areas such as CNRAD [13] and H4IRRAD [14], which have been extensively used by the accelerator community during the past years.

![Diagram of the IRRAD facility](image)

Figure 4 – Layout of the new EA-IRRAD facility combining IRRAD and CHARM

Part of the studies for the installation of the new IRRAD facility is funded via the AIDA project\(^3\), which also intends to support its future exploitation via transnational access in case the AIDA-2020 project will be approved. The equipment tested at IRRAD can be divided into four general categories:

- Small particle detector structures, samples of materials and electronic components irradiated “stand-alone” or mounted on individual test boards;
- Large equipment, such as prototypes of particle detector systems (including the detector and the associated front-end electronics), irradiated in operational conditions (powered) and sometimes cooled;
- Heavy equipment such as samples of material and/or absorbers used for calorimeter detectors (scintillating crystals, etc.);
- Small particle detector structures, samples of materials and electronic components irradiated at cryogenic temperatures (1.8k/4.2k).

The IRRAD facility is planned to start operation as from autumn 2014. The current document provides a description of the IRRAD facility, its main elements and infrastructures.

3. TECHNICAL DESCRIPTION

3.1 GENERAL LAYOUT

The new proton facility (IRRAD) is located on the T8 beam-line in the PS East Hall (building 157) where a primary proton beam with a momentum of 24GeV/c is extracted from the PS ring. As shown in Figure 4 and ANNEX 1, the space allocated for irradiation tests in the south part of the PS experimental area (~>500 m\(^2\)) is

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\(^3\) [www.cern.ch/aida](http://www.cern.ch/aida)
shared between two irradiation facilities: the proton IRRAD is located upstream while the CHARM mixed-field facility is implemented downstream. Since most of the protons pass through the IRRAD facility without interacting, the mixed-field facility can profit from the same protons used by IRRAD.

ANNEX 2 shows the details of the IRRAD bunker surrounded by the shielding blocs where the proton beam travels in the air. The bunker defines the space available for the installation of the irradiation equipment (remote-controlled shuttle and tables) and has dimensions of about 3.2m (W) × 18.0m (L) × 2.4m (H) for a total volume of about 140m³. Locally, in the downstream part of the irradiation bunker, the ceiling of the facility is increased by 0.8m, to reach a total height of 3.2m in order to accommodate the cryogenic equipment. The shielding walls and roof are made of standard concrete and cast iron blocks. Several layers of blocks, properly arranged, are needed to guaranty the reduction of the prompt radiation down to a level compatible with the radiological classification of the PS East Hall as Supervised Radiation Area [15]. Extensive simulation studies were carried out in order to define first, and optimize later, the layout of the IRRAD facility bunker [16] as described later in section 4.9.1.

In particular, to limit the neutron skyshine, a roof made of concrete blocks with a thickness of 5.6m has been defined for the IRRAD area. As mentioned previously, the thickness of the roof is reduced by 0.8m over a length of 1.6m along the beam direction in the location dedicated to the cryogenic setup (section 3.3.4). It is not foreseen to open the roof for routine maintenance operations. With the exception of the cryogenic transfer-line, the beam elements, as well as most of all other equipment inside the IRRAD facility bunker, are positioned on the floor of the experimental area.

Standard room temperature (RT) and humidity conditions are requested for the environment inside the bunker. A dedicated ventilation system guarantees the respect of the min/max temperature parameters, the removal of the heat loads present in the rooms and a constant air extraction to enhance the dynamic confinement (e.g. small under-pressure) of the IRRAD and CHARM volumes with respect to the adjacent areas. The volume of IRRAD vented by this system is shown in detail in ANNEX 1. Details about the ventilation system are available in [17] as well as in the Descriptive part of the CHARM Safety File [10].

The IRRAD bunker is subdivided in three zones (going from upstream to downstream) according to the nature of the samples to be irradiated: see details in section 3.3.1. In between each irradiation zone, a separation concrete wall of thickness 80cm (with a hole to allow the beam to pass through) is placed in order to reduce the radiation background during irradiation and to minimize the ambient equivalent dose to the personnel during the access to the area. As visible in ANNEX 2, in order to minimize further the secondary radiation produced by the interaction of the proton beam with the air, two vacuum beam-pipes are installed in the empty space between the installed irradiation systems.
ANNEX 2 also shows the details of the peripheral infrastructure, the area containing the external premises annexes to the proton irradiation bunker accessible by the personnel during beam operation. These include storage space, services (gas supplies, cooling systems, etc.) and irradiation equipment control. The accessible area extends over about 200m². In summary, with respect to Figure 5, the IRRAD facility consists of two main areas:

- Area accessible during beam operation:
  - Control room
  - Technical area
  - Storage area and Buffer Zone (including the IRRAD1b barrack)
  - Dewar delivery area

- Area not accessible during beam operation:
  - Irradiation Bunker
  - Access chicane

### 3.2 ACCESSIBLE AREA DURING BEAM OPERATION

The aim of the accessible area is to control the irradiation experiments, prepare the samples for irradiation and allow the user of the facility to setup their equipment to test and measure the Devices Under Tests (DUT) installed in the non-accessible area of T8 during and after irradiation. A detailed view of the IRRAD peripheral infrastructure is given in Figure 6.
The entrance in the East Hall of bld. 157 (Supervised Radiation Area) is granted to people wearing a personal Dosimeter (DIS type)\(^4\) who have followed the appropriate CERN Safety Courses and with the required PPEs. More details on the access conditions will be available on the Operational Part of the Safety File.

### 3.2.1 Control Room

The new EA-IRRAD control room in bld. 157 is realized as a modular office space mounted on a large metallic structure (Figure 7) next to the PAD/MAD system giving access to both the IRRAD and CHARM areas (see Figure 5). The IRRAD control room, with a surface of about 42m\(^2\), is the barrack sitting on the ground floor (157/R-005). This room hosts the front-end electronics used to control the irradiation tables and the shuttle system, multiple fix displays for the beam and the irradiation equipment survey, as well as the users’ equipment installed during the irradiation experiments. The position of the counting room has been chosen to minimize the cable length required to connect the DUT exposed to the proton beam in the irradiation area. The detailed layout of this counting room is available in [18].

The control room will house the following equipment (Figure 8):

- 2x patch panels (indicated by PP in Figure 8) providing the connectivity with the equipment inside the irradiation area;
- 1 rack (also used to host the PS timing distribution system);
- several desks equipped as work-spaces for the users;
- 1 cupboard for the storage of instrumentation and equipment.

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\(^{4}\) The DIS dosimeter will be soon required to open (e.g. unlock) the entrance doors of bld. 157.
One barrack with a surface of about 20-25m² dedicated to the IRRAD users outside the East Area (close to the main access door 17 of bld. 157.) is also foreseen as part of the infrastructure. This space will allow the users to prepare the samples for the proton irradiation, as well as to control remotely the measurement equipment during their irradiation tests. The availability of this external workspace will reduce the time spent by the users inside the supervised radiation area. For the year 2014, a temporary barrack has been rented and shared with the CHARM team (bld. 6157). The need of a permanent barrack outside bld. 157 will be assessed during the run 2014.

3.2.2 Technical Area

As shown in Figure 6, the technical area of about ~25-30m² hosts the loading station for the remote controlled shuttle system as well as the cooling systems (two Chillers to produce cooling fluid down to -30°C and one VORTEX generator). From this area, it is also possible to access the shuttle conduit (located behind a portion of easily removable radiation shielding) in case of maintenance interventions. The technical area can also be used to locate experimental equipment belonging to the users during irradiation experiments.
3.2.3 **Storage Area, Buffer Zone and Irrad1B Barrack**

The storage area is a bunker of about 5m×10m delimited by concrete shielding blocks of 0.4m thickness classified as Supervised Radiation Area. The internal layout of this area is organized in two sub-areas that will be used for the storage of the irradiated samples at both room and low temperature (-20°C) inside dedicated freezers. As visible in Figure 9, the whole area is accessible through a door placed at the end of the technical area. A second door, giving access to the storage space under the IRRAD1b barrack can be opened only from the inside of the storage area as an emergency exit. The access door is kept locked under the responsibility of the IRRAD facility personnel. The walls of the inner part of the bunker are painted and the floor covered with a resin (e.g. the same material used for the floor of the irradiation bunker area).

![Figure 9 – Layout of the IRRAD storage area. This includes the RP buffer zone used for the transport of the irradiated materials inside/outside bld. 157.](image)

The first storage bunker of about 8m² (on the left-hand side of Figure 9) is dedicated to the storage of the high activity material; this space is covered with a 0.4m thick concrete roof. The access to this storage space is key-locked. The second storage area of about 12m², on the right-hand side of Figure 9, is instead used for the storage of low activity samples and for the preparation of cumbersome equipment (such as the cryostat as an example) before the irradiation experiments. The low activity area is without roof such as, in case of need, it is possible to lift/transport equipment using the overhead crane.

The middle area is instead a dedicated workplace equipped for the manipulation of the irradiated samples and the installation of semi-permanent measurement setup. Moreover, as shown in Figure 6, the storage bunker is located next to the existing IRRAD1B barrack (see Figure 10). This is installed in the first floor of bld. 157, and accessible through the footbridge on the sidewall of the East Area (see Figure 5 on the right-hand side). The IRRAD1B barrack will allow the users to install long-lasting post-irradiation measurement setups wired to the samples in the downstairs area via a series of dedicated pre-installed cable ducts and patch-panels. This
allows the users to keep, when possible, their irradiated material on site without the need of transporting it outside the shielded and the classified radiation area. The roof of the workplace is covered with a 0.4m concrete shielding and it access is controlled via a key-locked fenced door.

Figure 10 – IRRAD1B barrack (left) bld. 157, 1st floor. Fenced-area under IRRAD1B (right): non-radioactive storage

The 23m² fenced area delimited under the IRRAD1B barrack shown on the right-hand side of Figure 10 is accessible directly from bld. 157 and it is used to store non-radioactive items as new cables to be used in both the CHARM and the IRRAD Facility.

Finally, for the RP buffer zone visible in Figure 6, a shielded area of more than 12m² is foreseen next to the IRRAD counting room. This area built with concrete blocks is compliant with INB rules and equipped for the transit and the traceability of radioactive material (accessible for users, RP and the infrastructure coordinators) [19].

3.2.4 Dewar Delivery Area

This area (see Figure 6) is the location where the Dewars filled with liquid He are installed and connected to the cryogenic transfer line of T8 as described later in sections 3.3.4 and 5.3.3. The Dewars are moved in this location using the overhead crane available in bld. 157.

3.3 NON-ACCESSIBLE AREA DURING BEAM OPERATION

The overall aim of the non-accessible area is to perform irradiation tests on samples, materials, electronic components & systems. It will house equipment that will allow for automatic or semi-automatic positioning of the DUT (Figure 11).

In addition to the personal Dosimeter (DIS type), an operational Dosimeter (DMC type) and a valid activity declared in the CERN IMPACT⁵ system will be mandatory to access the irradiation bunker on T8. In addition, a new material access folding door (MAD) has been installed for the T8 operation, while the previously existing door PO17 has been condemned (see section 4.9.2) [2].

⁵ https://pptevm.cern.ch/impact/secure/index.gsp
3.3.1 Irradiation Zones

With reference to Figure 11, the IRRAD bunker is sub-divided in zones dedicated to different type of irradiation experiments. Details about each irradiation zone and their usage are available in Table 2. Moreover, a fourth zone labelled Zone 4, in a partially shielded area, is equipped for the installation of readout electronics and/or DAQ systems that need to sit close to the DUT during irradiation. The average distance from the irradiation tables of Zone 2 to the Zone 4 area is of about 5m. Zone 4 consists of a series of shelves installed at 20cm from the floor and of a dedicated Patch Panel allowing the direct connection of the electronic systems with the IRRAD counting room as shown in ANNEX 2. Information about the radiation background expected in the region of Zone 4 is available in section 5.3.4.

During beam operation mode, access to the non-accessible area will be forbidden due to the presence of significant radiations. Besides, as the IRRAD non-accessible area is classified as “controlled radiation area” when the beam is OFF, a DGS/RP technician has to be present to perform a radiological control and remove the RP veto and thereby grant access for any intervention done in the area.

Inside the IRRAD bunker a fenced gate, separate the access of Zone 3 from the other two zones (not visible in Figure 11). This physical separation has been put in place in order to limit the unattended access of the facility users close to the most activated equipment as well as to limit the access close to the cryogenic equipment during the filling procedure for the cryostat (see later section 3.3.4). A rail system is installed on the ceiling of Zone 3 to allow the handling of heavy objects and of the cryostat.

Table 2 - Detail of the irradiation zones in which the new IRRAD facility is sub-divided

<table>
<thead>
<tr>
<th>Name</th>
<th>Usage</th>
<th>Details</th>
<th>Irradiation Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 1</td>
<td>Tests of low-Z material</td>
<td>Zone dedicated to the irradiation of low-Z materials such as small silicon detectors. The samples are mounted on remote controlled irradiation tables (at RT or cooled down) or positioned into the proton beam by means of the remote controlled shuttle system. The irradiation of big surfaces (of the order of 100cm²) is possible by periodically moving the samples on the irradiation tables in the transversal plane (x,y) w.r.t. the beam direction.</td>
<td>remote-controlled irradiation tables &amp; shuttle system</td>
</tr>
<tr>
<td>Zone 2</td>
<td>Tests of medium-Z material</td>
<td>Zone dedicated to the irradiation of medium-Z materials such as electronics components, PCBs, etc. The irradiation of big surfaces (of the order of 100cm²) is possible by periodically moving the samples on the irradiation tables in the transversal plane (x,y) w.r.t. the beam direction.</td>
<td>remote-controlled irradiation tables</td>
</tr>
<tr>
<td>Zone 3</td>
<td>Test of high-Z material and under cryogenic conditions</td>
<td>Zone dedicated to the irradiation of high-Z materials such as calorimeter crystals. The samples will be mounted on remote controlled irradiation tables (at RT or cooled down). The irradiation of big surfaces (of the order of 100cm²) is possible by periodically moving the samples on the irradiation tables in the transversal plane</td>
<td>remote-controlled irradiation tables and cryostat</td>
</tr>
</tbody>
</table>
(x,y) w.r.t. the beam direction. To simplify the handling of heavy objects, a rail with a hoist is also installed on the ceiling of this zone.

In this zone, it is also possible to perform irradiations in cryogenic conditions using a cryogenic setup operating with liquid He. The position of the cryostat (x,y) w.r.t. the beam axis will be controlled remotely.

![Diagram of the irradiation area](image)

*Figure 11 – Layout of the non-accessible area*

### 3.3.2 Access Point

As in all other CERN primary beam areas, a common set of one Personnel (PAD) and Material (MAD) access devices control the entrance to both irradiation facilities and provides the required beam-interlock functionalities. The access gate is located in the control room area, next to the IRRAD control room at the ground floor as shown in Figure 5 and Figure 11. Details about this system and the sectorisation of the irradiation areas are available in Reference [20].

### 3.3.3 Irradiation Systems

In the proton irradiation area, the particle beam impinges directly on the samples to be tested. The samples are installed and positioned in the proton beam by using two different types of holders: the *IRRADx* tables and the shuttle (*IRRAD1*).

#### 3.3.3.1 Irradiation Tables

The tables are remote-controlled stages providing the possibility to position the samples with ±0.1mm precision in the transversal plane (X-Y) with respect to the beam axis. The tables also rotate over the azimuthal
angle (θ) in order to achieve a precise alignment with the beam within ±0.025°. The prototype of an irradiation table is shown in Figure 12. The installation of the samples on the table requires the access to the proton area.

Three independent groups of tables will be installed in the three zones of the IRRAD facility bunker. Zone 4 will be used to install users’ electronics equipment and, therefore, will not host any irradiation equipment (see previous section 3.3.1). A maximum of three tables per group (e.g. 9 in the whole facility) can be installed and operated. The standard facility configuration will be:

1. 3 tables in Zone 1 (named IRRAD3, IRRAD5, IRRAD7) and Zone 2 (named IRRAD9, IRRAD11, IRRAD13);
2. 2 tables in Zone 3 (named IRRAD17, IRRAD19), next to the cryogenic setup (named IRRAD15).

This enables the irradiation of several materials at the same time with a “clean” proton beam and minimum background induced by scattered secondary particles. Moreover, the implemented shielding configuration minimizes the dose to the personnel during the access to the different groups of tables inside the area. On each table of Zone 1 and Zone 2, the maximum volume available for irradiation is of 200×200×500mm³ while the maximum samples weight allowed is 10Kg. In Zone 3, the maximum weight allowed is 50Kg. The tables can automatically move (e.g. “scan”) the samples during irradiation in order to provide a uniform irradiation spot over the 200×200mm² surface (or a smaller portion of it, depending on the users request). On these tables, the test of equipment “in operation” (e.g. powered and connected to a DAQ system) is possible as well as irradiation of detector components at low temperature, down to -15°C. Four separated cooling systems, located in the outside technical area, provide chilled refrigerant and compress air for the VORTEX system to custom designed thermostatized irradiation boxes (see Figure 6). More details on the irradiation table construction and operation can be found in [21]. Each irradiation table is equipped with an emergency stop button (AU) which cut the motors power in case of failure or abnormal operation.
3.3.3.2 Irradiation Shuttle

The shuttle (named IRRAD1) is a remote-controlled conveyor travelling on a rail system that allows the positioning of “small” objects in the beam (typically silicon detector test-samples) without the need of human access into the area. This system guarantees a precise X-Y alignment of ±0.1mm with respect to the beam axis and it is mainly designed for the irradiation of passive samples at RT.

![Remote-controlled shuttle for proton irradiation](image)

The shuttle for the new proton irradiation facility is cloned from the previous IRRAD1 and IRRAD2 shuttles already installed and operational on the T7 and T8 beam lines of the East Area since 1998 [4]. The shuttle travels across the shielding blocks for a length of about 10m inside a conduit of 400×400mm². To minimize the direct radiation streaming, the path of the conduit follows a chicane located in between the first and the second group of irradiation tables (see Figure 11). Figure 13 shows the sample holder for the shuttle system. Figure 14 shows instead the shuttle chicane and the loading station, which is located next to the counting room outside the irradiation area.

On the shuttle, the maximum volume available for irradiation is of about 50×50×200mm³ for a maximum weight of about 1Kg. The standard size of the beam spot on the shuttle system (σ) is of about 5-7mm RMS but it can vary according to the different beam focusing options (see section 3.4). In particular, focusing on the shuttle system, the spot size can be reduced further down during high-intensity irradiation periods.

Two radiation monitors (Automess 6150AD6) are used to measure remotely the radiation levels of the irradiated samples. One AD6 is located on the loading station, while an AD6 remote probe is located inside the conduit at the position used for the cool-down of the samples before manipulation (“park position” in between the shielding blocks). Both probes perform measurements at ~10cm from the samples. The shuttle system is equipped with an emergency stop button (AU) which cut the motors power in case of failure or abnormal operation.
3.3.4 Cryogenic System

The IRRAD proton facility is also equipped with a cryostat (named IRRAD15) filled with liquid Helium to allow special irradiation runs with samples exposed at cryogenic temperature down to 1.8K (see Figure 11). The thickness of the cryostat wall is reduced in the beam penetration region to minimize the interaction of the proton beam with its material (see Figure 15 – right-hand side). The cryostat is mounted downstream the proton area on a dedicated remotely controlled irradiation table (see Figure 15 – left-hand side) which allow moving the cryostat into the beam or close to it (along the x-axis only). The characteristics of this remote stage are equivalent to the one described in section 3.3.3.1.

The mounting of the samples inside the cryostat and their electrical connectivity is carried out while the cryostat is sitting in the storage area. Afterwards, the cryostat is transported inside the irradiation bunker, through the access chicane, using a custom-made trolley on four wheels. Once Zone 3 is reached, the cryostat is loaded on the irradiation table using a hoist installed on the rail system (see section 3.3.1). For the installation/removal of the cryostat, the irradiation table can also be moved up and down (along the y-axis). This operation can be performed with a remote control located inside the IRRAD bunker. This requires the presence of an operator on place in order to survey the vertical movement and therefore reduce the risk of collision (e.g. damage) with the transfer line.

Once the installation inside the IRRAD bunker is completed, this cryogenic system will be used by the BE-BI group (main user) and operated by qualified users (with valid CERN Cryogenic Safety Training) under the supervision of the TE-CRG group. The liquid Helium will be supplied to the cryostat by manual refilling via a dedicated (permanent) transfer line connected to a Dewar located outside the radiation area.
3.3.5 Motor Room (Charm Mobile Shielding)

The motorisation of the mobile shielding use in the CHARM facility [10] is located in the technical room located between the IRRAD and CHARM facilities (see ANNEX 1), and thus access for repairs or maintenance of this equipment will be done via the IRRAD facility.

3.3.6 Access Chicane

The access chicane is the corridor that allows the users to access the irradiation area for the installation of their equipment on the irradiation tables and their connection/disconnection. Ventilation doors (Figure 11) are placed on the IRRAD chicane to guarantee the confinement of the area and the proper operation of the ventilation system. The equipment is transported inside the area by hand or with the help of trolleys.

3.4 BEAM INTENSITY AND OPTICS

The standard proton irradiation beam with a momentum of 24 GeV/c is extracted from the PS ring to the T8 beam-line in “spills” of about $5 \times 10^{11}$ particles (EASTB). The intensity of the irradiation beam depends on the number of spills per PS super-cycle (CPS). The duration of the basic CPS foreseen for the operation 2014 onward is of about 30s. Beam scheduling and sharing among the other experiments running in the East Area allow estimating a maximum of three spills per CPS delivered to the irradiation facilities during the high-intensity periods. This number decreases to one or two when the other experiments require the beam or when the PS serves as injector for the other accelerators of the CERN complex [22].

Having a dedicated beamline for the irradiation facilities operation results in a great flexibility in terms of beam sizes: the focus can be moved slightly upstream (toward the position of the first irradiation table) or downstream (toward the table located in zone 3) by any amount. The beam size ($\sigma$) relevant for proton irradiation experiments, on both the horizontal and vertical planes, ranges from 5mm to 15mm RMS. Reference [11] describes all relevant parameters for the T8 beamline including the variation of the beam spot along the Z coordinate as function of the various focusing options. In order to optimize the dimensions and the homogeneity of the beam spot, the convergence of the beam over the Z coordinate can be further tuned by sweeping it on both coordinates using quadrupole corrector magnets.
4. INFRASTRUCTURE

4.1 ELECTRICAL SUPPLY

4.1.1 General Power and Distribution

The IRRAD infrastructure (bunker and external premises) is supplied with the 220V and 380V power network for standard equipment as well as for general services. The electrical power is derived from the substation located in building 152 as described in the CHARM Safety File [10]. The power needed for the irradiation equipment and experiments is driven inside the IRRAD bunker on separate connections and made available to the users toward dedicated patch-panels (see section 4.5.1). All the power systems in IRRAD will be controlled by a chain of local emergency switches (AUL) and in case of failure or abnormal operation power, the whole zone will be isolated with exception to normal and emergency lighting systems.

4.1.2 Unbreakable Power Supply (UPS)

The UPS power supplies for bld. 157 will be renovated after LS1. Two independent UPS networks will serve the East Hall:

- UPS No1 (40kVA): CHARM, IRRAD and CLOUD facilities
- UPS No2 (20kVA): Rack BY03, Beam Stopper and Access system

The UPS power necessary for IRRAD (estimated to 5kVA) is supplied by the UPS No1 which is based on standard network (not backed-up by diesel motor). This system guarantees an autonomy of 10-20 minute as required to shutdown the sensitive electrical equipment and/or put the irradiation systems in a safe state.

4.1.3 Lighting

The standard lighting installed inside the IRRAD bunker is qualified for operation in radiation environment. The master switch for its control is located in the IRRAD counting room. An emergency network will be created to provide lighting in case of evacuation or unforeseen power cut causing the loss of the general supply. This network will be powered by a 48V DC battery system.

4.2 COMPUTER NETWORK

Ethernet sockets for fixed and portable computers on the General Purpose Network (GPN) are available in the IRRAD control room as well as in the IRRAD1B barrack. The external premises of IRRAD are equipped with Wireless Local Area Network (WLAN) using CERN standard WI-FI.

The IRRAD bunker is not equipped with WLAN. A series of Ethernet connections (on RJ45 connectors) are available on the patch-panels installed in each irradiation zone and are supplied from a main programmable Ethernet switch (24-ports) located in the IRRAD control room. Inside the IRRAD bunker, the GSM network (with data connection) will be also present.

4.3 GAS AND COMPRESSED AIR

The IRRAD facility is supplied with the standard neutral gas available at CERN. Nitrogen and oil-free and dry compressed air (6 bars main line with high flow) are delivered in the technical area by the EN department as part of the general services. From this point, a dedicated network of pipes brings the nitrogen and the compressed air in the various locations of the IRRAD infrastructure. Compressed air is used to supply the...
VORTEX cooling system [23], while nitrogen is flashed inside the cold-boxes in order to guarantee a dry atmosphere and the absence of condensation during irradiation. The maximum flow of nitrogen is of 200cc/min when all cold boxes are simultaneously operational. No flammable gas is used for standard irradiation experiments. The facility is not equipped with other types of gas for the operation of particle detectors.

4.4 COOLING

In addition to the VORTEX cooling system described in the previous section (two units finally installed in IRRAD), two independent liquid-based cooling systems (Chillers), located in the technical area, provide chilled refrigerant to custom designed thermostatized irradiation boxes (as the one visible in Figure 12). These are closed-loop systems circulating a few litres of refrigerant from the outside to the inside of the IRRAD bunker. The Chiller units are supplied with the 380V power network. Both the VORTEX and the Chiller units are operated and maintained by PH-DT.

4.5 CABLEING & PIPING

As shown in ANNEX 1, two cable-trays dedicated to the IRRAD facility have been installed between the counting room and the irradiation bunker. Space for installing users’ equipment is available inside the control room, as well as in the technical area.

Several dedicated conduits allow the passage of cables and pipes through the shielding walls:

1. The first two channels (200mm (W) × 100mm (H)) are located in the access chicane. This allows the users to install temporary signal and power cables from the counting to the irradiation zones 2 and 3 with the shortest-possible distance.

2. The second three channels (of about 300mm (W) × 100mm (H) each) are embedded in the shielding upstream the shuttle system. Thanks to the arrangement of the shielding walls, it has been possible to build a conduit connecting the technical area to the irradiation Zone 1 through a straight line.

Cables and pipes belonging to the services and to the fixed IRRAD infrastructure, as well as dedicated users’ cables are driven through this second “big” channel. The document EDMS 1378434 lists in detail the cables and pipes installed in the channel as part of the fixed IRRAD infrastructure. The cable length required to connect the fixed IRRAD equipment to the counting room range from 13m to 20m, depending on the considered irradiation zone. The fixed infrastructure does not include pre-installed optical fibres lines.

4.5.1 Connectivity inside the IRRAD Bunker

A set of pre-defined connections for the users are distributed over four patch-panels located inside the irradiation bunker. The position of the patch-panels is indicated in ANNEX 2 (red squares). The patch-panels are installed 1.5m above the ground level and are based on front panels for industrial chassis (CERN SCEM 06.61.12.303.9). An example of a patch-panel installed inside the IRRAD bunker is shown in Figure 18. These connections of the IRRAD bunker are made available inside the IRRAD counting room over two-patch panel located as shown in Figure 8.

The detailed list of connections available on all patch-panels installed in every zone is detailed on the Document EDMS 1378434.
4.6 EQUIPMENT HANDLING AND LIFTING

A rail system with a hoist is installed in Zone 3 inside the IRRAD bunker. The installed rails support a total charge of 200kg. A custom-made trolley is used for transporting the cryostat in its irradiation position. In most of all other cases, the DUTs are manually handled lifted and transported inside IRRAD by the users.

4.7 VIDEO CAMERAS

The three-irradiation zones are equipped with video cameras. The chosen locations allow surveying the operation of the movable irradiation equipment inside the IRRAD bunker (Figure 16). The chosen devices are Radiation-hardened solid-state CID-based video camera [24] as the one already in use at CERN in transfer lines and target areas. The CID structure is inherently radiation resistant allowing at least an order of magnitude improvement in operation in radiation environments compared to CCD and CMOS-based cameras. The relatively low radiation background inside IRRAD (see later section 5.3.4) will allow a smooth operation of these devices, preserving the quality of the image over a long time without the need of regular maintenance.

4.8 VENTILATION SYSTEM

A ventilation system for the new IRRAD and CHARM facilities has been designed and it will be installed and commissioned by the cooling and ventilation group (EN-CV) of the EN department. Details about this system and the requirements of the two facilities are available in [17].
Figure 17 - Cables and pipes installed in IRRAD as part of the fixed infrastructure (PRELIMINARY)
4.9 SAFETY SYSTEMS

4.9.1 Radiation Safety

4.9.1.1 Shielding

Shielding blocks made of concrete and steel or cast iron surround the IRRAD facility. Additional layers of Makrolon/plaster, some steel sheets, as well as optional internal sealing will be used in case of need to enhance the air-leak tightness. The overall aim of the shielding is to reduce the prompt radiation dose around IRRAD below the limit value of 3 µSv/h for Supervised Radiation Area - permanent workplaces (for the control room) and below the limit value of 15 µSv/h for Supervised Radiation Area – low occupancy places (for the other annex areas) [15].

The layout of the shielding for IRRAD (ANNEX 2) has been defined according to the different operational scenarios (beam intensity, beam-spot size, etc.) taking into account the variety of materials that can be exposed to the primary beam. The 24 GeV/c proton beam impinging on the samples to be irradiated generates a shower of secondary particles, among them, significant amounts of charged hadrons, neutrons, photons and muons are produced. As a result, the equipment and the air located in the target area and exposed to the beam or the secondary particles will be activated.
Table 3 - Irradiation scenarios foreseen for the different types of proton irradiation experiments

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Material loaded on IRRAD systems</th>
<th>Beam size (FWHM)</th>
<th>Instantaneous intensity</th>
<th>Integrated intensity (# days)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>Silicon (1×1×9 cm³) + PCB (10×10×2 cm³)</td>
<td>1.2×1.2 cm²</td>
<td>6.7×10^{10} p/s (5×10^{11} p/spill)</td>
<td>1.0×10^{19} p (180 d.)</td>
<td></td>
</tr>
<tr>
<td>Special 1</td>
<td>LYSO (3×3×22 cm³)</td>
<td>3.0×3.0 cm²</td>
<td>7.5×10^{9} p/s (3×10^{11} p/spill)</td>
<td>9.0×10^{15} p (14 d.)</td>
<td>2 runs (1 run = 7 days)</td>
</tr>
<tr>
<td>Special 2</td>
<td>Pb (12×12×25 cm³)</td>
<td>3.0×3.0 cm²</td>
<td>1.1×10^{10} p/s (5×10^{11} p/spill)</td>
<td>7.3×10^{15} p (7 d.)</td>
<td>1 run over 7 days</td>
</tr>
<tr>
<td>Special 3</td>
<td>Cryostat (1.5 cm Si + He-filled vessel)</td>
<td>1.2×1.2 cm²</td>
<td>6.7×10^{10} p/s (5×10^{11} p/spill)</td>
<td>8.0×10^{16} p (14 d.)</td>
<td>2 runs (1 run = 7 days)</td>
</tr>
</tbody>
</table>

Table 3 defines the irradiation scenarios foreseen for the different types of proton irradiation experiments. This includes the typical materials exposed to the proton beam, together with their transversal dimensions and their maximum thicknesses. The standard irradiation conditions are defined using the maximum conceivable proton flux obtainable from the PS accelerator (6.7×10^{10} p/s). This corresponds to six proton spills per CPS of about 45s duration as used before the LS1. More details about the FLUKA calculations and the radiation protection assessment of the IRRAD facility can be found in [16] and [25].

4.9.1.2 Radiation Monitoring (RAMSES)

Radiation Safety is assured by a set RAMSES radiation monitors installed inside the irradiation bunker as well as on the external perimeter and in the access area of the new facilities as shown in Figure 19. The RAMSES system allows for the measurement of the prompt radiation (mainly neutrons and muons) and the residual radiation inside the irradiation area. The layout and list of monitoring instrumentation are the following (see glossary for the abbreviations):

- 5 AMF at the beam level and 2 AMF on the shielding roof (indicated in blue in Figure 19) to monitor the neutron and photon radiation fields;
- 2 IAM to measure the ambient residual radiation before entering the zone;
- 1 HFM to monitor the potential presence of contamination on feet and hands;
- 1 AGM to monitor the gamma and muon radiation fields behind the beam dump;
- 1 VGM to monitor the activation level of the released air.

Relevant for the access in the IRRAD bunker are the Induced Activity Monitors (PMI) number 812 and 813 located in the pathway separating Zone 1 from Zone 2 and in the Zone 3 respectively. A Hand & Foot Monitor (HFM) is also available at the entrance of the irradiation areas. More information on the air activation and RP monitoring studies can be found in [25].
4.9.1.3 Radiation Alarm

Local radiation alarms and flashing lights (PADEA811S-x) are installed in both counting rooms and are triggered if excessive radiation levels are detected by the monitor located at the entrance of the IRRAD and CHARM areas. Their layout is detailed in the CHARM Safety File [10]. Two thresholds have been defined:

- **ALERT**: visual alert in the Radiation Alarm Unit (orange light) and audible alarm;
- **ALARM**: visual signal in the Radiation Alarm Unit (red light) and audible alarm, the Cern Control Centre (CCC) is informed automatically. An operator has to stop the primary proton beam from the control room.

4.9.2 Access Safety

IRRAD is part of the new East Area Irradiation Facility (EA-IRRAD) located on the T8 beam line. As a primary beam area, a SIL 3 access system has been required. A common and new PAD-MAD system is shared with CHARM on the Salève (Bellegarde or South) side of the East Area. This system complies with the PASS-PACS implementation over the LS1 period on the PS Complex. The transport of standard materials, samples and the cryostat to the IRRAD facility is done through the MAD. More details about the access system can be found in [2].

4.9.2.1 Interlocks

In order to ensure the Safety for the personnel, a safety chain is implemented. This chain consists in a defined number of successive interlocks that need to be activated before putting the beam ON. IRRAD, being located on the T8 beam line, it is part of the general beam security chain of the East Area. Details on the beam safety chain can be found in [2].
4.9.3 Other Safety and Emergency Systems

4.9.3.1 Fire Detection and Alarms

Smoke detectors are installed in order to facilitate the evacuation of people and warn the CFRS (CERN Fire & Rescue Service) in case of fire. Any smoke detection in the IRRAD facility will trigger the evacuation siren(s) of the facility and the Hall (bld. 157) (upon trigger on two detectors) and send an alarm to the CFRS (upon trigger of one detector). A series of aspirating (ASD) and/or optical detectors are installed in both the IRRAD bunker and the control room area.

4.9.3.2 Emergency Stop Systems

The Electrical Safety is guaranteed by Emergency Stop buttons (AUG and AUL) installed both inside the irradiation bunker and the counting room as well as by Emergency Stop buttons (AU) installed on every movable irradiation equipment.

4.9.3.3 Safety Lighting

More details about the layout of the safety lights network are available in the CHARM Safety File [10].

4.9.3.4 ODH Detection System

The presence of the cryogenic system inside the IRRAD area triggered a dedicated assessment regarding the Oxygen Deficiency Hazard (ODH). The study presented in Reference [26] concludes that no OHD detection is required in the IRRAD area if compensatory measurements are taken, namely to limit the access to the IRRAD area during the filling of the cryostat.

5. OPERATIONAL PROCESSES

5.1 MONITORING OF THE BEAM CONDITIONS

The intensity of the extracted proton spills is monitored using a Secondary Emission Chamber (SEC) device provided by PS beam instrumentation group (CERN BE-BI). In particular, for the monitoring of the proton beam of IRRAD, a special 20-foils SEC with improved sensitivity is used. This device, shown in Figure 20, is installed in the upstream machine area, and its signal is made available in the counting room together with the other signals provided by the PS timing-distribution. A second SEC device is installed downstream the IRRAD area just before the beam crosses the separation between IRRAD and CHARM.
The profile of the proton beam with a spill-by-spill resolution is obtained by custom-made Beam Profile Monitor (BPM) devices as shown in Figure 21. This instrument bases its operation on the secondary electrons emission effect. One BPM is located upstream the IRRAD area, in the same location used for the SEC. Additional BPM devices will be distributed among the 3 irradiation zones, along the trajectory of the proton beam, to guarantee the fine tuning of the beam profile on all irradiation systems. At the exit of the IRRAD area, the position and the shape of the proton beam are also monitored using scintillating screens.

While the BPM is a dedicated IRRAD instrument, installed on the irradiation equipment, the scintillating screens are part of the PS beam instrumentation and are mounted on a target system located downstream the IRRAD area. The scintillating screens are remotely controlled from the CCC and displayed there with a dedicated camera (MTV). The screens are the main beam instrumentation tool needed by the PS operation crew for the alignment and steering of the T8 irradiation beam.
dynamically written on an ORACLE database together with the position of the irradiation systems and other relevant data measured during the irradiation experiments.

As shown in Figure 22, also the beam intensity measured by the IRRAD SEC is recorded using the same server and following an equivalent data-flow. A dedicated web-application [27] finally allows the extraction, the display and the analysis of these data in real-time. The display features of this application are integrated in the tools available for the PS operation (www.cern.ch/opwt) and used to for the tuning of the proton beam on the IRRAD irradiation systems.

The absolute measurement of the 24GeV/c proton beam intensity (fluence) is obtained off-line via the activation-foils technique. This is achieved by evaluating the $^{24}$Na and $^{22}$Na activity of Aluminium (Al) foils. A dedicated spectrometry laboratory is installed in building 14/R-12.

In the case of high-energy protons, the Na isotopes are produced via the nuclear reactions $^{27}$Al ($p,3pn$) $^{24}$Na and $^{27}$Al ($p,3p3n$) $^{22}$Na respectively. The cross-sections of these two reactions have been well characterized such that with these activation techniques it is possible to obtain fluence measurements with an accuracy of ± 7%. The size of the aluminium foils to be used, with a thickness of some hundred micrometres, is varying from 0.5cm$^2$ to 2cm$^2$ according to the size of the irradiated samples. The half-lives of $^{24}$Na and $^{22}$Na are about 15 hours and 2.6 years, respectively. According to the time elapsed after irradiation and the irradiation time itself, one of the two isotopes is chosen for the spectrometric analysis and hence for the fluence calculation.

### 5.2 CONTROL AND MONITORING OF THE IRRADIATION EQUIPMENT

The positioning of the IRRAD shuttle system (see Figure 14) and IRRAD Tables (see Figure 12) is controlled by means of control unit boxes such the one shown in Figure 23 (right-hand side). Through the patch-panel on the control unit, by pressing the corresponding buttons, it is possible to set the movable axes of the various irradiation systems to some pre-set positions (such as “load”, “park”, “beam”, “scan”, etc.). The x,y,z positions
of the axes are calibrated, pre-defined and programmed inside the control unit via software by the IRRAD operation team. The positions of the axes may vary as function of the irradiation experiment and of the DUT.

The various control units are based on ICP DAS remote I/O unit for industrial monitoring and controlling applications [28]. This allows the control unit to communicate with the rest of the IRRAD monitoring infrastructure as shown in Figure 22 for the logging and the display of the motor positions. The same control units integrate monitoring capabilities for the irradiation tables equipped with thermostatized boxes (see section 3.3.3.1).

5.3 SAMPLES IRRADIATION

Every sample to be irradiated must be registered in the PH-Irradiation Facilities database. A traceability number (SET number, see later) is attributed to each sample and corresponding labels can be printed for its identification. A dedicated software interface (see Figure 24) to create new entries in the database is available in the irradiation facilities laboratory of building 14 (14/R-012) and in the IRRAD counting room (157/R-005). No sample will be irradiated without a SET number. Samples of the same type, irradiated to the same fluence, and which will be not separated after irradiation (e.g. moved to the same destination) can be grouped in one unique irradiation SET.
The SET number gives the link between the sample the irradiation experiment and dosimetry data related to it (irradiation time, proton fluence, storage place, expedition, etc.). The SET numbers identify also the samples in the CERN database for radioactive materials (TREC) [29]. All irradiated samples are considered as a radioactive source and are therefore treated according to the CERN rules for radioactive materials. When the sample leaves the IRRAD facility in building 157, it is moved to the buffer zone and labelled with a unique TREC identifier. In the TREC interface, when applicable, the SET number from the PH Irradiation Facility must be indicated using the Other Identifier field.

The main process for the irradiation of a sample/equipment in IRRAD (from its reception to its storage/transport outside the facility) is described and studied in detail in the Demonstrative Part of the safety file (EDMS 1327483) [30].

The weight and the nature of the sample have to be exactly declared in the SET registration. Light samples made from low-Z materials do not need special authorization (other than the one of the PH-DT operation team) to be irradiated in the proton facility. For all other materials, according to the rules set by the CERN Radiation Safety Officers Committee (RSOC), a special irradiation permit as described in the Radiation Protection Procedure (PRP) 17 have to be requested [31].
5.3.1 Shuttle System

Figure 25 shows the standard way to mount small samples on the IRRAD shuttle. This is done using 50×50mm² cardboards fitting into the shuttle support. Samples with transversal dimensions ranging from 5×5 to about 15×15 mm² are then fixed the centre of the cardboard using Kapton foils and tapes. Details about sample preparation and packaging instructions are available on a dedicated document on the irradiation website (www.cern.ch/irradiation). Samples are mounted (and un-mounted) behind a glass shielding in the shuttle station located in the technical area of the facility. The samples are then moved inside/outside the proton beam without interfering with its operation.

Figure 25 – Samples holders for IRRAD shuttle (left) and for the IRRAD tables (right)

5.3.2 Irradiation Tables

The irradiation tables, located in the different zones upstream and downstream the irradiation shuttle (see Figure 11) allow the irradiation of samples of much larger dimensions. The tables are located inside the primary beam area. This implies the stop of the T8 beam line, influencing both the IRRAD and the CHARM facility. The access is therefore restricted to defined periods as described later in section 5.4. The standard volume available for the irradiation on the tables is of 200×200×500mm³ (w × h × l) for a maximum weight of about 10-50Kg depending on the samples to be irradiated.

Before using this equipment, it is always necessary to build dedicated supports to hold the samples on the table and guarantee a precise alignment with respect to the proton beam. The details of the support plate to be used to fix custom-made sample holders are available in Figure 25.

5.3.3 Cryostat System

Experiments inside the cryostat require a longer preparation and the scheduling of a dedicated special irradiation period during the year (see section 5.4). Although the main user (owner and responsible) of the equipment is the BE-BI group, the system can be also used by other IRRAD users.

The Cryogenic system is put into operation only when a cryogenic irradiation is requested. For the rest of the time, the cryogenic system is switched off. The irradiation request has to go through the PH irradiation team, which is also taking care of coordinating the preparation of the experiment, the installation in the IRRAD bunker, as well as the positioning of the cryostat inside the beam during irradiation.
The CERN Cryolab team (TE-CRG) will take care of the commissioning of the new system together with the required maintenance and the safety checks [32]. The connection of the cryostat inside the test area to the Dewar sitting outside the shielding (through the Cryo-line), is performed only by qualified personnel from the TE or BE department. Once the system is setup, the cryogenic group will deliver liquid helium to the test area in Dewars. When handing over the equipment for operation, the responsibility of the installation will goes over to the BE-BI group [33]. Dedicated safety documentation (folder) for this special equipment is available in [34].

5.3.4 Radiation Background in the IRRAD Area

Figure 26 shows the intensity of the radiation field generated inside the irradiation area by the interaction of the beam with the air and with the samples material during standard irradiations [35]. Figure 26 takes also into account the parallel operation of the CHARM facility target with the shielding walls moved IN during irradiation.

![Figure 26 - Prompt radiation dose-rate (Gy/h) inside the IRRAD bunker during a standard irradiation experiment and parallel operation of the CHARM facility with shielding walls IN.](image)

During the parallel operation of the two facilities, the contribution of the radiation backscattered by the downstream CHARM target has been evaluated to be lower than the direct air production of the primary beam inside the IRRAD area [36]. Therefore, the background produced by the primary proton beam in the IRRAD bunker quickly drops to the level of 1Gy/h moving away from the proton beam-axis.
A further reduction of the background radiation produced by the interaction of the protons with the air is obtained by introducing two sections of vacuum beam pipe upstream Zone 1 and in between Zone 2 and Zone 3.

Figure 27 shows instead the result of a simulation run (standard irradiation conditions) which takes into account the effect of the CHARM mobile shielding completed retracted during irradiation (position OUT). The comparison of Figure 26 and Figure 27 shows no significant increase of the background radiation levels.

Figure 28 - Prompt radiation dose-rate (Gy/h) inside the IRRAD bunker during a special irradiation experiment (case “Special 2” in Table 3). In this configuration, the CHARM facility is not running.
Dedicated FLUKA simulation runs were carried out in order to characterize the radiation background of the air region of Zone 4 [35] (volume of 160×40×20 cm³). These refers to the “standard irradiation” case listed in Table 3 and have been normalized to one hour of irradiation with the intensity of 1 spill/CPS (corresponding to about 4×10¹³ p/cm² on a 1.44 cm² sample surface directly exposed to the primary beam). The results of these simulations are summarized in Table 4. The air KERMA rate simulated for Zone 4 does not exceed 0.1–0.5 Gy/h for the above mentioned irradiation conditions.

<table>
<thead>
<tr>
<th>Radiation Type</th>
<th>Energy</th>
<th>Intensity (cm² h⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>protons</td>
<td>~ 200 MeV (peak)</td>
<td>~ 5×10⁷</td>
</tr>
<tr>
<td>pions (+)</td>
<td>~ 300 MeV (peak)</td>
<td>~ 3×10⁷</td>
</tr>
<tr>
<td>pions (-)</td>
<td>~ 300 MeV (peak)</td>
<td>~ 3×10⁷</td>
</tr>
<tr>
<td>neutrons (all)</td>
<td>thermal – few GeV</td>
<td>~ 2.5×10⁹</td>
</tr>
<tr>
<td>neutrons</td>
<td>&gt; 20 MeV</td>
<td>~ 3×10⁸</td>
</tr>
</tbody>
</table>

Finally, Figure 28 shows the background inside the irradiation area during a special irradiation of a calorimeter target made of lead (case “Special 2” in Table 3).

5.4 BEAM SCHEDULING

The proton from the PS are shared among the irradiation facilities on T8 (IRRAD and CHARM), the other beam-lines operational in the East Area (T9, T10, T11) and the various accelerators in the CERN complex. Beam conditions are therefore variable during the year as function of the beam time required by the other users as well as function of the dedicated facility needs.

A typical year of operation is composed of about 30 weeks grouped in six irradiation periods. As indicated in Table 5, two of these periods are dedicated to High Intensity runs where the priority for the beam is given to the IRRAD facility such that the highest possible particle fluence is integrated on the DUT. Moreover, the protons are focused in a small surface and the beam downtime is minimized. During the two Standard periods, priority is given to other experiments and the goal is to integrate as much as possible particles on the DUT. During these periods, which are usually slots of five consecutive weeks, the parallel operation of IRRAD and CHARM is possible.

The two remnant periods are dedicated to run Special irradiation experiments. For what concern the IRRAD area, these can be the irradiation runs on high-Z materials or the irradiations of samples inside the cryostat system. During these runs, special conditions in terms of both beam focusing and intensity can be requested. Moreover, the type of material in the beam can prevent from the parallel operation of the two-irradiation facilities.
Table 5 - List of irradiation periods for the EA-IRRAD Facilities

<table>
<thead>
<tr>
<th>PERIOD</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition (weeks)</td>
<td>5 consecutive</td>
<td>5 consecutive</td>
<td>5 consecutive</td>
<td>5 consecutive</td>
<td>5 not consecutive</td>
<td>5</td>
</tr>
<tr>
<td>Run Name</td>
<td>High Fluence</td>
<td>High Fluence</td>
<td>Standard</td>
<td>Standard</td>
<td>IRRAD Special</td>
<td>CHARM Special</td>
</tr>
<tr>
<td>Beam Spot at IRRAD (cm) FWHM</td>
<td>smaller than 1.2x1.2</td>
<td>smaller than 1.2x1.2</td>
<td>1.2x1.2</td>
<td>1.2x1.2</td>
<td>up to 3.0x3.0</td>
<td>--</td>
</tr>
<tr>
<td>EASTB</td>
<td>3</td>
<td>3</td>
<td>1 to 3</td>
<td>1 to 3</td>
<td>1 to 3</td>
<td>--</td>
</tr>
<tr>
<td>Intensity (p/s)</td>
<td>~5x10^-10</td>
<td>~5x10^-10</td>
<td>max 5x10^-10</td>
<td>max 5x10^-10</td>
<td>10^-9 – 10^-10</td>
<td>--</td>
</tr>
<tr>
<td>Target Φ (p/cm^2)</td>
<td>~5x10^-16</td>
<td>~5x10^-16</td>
<td>as much as possible</td>
<td>as much as possible</td>
<td>as needed</td>
<td>--</td>
</tr>
<tr>
<td>Beam Focusing</td>
<td>IRRAD1 shuttle</td>
<td>IRRAD1 shuttle</td>
<td>Tables in Zone 1 &amp; 2</td>
<td>Tables in Zone 1 &amp; 2</td>
<td>Tables in Zone 3 / IRRAD15</td>
<td>--</td>
</tr>
<tr>
<td>Parallel Operation</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>Access scenario ( / week)</td>
<td>1</td>
<td>1</td>
<td>1 or 2</td>
<td>1 or 2</td>
<td>1 (2xCryo)</td>
<td>--</td>
</tr>
</tbody>
</table>

The scheduling of the different periods along the year is done in agreement with the PS-SPS coordinator and it is reviewed weekly at the PS/SPS Users Schedule Meeting^6^.

6. DISMANTLING PHASE & DISPOSAL

The IRRAD facility, as well as the whole EA-IRRAD infrastructure has been built following an integrated and iterative safety approach. This includes the radiation protection as well as design and construction aspects in the scope to ease the disposal of the irradiated samples and DUTs during operation and the dismantling of the infrastructure at the end of its lifetime.

Regular meetings [37] took place at several intervals along the project construction phase, to define the best organisation to minimise failure occurrences and potential exposure of interveners during the operation and, later, during the decommissioning of IRRAD. This includes:

- shielding organisation and layout;
- space and volumes for an easy access with handling devices;
- choice in materials, rad-hard systems in order to minimise system failures and material activation over the operation lifetime;
- etc.

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6 http://sps-schedule.web.cern.ch/sps-schedule/
Radioactive waste will arise from the following activities:

- operation of the facility (samples and DUTs);
- corrective and preventive maintenance (with low frequency): equipment and devices located in the irradiation bunker;
- decommissioning of the facility.

In the framework of the application of the tripartite agreement [38], radioactive waste are evacuated towards the final repositories available in the two Host States in agreement with the national radiation protection regulation of the Host State receiving the waste and the specific acceptance criteria of the final repository. Low-level waste will be disposed of towards France, while waste that satisfies the requirements for free-release [39] will be eliminated towards Switzerland, where this practice is allowed. The estimation of the quantities of samples and equipment disposed during the IRRAD lifetime will be integrated in the demonstrative part of the safety file [30].
7. REFERENCES


[33] *IRRAD15 Cryostat Operational Procedures*.


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8. ANNEXES

8.1 ANNEX 1

General Layout of the EA-IRRAD facility (including the volume of the main areas).
8.2 ANNEX 2

IRRAD Facility Infrastructure (storage area, followed by the irradiation bunker)
Upgrade of the Proton Irradiation Facility in the CERN PS EAST AREA

AIDA-Del-D8.4

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