GOALS OF THE SAFERIB WORKSHOP

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Abstract
Presently several new radioactive ion beam (RIB) facilities are planned, which typically will have three orders of magnitude larger radioactive inventory than already existing facilities. These radioactivities mostly are produced by ion beam irradiation with many kW of power. The radioactive ion production target is hot and shows outgassing, but at the same time ionized species are extracted. To safely confine and control the radioactive inventory of this open source special efforts are required. Here many new innovative concepts are being developed. Risk studies for external and internal accidents have to be performed and the approval procedures approximately make up about 10-20% of the total cost of the RIB-facilities. With this SAFERIB workshop we want to bring together experts from different facilities working in this field of radioprotection. Furthermore this meeting is planned as a starting point for a European network on this subject within the 6th framework EU-programme. Existing and planned facilities will benefit from this exchange of technical know-how and find more cost-effective solutions.

1 INTRODUCTION
Radioactive ion beams (RIB) are produced either via the inflight technique projectile or via the ISOL technique. With the inflight method a fast (0.1-1 GeV/u) primary heavy-ion beam is fragmented or fissioned on a typically low-Z production target with subsequent in-flight separation of the fragments. GSI (Germany) and the present facility at GANIL (France) represent this technique. In ISOL facilities a direct or indirect production approach is pursued. In the direct production (with the ISOLDE facility at CERN as prototype), protons with 1.0 GeV or 1.4 GeV hit different thick targets and produce a broad range of neutron- and proton-rich nuclei by fragmentation or spallation. Presently maximum currents of 4 \(\mu\)A are being used with an envisaged increase to 100 \(\mu\)A and heat loads of 100 kW in the targets. In the indirect approach secondary particles like fast neutrons, thermal neutrons or bremsstrahlung-photons are generated and then an intense source of neutron-rich fission fragments is obtained by fissioning of uranium or thorium targets. Primary heat loads of the target in the MW region are being explored here [1, 2].

Several new radioactive beam facilities are being planned or extended in Europe like: the next generation ISOL facility in Europe EURISOL [2], REX-ISOLDE [3] (CERN, Geneva, Switzerland), the fission fragment accelerator MAFF [4] (Maier-Leibnitz Lab., Munich, Germany), or fission fragment facilities driven by an intense deuteron beam like SPIRAL-II [5] (GANIL, Caen, France) and SPES [6] (INFN-LNL, Legnaro, Italy) or the new projectile fragmentation facility SUPER-FRS [7] (GSI, Darmstadt, Germany), all requiring improved methods to guarantee a safe handling of the much larger radioactive inventory. Here we can build on experience from already existing facilities like ISOLDE [8] or SPIRAL-I. We can also learn from approval procedures and barrier concepts of other facilities like the new Munich research reactor FRM-II [10] or the neutron spallation sources SINQ [11] (PSI, Villingen, Switzerland) or ESS [12] (represented by PES/FZY, Jülich, Germany). Similar questions are studied at facilities in America like at the ISAC facility [13] (TRIUMF, Vancouver, Canada) or the RIA project [14] (ANL/MSU, Argonne/Michigan, USA). A first aim of the workshop was to collect all the approaches and ideas of radioprotection of the different facilities, to offer a platform for colleagues working on similar
problems to discuss and exchange novel ideas, to encourage synergy effects and to get the specialists acquainted to each other.

The much larger radioactive inventory of the new facilities increases the requirements for safe operation significantly. Furthermore the safety regulations have become more strict in recent years. Consequently novel safety aspects evolving from the radioactive inventory of these new facilities, which typically are comparable to the fuel element of a research reactor, will play a major role in the design and approval procedures. The handling of open radioactive high-intensity RIB production targets, which are operated at high temperatures with fatigue and outgassing, is yet unexplored and needs new technological concepts and developments. Though complementary in their scientific approach and technological realization, common safety-related fields of interest can be identified among European radioactive beam facilities. Moreover, in the course of an ongoing harmonisation of European radioprotection standards the most effective and economical way to address these safety-related aspects is to form a network amongst the European institutions aiming at the development of techniques for the safe handling of the radioactive inventory for next generation high intensity radioactive ion beam facilities in Europe. This is the objective of a proposal for a EU-network within the 6th framework programme. Thus a second goal of the workshop is to bring together interested groups to discuss the objectives of such a network. The planned facilities will benefit from the exchange of technical know-how, risk scenario studies and coordinated R&D tasks. The proposed project will help with solutions to the central questions for the realization of intense RIB facilities and with the development of critical technical components in a cost-effective cooperative effort.

2 COMPARISON OF DIFFERENT FACILITIES

In table 1 we have compiled properties of some of the facilities which report on their radioprotection efforts at this workshop or which are planned to be built. We divided the table into three sections: the beam, the production target and the radioactivity. Many general features become apparent, but we also find a wide-spread range of operational parameters. The power levels vary between 3 kW and 20 MW. The reactor FRM-II and the neutron spallation facilities with a closed production target show the largest power levels. A clear increase of power with the starting year of operation can be seen for the different types of facilities. The inflight-facilities RIA and SUPER-FRS produce less power than the ISOL facilities because these can use much thicker targets in their radioactive beam experiments. Facilities with a small duty factor of the beam face the problem of generating shock waves in the target.

The production targets have temperatures between 100°C and 2400°C. To withstand high temperatures and power levels the targets are either built from materials with high melting point or from liquids. For open targets the high temperatures result in large outgassing. Large volume targets are less efficient in the release of the produced activities, while high temperature enhances their diffusion and effusion. Typically after one week of running the efficiency of the RIB-targets deteriorate.

To judge the radioprotection problems we roughly have estimated (i) the instantaneous radioactivity at the end of the running period, (ii) the target dose rate in mSv/h without shielding at 1m distance after a decay time of 1 year and (iii) the activity in Bq of α-emitters. The radioactive inventory with values between $10^{12}$ Bq and $10^{19}$ Bq is quite large and requires remote handling of the production targets. Compared to the natural radiation exposure of 1 mSv/a also the dose rates after 1 year are very large. They differ by seven orders of magnitude. For the dose rates after 1 year certain fission products (like $^{91}$Y, $^{95}$Zr,$^{144}$Ce,$^{144}$Pr) with half lives around 100 d contribute most. For the thermal neutrons of a reactor the capture rate and activation strongly depends on the material. However, for the MAFF-target the possible materials are rather limited, because they have to withstand the high target temperature. By properly choosing the surrounding materials this activation of a reactor can be quite small compared to the fission activity.
Table 1: Existing or planned RIB facilities, spallation neutron sources or ν-factories and their beams, targets and radioactivity

<table>
<thead>
<tr>
<th>Facility (starting Year)</th>
<th>Proj.</th>
<th>Energy</th>
<th>Beam Flux/ intensity</th>
<th>Power [MW]</th>
<th>Duty factor</th>
<th>configuration</th>
<th>Target volume</th>
<th>temp. [°C]</th>
<th>running time</th>
<th>Radioactivity instantaneous</th>
<th>Target dose rate mSv/h in 1m after 1 year</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRM-II (2003)</td>
<td>n</td>
<td>1/40 eV</td>
<td>10^{14}/cm²s</td>
<td>20</td>
<td>cw</td>
<td>closed solid USi</td>
<td>10^{4} cm³</td>
<td>ca. 100</td>
<td>52 d</td>
<td>fiss.: 3·10^{28} Bq activ.: 1·10^{16} Bq α-emit.: 1·10^{11} Bq</td>
<td>5·10^{9}</td>
</tr>
<tr>
<td>MAFF (2006)</td>
<td>n</td>
<td>1/40 eV</td>
<td>10^{14}/cm²s</td>
<td>0.003</td>
<td>cw</td>
<td>open solid UC₂</td>
<td>20 cm³</td>
<td>ca. 2400</td>
<td>52 d</td>
<td>fiss.: 4·10^{24} Bq activ.: 5·10^{14} Bq α-emit.: 3·10^{5} Bq</td>
<td>~ 5·10^{2}</td>
</tr>
<tr>
<td>ISOLDE 1992</td>
<td>p</td>
<td>1400 MeV</td>
<td>1·10^{13}/s</td>
<td>0.003</td>
<td>2·10^{-6}</td>
<td>solid UC₂</td>
<td>ca. 80 cm³</td>
<td></td>
<td>7 d</td>
<td>1·10^{22} Bq</td>
<td>~ 1</td>
</tr>
<tr>
<td>ν-factory (2010)</td>
<td>p</td>
<td>2200 MeV</td>
<td>1·10^{16}/s</td>
<td>4</td>
<td>2·10^{-4}</td>
<td>liquid Hg</td>
<td>2 cm dia.</td>
<td>ca. 600</td>
<td>(1 y)</td>
<td>~ 10^{9}</td>
<td></td>
</tr>
<tr>
<td>ESS (2010)</td>
<td>p</td>
<td>1330 MeV</td>
<td>2·10^{16}/s</td>
<td>5</td>
<td>1·10^{-4}</td>
<td>liquid Hg</td>
<td>2 cm dia. 10^{6} cm³</td>
<td>ca. 600</td>
<td>(1 y)</td>
<td>max.: 1·2·10^{17} Bq</td>
<td>~ 10^{6}</td>
</tr>
<tr>
<td>SINQ 1996</td>
<td>p</td>
<td>570 MeV</td>
<td>1·10^{18}/s</td>
<td>1</td>
<td></td>
<td>liquid PbBi</td>
<td>8.2·10^{4} cm³</td>
<td>300</td>
<td>1 y</td>
<td>1·1·10^{16} Bq</td>
<td>~ 2·10^{3}</td>
</tr>
<tr>
<td>ISAC 1998</td>
<td>p</td>
<td>500 MeV</td>
<td>6·10^{14}/s</td>
<td>0.05</td>
<td>cw</td>
<td>Ta (surf. ion.)</td>
<td>ca. 2000</td>
<td></td>
<td>~ 10^{4}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPIRAL-I 2001</td>
<td>HI</td>
<td>85 MeV/A</td>
<td>2·10^{13}/s</td>
<td>0.006</td>
<td>cw</td>
<td>solid C</td>
<td>1 cm³</td>
<td>ca.2000</td>
<td>15 d</td>
<td>max: 1·10^{11} Bq</td>
<td>~ 0.1</td>
</tr>
<tr>
<td>SPIRAL-II (2008)</td>
<td>d</td>
<td>40 MeV</td>
<td>2·10^{14}/s</td>
<td>0.02</td>
<td>cw</td>
<td>open, converter+ solid UC₂</td>
<td>150 cm³</td>
<td>90 d</td>
<td>fiss.: 2·10^{14} Bq α-emit: 6·10^{8} Bq</td>
<td>~ 10^{4}</td>
<td></td>
</tr>
<tr>
<td>SPES (2008)</td>
<td>p</td>
<td>100 MeV</td>
<td>6·10^{14}/s</td>
<td>0.1</td>
<td>cw</td>
<td>open, converter+ solid UC₂</td>
<td>200</td>
<td>&lt;2300</td>
<td>90 d</td>
<td>fiss.: 3·10^{13} Bq</td>
<td>~10^{4}</td>
</tr>
<tr>
<td>RIA (2010)</td>
<td>p</td>
<td>400 MeV/A</td>
<td>10^{13}/s</td>
<td>0.10</td>
<td></td>
<td>solid Be, molten Li solid</td>
<td></td>
<td></td>
<td>fess: 1·10^{12} Bq</td>
<td>~ 1</td>
<td></td>
</tr>
<tr>
<td>SUPER-FRS (2010)</td>
<td>U</td>
<td>1000 MeV/A</td>
<td>10^{12}/s</td>
<td>0.04</td>
<td></td>
<td>open solid C</td>
<td></td>
<td></td>
<td>fess: 1·10^{11} Bq</td>
<td>~ 0.1</td>
<td></td>
</tr>
<tr>
<td>EURISOL (2010)</td>
<td>p</td>
<td>1000 MeV</td>
<td>3·10^{10}/s</td>
<td>5</td>
<td>cw</td>
<td>converter + solid UC₂</td>
<td></td>
<td></td>
<td>~ 3·10^{3}</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
For fission fragments a rough conversion from the instantaneous radioactivity in Bq to a dose rate in mSv/h at 1 m distance from the source and a decay time of 1 year is possible: $8 \cdot 10^{11}$ Bq correspond to 1 mSv/h. While the reactor FRM-II and the spallation neutron sources SINQ and ESS have encapsulated fission sources the RIB facilities have open fission sources, where the release of gaseous activities causes new problems. For the hot production targets typically 20-30% of the radioactivity are released in a gaseous form, while for used targets, after cooling down, most of the radioactivity is confined in their matrix.

When Uranium is used as a target, neutron capture leads to α-emitters, which frequently are highly radiotoxic and mostly have very long lifetimes. Their very small accepted free contamination levels make them of concern for radioprotection. The much larger fractional contribution of α-emitters at the FRM-II reactor compared to the MAFF-target results from the fact that the reactor uses only 93% $^{235}$U in the fuel element, while MAFF has 99.9% $^{235}$U. Thus targets with a high $^{238}$U content have a much larger problem with α-emitters and their migration along the beamtubes. For fast neutrons from a converter and a $^{238}$U target like in the SPIRAL-II project the ratio of the radioactivities from α-emitters to fission fragments is much larger.

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Fig. 1: Overview of SAFERIB-network, the institutes and the tasks.
3 THE EU-NETWORK SAFERIB

Fig. 1 gives a schematic overview of the proposed EU-network. In the top part we show the participating institutes. There are five facilities planning or building a European RIB facility. In the long run EURISOL will be the next generation ISOL facility in Europe. The neutron spallation sources SINQ and ESS can add special contributions to the network, because they face similar problems. The American RIA project and ISAC project will we associated. The lower part of Figure 1 shows the different tasks of the network. The main tasks are:

1. Characterization of production rates of radionuclides from RIB targets
2. Characterization of the radioactive inventory in target areas/beam transport systems
3. Characterization of mechanical, thermal, radiation-correlated material properties for production targets and fission sources and handling devices
4. Optimization of radiation shielding: simulations and dosimetry measurements
5. Migration of radioactivity
6. Containment of volatile radioactivity
7. Reliable remote controlled target/ion source manipulators
8. Contamination-free transport, diagnostics, storage of used targets/sources

Many tasks are done routinely by all facilities, like characterization of radiation and radioactive inventory. They still require improved programmes. The more innovative tasks are placed within the dashed red rectangle of Fig. 1. The network will focus on these new questions, while tasks 1, 2, 4, 8 and 9 mainly comprise a collection of available knowledge, not requiring much manpower.

Although the techniques used to produce high-intensity radioactive beams are different among the participating institutes, several still unsolved problems are common to all or some of them:

- The radioactive inventory that has to be handled will come close to that one of a research reactor fuel element. Consequently similar precautions against all sorts of failure are necessary.
- Whereas fuel elements are always closed units, all ISOL facilities require open targets. The radioactive exhaust gas has to be treated appropriately and additional safety-barriers must be introduced to close the system in case of failure. This situation is different from other sources of secondary particles like neutrons, neutrinos or pions, where encapsulated sources can be used.
- For the containment of gaseous radioactivity new techniques are being explored:
  - The open targets require fast-closing valves. Here special piggy-back valves are being designed. A large valve allows to slowly open a large cross-section while on its lid a small fast-closing valve is mounted. In this way large parts can be moved through the valve, but then the beam is extracted through the smaller aperture, which in case of emergency can be closed rapidly.
  - Cryo-pumps are very effective to fix all gaseous radioactivities close to the production target. By radioactive decay volatile elements on the cryo-pumps are converted to non-volatile ones. The cold heads of cryo-pumps show small failure rates, while the attached compressors can be exchanged easily without contamination problems. This is different from turbo-molecular pumps where the contaminated rotating parts wear out after some time.
  - Presently a big part of the radioactivity is collected in the pump oil of the roughing pumps. We want to circulate the exhaust gas in the storage tanks with roughing pumps and collect the radioactivity in dedicated filtering systems. In this way the activity is localized and the stored exhaust (after reaching the acceptable levels) can be released much earlier.
- High radioactivity levels and the use of open sources demand generally remote-controlled robotic devices that allow the contamination-free handling of the production target and/or ion sources. They must be able to reliably operate in high-radiation environments.
- Besides contamination, activation cannot be neglected. Facilities using beams of high-energy particles are specially concerned. Existing computer codes for shielding calculations have to be adopted.
to meet the specific situations. For the inflight facilities the main contribution to the radiation exposure can be found in the shielding and the magnets right after the fragmentation target.

As European radiation safety standards converge, an exchange of safety studies, computer simulations and a coordination of special technical developments in a European network is intended. It increases the safety of the facilities, avoids costly parallel developments and leads to a new evaluation and perspective for the realisation of future RIB facilities. All participating Large Scale Research Infrastructures are currently involved in either planning or construction activities for next generation RIB facilities, where safety aspects of handling the radioactive inventory will be crucial prerequisites of legal approval and responsible operation. The combined effort and synergy effects expressed by the present proposal will accelerate the process of layout optimisation significantly in the most efficient way.

References


