6 Radiation protection issues for HIE-ISOLDE
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6.1 Introduction
In the ISOLDE facility, radioactive isotopes are produced by proton bombardment of a thick target. The products are ionized, accelerated to an energy $E = 60$ keV, mass-separated and transported to experimental stations.

At present, the production target is bombarded by protons with $E = 1.4$ GeV. The beam is extracted from the PSB in pulses, each containing up to $3 \times 10^{13}$ protons. The PSB can deliver one pulse every 1.2 seconds, half of which is dedicated to filling the Proton Synchrotron (PS). The average proton beam current on the target is therefore $2.0 \mu$A at the energy of 1.4 GeV, resulting in an average power dissipation of $2.8$ kW in the target and on the following beam dump.

A recent proposal from the ISOLDE Group envisages an increase of the average particle current to $10 \mu$A, partly by making use of a faster cycling rate of the PSB, but mostly through the availability of higher currents of low-energy protons from a potential new linear accelerator, Linac 4. We highlight the different radiation protection issues resulting from the increased particle current in the projected facility, which is called High Intensity and Energy (HIE) ISOLDE.

In Section 6.2, the shielding of the target area with respect to the experimental area and to the zones accessible to the public around the facility against stray radiation from the target is described. Section 6.3 deals with gaseous and aqueous releases from ISOLDE into the environment. Section 6.4 assesses the activation of the targets and the target area and the resulting radiation dose to personnel. Section 6.5 addresses protection against radioactive contamination. Sections 6.6 and 6.7 deal with the necessary construction improvements in the target and experimental area, respectively. Section 6.8 reviews the situation regarding radioactive waste from ISOLDE.

The aim of this report is to point to the areas where the present provisions for radiation protection are insufficient for operation of HIE-ISOLDE and where investment in technical solutions and manpower are required. The report is partly based on a Technical Note from the year 2000 [1], which came to similar conclusions.

6.2 Shielding of the target area
The purpose of the shielding around the target area is to protect members of the public outside the facility and personnel working within the facility from stray radiation. It is designed so that the dose limits applicable to these groups cannot be exceeded under normal operating conditions and in case of accidents with higher dose rates than normal.

The shielding must guarantee that the dose rate in spaces accessible to the public does not exceed $0.5 \mu$Sv h$^{-1}$, or $2.5 \mu$Sv h$^{-1}$ in places without permanent occupancy (parking spaces, corridors, staircases, toilets). In a supervised radiation area\(^1\), such as the ISOLDE experimental area, the ambient dose equivalent rate is limited to $3 \mu$Sv h$^{-1}$ at workplaces and to $10 \mu$Sv h$^{-1}$ at places which are not permanently occupied, such as passageways or staircases. Only locally, at positions inaccessible to personnel, can higher values be tolerated.

Line-of-sight shielding models [2] give a first, conservative estimate of expected dose equivalent $H$ from the collision of high-energy protons with matter behind a shielding. Such models

\(^1\) In the next revision of Safety Code F, Protection against Ionising Radiation, the naming of designated radiation areas follows the conventions in France and other EU countries. The characteristics of the ‘supervised area’ correspond largely to those of the currently defined ‘simple controlled radiation area’.
are based on a source term depending on proton beam energy and angle of radiation incidence \( H_0(E, \theta) \), a \( 1/r^2 \) geometrical attenuation with total distance \( r \) and an exponential taking into account the radiation attenuation in a composite shield employing \( n \) different materials with thickness \( d_i \) and radiation mean free path lengths \( \lambda_i \):

\[
H(r, d) = H_0(E, \theta) \frac{1}{r^2} \exp \left( -\frac{d_1}{\lambda_1} - \cdots - \frac{d_n}{\lambda_n} \right).
\]

The source term is calculated for an energy of \( E = 1.4 \) GeV and a target for one mean free path length in which 63% of the protons will react. This choice is conservative even for the densest targets employing lead. It does not take into account the additional neutrons emitted from fission in U-C and Th-C targets.

All shielding walls for the present ISOLDE facility were designed before 1990 with the assumption that the average beam intensity on the target is \( 10^{13} \) protons s\(^{-1} \) at an energy of 1 GeV [3]. This corresponds to a current of 1.6 \( \mu A \) and a power of 1.6 kW, lower than currently used beam parameters. The ISOLDE target area has been shielded with concrete walls and earth shielding against areas accessible to the public (the parking spaces and the Route Democrite). The thickness of this shielding, resulting from the 1990 estimates, is equivalent to 8 m of earth. The weakest point of the shielding is situated at the emergency exit from Bldg. 179 to Route Democrite where ambient dose equivalent rates can temporarily exceed the guidance value of 2.5 \( \mu Sv \) h\(^{-1} \) at present proton beam intensities.

There is approximately 4 m of earth shielding reinforced by 0.8–1.2 m of iron between the target and separator areas. The separator areas are shielded from the experimental area by concrete blocks, with a thickness of between one and three metres. Access mazes with a passage width of one metre lead from the experimental area to the separator areas.

For the proposed HIE-ISOLDE beam with a current of 10 \( \mu A \), the concrete and earth shielding around the target area is not sufficiently strong to protect the public: at 10 m distance behind an earth shield of 8 m thickness, the expected ambient dose rate is 14 \( \mu Sv \) h\(^{-1} \). This exceeds the relevant dose rate guidance value by a factor of 6.

For places in the experimental hall close to the shielding of the separator areas, ambient dose rates originating in the target area may reach 30 \( \mu Sv \) h\(^{-1} \) (access door to HRS separator area) or 80 \( \mu Sv \) h\(^{-1} \) (at the GHM or GLM beam line). These values exceed the guidance value for not permanently occupied places in a supervised radiation area by a factor of up to 8. To this, the dose rate from radioactive gases in the vacuum system of the GHM and GLM lines has to be added.

It is well known that neutrons stream through the ‘Boris tubes’ from the target area into the High Voltage Room (HVR) and from there into the experimental hall. The HVR has been equipped with an access control system to protect personnel from the significant dose rates prevailing therein when uranium or thorium targets are used. Today, the ‘sea’ of neutrons in the experimental hall creates an ambient dose rate of 1–2 \( \mu Sv \) h\(^{-1} \), measured by radiation monitors on the wall opposite the target area. A five-fold increase in beam power would increase the ambient dose rate to 10 \( \mu Sv \) h\(^{-1} \) for a large fraction of the hall, leaving no margin for the extraction of radioactive beams into the experimental area.

In the controlled separator areas and the HVR, radiation monitors are included in the interlock chain of the access control system. Access to the HVR is authorized only when the ambient dose rate is lower than 100 \( \mu Sv \) h\(^{-1} \). At present beam intensities, the HVR is closed during operations with U-C or Th-C targets on either separator.
Once the proton beam is turned off, authorized personnel can access the separator areas when the ambient dose equivalent rate has dropped significantly below that of a high radiation area (2 mSv h\(^{-1}\)). Even then, careful planning of work and optimization of radiation exposure are mandatory.

### 6.3 Radioactive releases from ISOLDE

The annual dose limit for the public from air releases is 300 μSv for the whole of CERN [4]. In Switzerland, no further optimization efforts are required once members of the public are exposed to less than 10 μSv a\(^{-1}\) [4, 5]. It is considered good practice at CERN not to exceed this constraint for gaseous releases. For comparison, exposure of the public to releases from nuclear power plants in Switzerland is between 1 and 5 μSv a\(^{-1}\). In 2004, air releases from TT10 contributed 1.3 μSv to the dose to members of the public. This value will increase with the operation of the CNGS beam; a first, conservative estimate for \(4.5 \times 10^{19}\) protons on the CNGS target indicates an annual dose of 5.3 μSv. The unrestricted running of all experimental facilities on the Meyrin site will call for technical solutions to reduce releases and the dose to the public [6].

To assess the impact of radioactive releases on the environment and the public, CERN implements the approach of estimating the dose to a member of the ‘critical group’ of the public. The critical group is defined so that the impact of releases from CERN is maximized (by age, by the place of residence or work, and by living habits). If the dose to the critical group does not exceed limits and can be shown to be optimized, this will be true for any member of the public. The calculation of the dose for a member of the critical group follows the regulations of the competent authorities in the host states [7].

There are three types of radioactive gaseous releases from ISOLDE:

- The release of mainly short-lived positron emitters (\(^{11}\)C, \(^{13}\)N, \(^{15}\)O) and \(^{7}\)Be. These are produced via the spallation reaction by the secondary particle cascade in air resulting from the 1.4 GeV proton beam hitting the target. During ISOLDE operations, these gases are emitted continuously via the ventilation system.

- The release of spallation products produced in the ISOLDE targets via the vacuum system of the separators and the experimental hall. Tritium and long-lived noble gases (\(^{42}\)Ar, \(^{85}\)Kr and \(^{127}\)Xe) are not retained in the roughing pump oil of the vacuum system. The gases are stored in retention tanks and released after allowing 5 to 12 months for radioactive decay. The retention tanks are placed in the ISOLDE target area and are activated, thereby making impossible an assessment of the activity contained in them by an external dose rate measurement. The tanks are filled to a positive pressure of 2000 hPa, forcing radioactive gases out in case of a leak.

- The short-term release of \(^{219, 220}\)Rn and its decay products \(^{211, 212}\)Pb and of iodine isotopes during the change of U-C and Th-C targets.

In a nuclear or accelerator facility it is standard practice to release activated air via a filtered and monitored stack. Filters retain most aerosols (notably \(^{7}\)Be) and monitors allow quantifying of the releases and demonstrate that no limits are exceeded and that the operation of the facility is optimized.

The ISOLDE stack constructed in 1990 was too short to allow for complete mixing of the released air and did not permit reliable absolute release measurements. During the shutdown in 2004/5, the ISOLDE facility was equipped with a new, longer stack. This stack guarantees a laminar flow pattern, the prerequisite for accurate airflow measurement and representative air sampling. Reliable figures on the release of short-lived \(\beta^+\) emitters were measured for the first time during 2005. They are now being compared to figures predicted from Monte Carlo models. This study aims to reproduce release figures from the present ISOLDE facility in order to reliably predict those of HIE-ISOLDE.
The regular measurements show that the short-lived positron emitters account for about 95% of the dose to the critical group. At constant beam energy, the production of short-lived $\beta^+$ emitters from spallation in air will increase proportionally to the beam current. In order to cope with increased air activation, different options are available:

- The Faraday cage will be shielded, reducing the track length of the secondary particle cascade in air and thus the air activation.
- The ventilation system will be modified so that the release of the activated air is delayed and a part of the activity decays within the target area.
- A significantly higher stack will be constructed so that the radioactive releases are distributed over a larger area and the dose to the critical group becomes smaller.

For the spallation products from the target, the proportionality to release is mitigated by the decay time, but for the long-lived isotopes of noble gases in the retention tanks the final result will remain approximately proportional to beam power.

The impact of the releases from the retention tanks is monitored by streaming the gas through a monitor chamber. There is no sampling bias involved. The calculated dose to the critical group of the public is negligibly small compared to the short-lived $\beta^+$ emitters. As long as the retention tanks are sufficiently dimensioned to allow storage of radioactive gases for sufficient decay time, releases will not represent a problem. With increased production rates of radioactive gases at HIE-ISOLDE, the retention tanks should allow external monitoring of the contained activity and they should be inherently safe against leakage as, for example, is the case at SPIRAL in GANIL [8].

The Rn emanations from target and front-end during target changes must be reduced by an appropriate design of new targets and front-ends.

The consequences of an accidental release of activity during partial or total breakdown of the target or front-end vacuum system must be estimated. The protective measures, which have to be taken in case of such an event, depend on its probability, which must be estimated with approved methods.

A second pathway of activity releases is water. Rainwater that infiltrates the earth shielding over the ISOLDE area may be activated and contaminated and reach the CERN drainage system or the ground water. Moisture of unknown origin is regularly observed in the target area. The source of the moisture may be in contact with drainage or ground water. Before increasing beam intensity and activation levels, a sampling pit should be installed in the vicinity of the ISOLDE target area, permitting regular controls of the water activation. Water from the ISOLDE facility is drained towards the CERN outlet ‘Car Club’ and discharged into the Nant d’Avril river (CH).

### 6.4 Activation in the target area and dose to personnel

The personal dose limit at CERN is 20 mSv, but for reasons of ensuring the legally required optimization of exposure, an action level of 6 mSv in one year has been set. This annual personal dose may be exceeded only in exceptional cases with special authorization. Installations at CERN must be planned and operated in such a way that a foreseeable excess of the action level under routine operating conditions is excluded.

The secondary particle cascade from the impact of the proton beam on the ISOLDE target activates all materials in the target area. Radioactive contamination in and around the front-end constitutes an additional radiation source and exposes personnel to a contamination risk.

At present, the dose equivalent rate in the Faraday cages around the two production targets is typically $H^*(10) \approx 4–5$ mSv h$^{-1}$. The ambient dose equivalent rate severely restricts ‘hands-on’ maintenance of the target and the front-ends. Each intervention is carefully planned and closely...
monitored by RP personnel. Interventions in the target area are deferred until the end of the annual shutdown in order to benefit from radioactive decay. These protective measures result in an annual collective dose for the ISOLDE target and separator areas between 15 and 25 man-mSv. Today, annual personal doses to a few specialists are in the range 4–6 mSv and therefore very close to the action level. The procedure of exchanging a whole front-end, which is required whenever a major breakdown occurs, leads to a collective dose of 3 man-mSv.

Activation and contamination and the dose equivalent rate resulting from them are proportional to the number of protons hitting the targets. An increase of the number of protons by a factor of 5 would result in an ambient dose rate in the vicinity of the front-ends of up to $H^*(10) \approx 25 \text{ mSv h}^{-1}$. If one simply scales the annual collective dose at HIE-ISOLDE with the same factor of 5, it would become comparable with that of the entire SPS.

It is obviously not possible to plan for a fivefold increase of activation and contamination and to continue with the present ‘hands-on’ maintenance procedures, because the action level for annual personal dose would be exceeded. Consequently, the front-ends and the targets must be constructed in such a way that urgent intervention during the running time of HIE-ISOLDE occur only very exceptionally and do not take more than a fraction of minutes. Even towards the end of a shutdown of six months duration, ambient dose rates will be so high that maintenance of the whole target front-end system must be reduced to the absolute minimum. A front-end change, for example, would lead to a collective dose of 15 man-mSv. This implies a redesign of the present target/front-end system, using manipulators and robots not only for changing targets but also for maintenance by changing whole functional groups of the front-end, when required.

### 6.5 Protection against radioactive contamination

Personnel working at ISOLDE are exposed to external radiation, as everywhere else in designated radiation areas at CERN. In addition, they risk being exposed to internal radiation after contamination with radioisotopes. The annual dose limit of 20 mSv and the action level of 6 mSv are understood as limiting the sum of external and internal exposure.

The isotopes produced in the ISOLDE targets present a risk of widespread contamination in the facility. The vacuum system in the target and separator areas is heavily contaminated. Past the switchyards, the contamination becomes gradually weaker, but it cannot be neglected when intervening on the vacuum system in the experimental area. Turbo molecular pumps, backed by oil-filled roughing pumps, maintain the vacuum. Radioactive isotopes contaminate all vacuum pipes and the interior of the turbo molecular pumps, making standard maintenance impossible. The volatile isotopes are retained in the oil of the roughing pumps, which are installed at various locations in the separator areas and the experimental area.

Depending on the type and concentration of isotopes captured in the oil, the pumps can have a significant dose rate (several mSv h$^{-1}$ on contact). The annually required oil change exposes personnel to a high contamination risk. The oil of the pump on the High Resolution Separator (HRS) contains 32 MBq of $\alpha$ emitters (mainly $^{208,209,210}$Po). This corresponds to the 16 000-fold of the authorization limit of these isotopes as defined in the Radiation Safety Code [4] in accordance with [5] and [9]. Extensive protective measures are required for this operation, which must be performed in a radioactive work sector of the highest protection Class A [9].

Finally, the storage, conditioning, and elimination of contaminated waste are more complicated and costly than for a comparable volume of activated waste. In the present layout, the HRS separator area (not classified as a Class A work sector) houses several roughing pumps for the separators. Changes in the layout of the experimental hall may require installation of more vacuum equipment in the separator areas.
In the separator areas, contamination risk occurs whenever the separators, switchyards and other beam line components are opened for maintenance. Owing to the high ambient dose rates during operation \( [H^*(10) > 100 \text{ mSv h}^{-1}] \), the separator areas are currently classified as primary accelerator areas. A physically tight separation between them and the experimental area, avoiding free exchange of air-borne contaminants during maintenance or in case of failure, is currently installed. Some control equipment is installed in one separator area, exposing its maintenance personnel to external and potentially internal radiation.

While optimization of radiation protection at the present ISOLDE facility would benefit from a strict separation of the different areas (target, separator, vacuum and experimental), this will become indispensable for the increased contamination risk in HIE-ISOLDE.

With a contamination of \( \alpha \)-emitters at the 100 000-fold of the authorization limit, the standard operation of changing the pump oil requires additional protective measures against contamination and external radiation for the maintenance personnel. Other personnel must be protected from external and internal exposure by the vacuum system. All potentially contaminated vacuum equipment, including that from the experimental area, will be grouped in the shielded HRS separator area, which should be upgraded to a work sector of Class A.

The GPS separator area shall be freed of all indispensible equipment, classified as a radioactive work sector, and be properly isolated from the experimental area.

Interventions in areas with high dose rates with the risk of personnel contamination require thorough job and dose planning and close supervision by RP personnel. At present, one RP engineer is delegated for work at ISOLDE; for difficult interventions he receives backup from another engineer. With the RP personnel available, it is generally not possible to work at the same time at two workplaces with a high dose rate or the risk of contamination.

6.6 Construction of an improved target area

The present ISOLDE target area is not suitable for an operation with three- to five-fold increased proton intensity. It has been designed for lower proton beam intensities than used routinely nowadays and the safety of operators, researchers, and the environment could not be guaranteed under the assumption of a further intensity increase of the proton beam. It has been proposed to dismantle the existing target area and to rebuild it, taking into account the lessons learnt from more than 15 years of operation as well as integrating passive and active safety features.

An improved target area would provide for some or all items of the following list:

- shielding of the targets and front-ends in order to reduce air activation;
- re-design of the ventilation system with the aim to reduce releases of radioactive air by recirculation of air in order to allow radioactive decay of short-lived activation products and/or a higher ventilation stack to dilute radioactive releases over a larger area;
- physical separation of target/front-end and ancillary equipment, such as vacuum system, in order to perform maintenance or repair without being exposed to the high dose rate from target/front-end;
- re-design of the target/front-end, allowing for an automated exchange of components with manipulators or actuators, reducing the risk of external or internal radiation exposure of personnel.

The plans of an improved target area must be developed with and controlled and approved by radiation protection specialists in order to implement the optimization of radiation protection in the design.
The existing ISOLDE target area needs to be dismantled before a new target area can be constructed. Dismantling of a nuclear facility, combining the hazards of high external and internal occupational doses from activation and contamination is a delicate proposal. All dismantled equipment will have to be controlled for activation and contamination before it can be eliminated in different radioactive waste streams. Storage or elimination of the waste has to be planned well before the start of the dismantling.

At CERN, no operative experience for such an undertaking exists and it is proposed to hire a specialized contractor for this work. The aim is to declassify the former target area as a conventional zone for the duration of the construction work to permit easy access for non-specialized workers.

The cost of dismantling ISOLDE forms an integral part of the construction cost of HIE-ISOLDE.

6.7 Improvements to the experimental area

The HIE-ISOLDE proposal includes an upgrade to the post-accelerator REX with the aim to accelerate the heavy, radioactive ions to an energy of 10 MeV/u. At this energy, intense neutron and gamma radiation will emerge from the target and beam dump of the post-accelerator. This requires a complete redesign of the shielding of the experimental area at the high-energy end, providing shielding to protect the experimental personnel present in Building 170 during experiments.

It is considerably more difficult to design appropriate shielding for heavy-ion accelerators operating in the energy range between the Coulomb barrier and 100 MeV/u than for proton and electron accelerators. Only scarce data exist for radiation source terms—essentially the flux of secondary particles emitted during an ion–ion collision—and it has been shown that heavy-ion interaction models developed for high energies (several 100 MeV/u and above) do not yield reliable results in the low-energy range.

The options for radiation protection in this case are either a conservative design, probably overshielding the facility by a large margin, or an in-depth study of neutron- and ionizing-particle yields from heavy-ion collisions in the energy range of 10 MeV/u and their implementation as a radiation source generator in a Monte Carlo radiation transport code. Both alternatives need additional investments in manpower or material.

The ISOLDE (and HIE-ISOLDE) experimental area is provisionally classified as a work sector of Class C [8] although the building does not fulfil the required fire resistance requirements for such an area. The activity which can be manipulated in unsealed form in the hall is limited to the 100-fold of the authorization limit. This limitation allows experiments to be conducted with reasonable amounts of gamma/beta emitters. Use of short-lived gamma/beta emitters may be limited by the ambient dose rate they create in the experimental hall, which is limited to 10 μSv h⁻¹. The availability of unsealed alpha-emitters for experiments is seriously limited by their low authorization limit. The benefit from an increased production rate will be marginal for experiments relying on collected radioisotopes in unsealed form or on short-lived gamma/beta emitters because of the limitations of the experimental area.

To make full use of a more intense ion beam, a shielded and isolated collection bunker must be constructed over one of the collection beam lines. It must be equipped like a work sector for unsealed sources while preventing the spread of contamination and providing sufficient shielding against the intense gamma-radiation from collections of some short-lived isotopes. Only properly packaged isotope collections must leave this work sector for destinations in the experimental hall, CERN, or collaborating institutes.
An overall increase of the risk of external and internal irradiation calls for increased efforts on the part of the Radiation Protection Group to monitor, plan, and supervise the scientific work at HIE-ISOLDE.

The increased risk potential demands a review of the practice of allowing control of the mass separator by CERN users. The round-the-clock presence of operators in the HIE-ISOLDE facility with fivefold increased proton current is necessary to guarantee operational safety of the targets, the separator, and the experimental area.

6.8 Production and elimination of radioactive waste

Radioactive waste is defined as activated or contaminated material or equipment for which no further use is foreseen and which can be disposed of. Legislation and regulations in the host states impose strict controls over radioactive waste. Only under well-defined technical and administrative conditions may radioactive waste be released for reuse, for example as scrap metal. CERN has intermediate storage space for radioactive waste. A treatment and conditioning centre is in preparation. There, radioactive waste will be prepared for transport to radioactive waste repositories in the host states. It is CERN policy that the producer of radioactive waste bears the cost of its elimination [4].

In contrast to most radioactive waste from other accelerators at CERN, waste from ISOLDE generally presents a substantial contamination risk. For the risk of external and internal exposure from ISOLDE waste, the remarks in Sections 6.4 and 6.5 apply. At the end of the annual shutdown, about 30 spent targets are transported to a provisional storage area in the ISR, prior to removal from CERN. The storage area for targets has 350 places; at present, it has reached full capacity and cannot be extended in the foreseeable future. A project in AB Department and the Safety Commission led to the definition of the tools and procedures necessary for characterization, conditioning and transport of the targets to the Federal Intermediate Storage Centre (Bundeszwischenlager BZL) at the Paul-Scherrer Institute PSI in Villigen, Switzerland. Thirty weakly activated targets will be dismantled and preconditioned for disposal as waste during autumn 2006.

The aim of HIE-ISOLDE is an increased production of radioisotopes for research purposes. This will go hand-in-hand with an increase in the production of radioactive waste; in particular, spent targets.

After an increase of proton beam current, the total activity declared as waste will increase proportionally. This will have consequences for the tools and procedures for waste conditioning at CERN. It will also have an influence on the price of elimination, which is determined by the volume of the waste. However, the waste volume cannot be reduced arbitrarily (e.g. by super compaction), because of additional limits on total alpha activity per storage container. Two limiting cases can be envisaged:

- The lifetime of the targets is related to the total number of protons received. The present lifetime limit is approximately $10^{19}$ protons. If the targets remain unaltered, the proton beam increase will result in an important increase in the volume of waste (up to a factor of 5), with the same activity per target. This amount cannot be handled in the facilities envisaged for the elimination project nor by the personnel available in either AB or SC Departments.

- If the target lifetime is increased, the result could be the storage of targets containing up to five times more activity than at present. This will impose longer waiting times before, and improved protective measures during, pre-conditioning operations. All installations and procedures envisaged in the project for target elimination should be designed with the consequences of a beam current increase in mind.

In either case, a new provisional storage area with the necessary protective measures against contamination needs to be provided at CERN for ISOLDE targets.
Finally, an increase of proton current will lead to higher activation levels in the whole HIE-ISOLDE facility. Final dismantling, conditioning and storage of parts or the whole of this facility will become more complicated and costly and the necessary funds for this must be foreseen in the CERN budget.

6.9 Summary and conclusions
The proposed increase of proton beam current in the HIE-ISOLDE facility will make current provisions for radiation protection inadequate. The necessary upgrade will require numerous modifications to the existing facility, new and improved work procedures, and additional staff in the areas of

- shielding and access
- optimization of external irradiation
- optimization of releases into the environment
- protection against contamination
- optimization of radiation protection in the experimental areas
- storage and conditioning of radioactive waste.

Without defining technical or manpower solutions for all items in this list, the total cost of the HIE-ISOLDE project cannot be reliably estimated.

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