CHAPTER X

SAFETY AND RADIOPROTECTION

10.1 Quality and safety management system for SPES

This chapter presents the Quality and Safety Management System (QSMS) for the SPES project: a tool developed for managing all phases of the facility life cycle, starting from the initial design of its elements to their final dismantling. The aim of the System is to achieve high quality and safety standards for the SPES facility.

10.2 Objectives and description of QSMS

The reference requirements of quality and safety for the SPES project are set by Legnaro National Laboratory (LNL) in agreement with Italian laws, technical standards and all mandatory prescriptions that the project must comply. Moreover the QSMS will be realized according to the international guidelines ISO 9001:2008 concerning Quality and OHSAS 18001:2007 about Safety.

The goal of QSMS is to define and apply quality and safety standards for each element[1] of the SPES project during the following phases of its life cycle:

- Design;
- Construction;
- Operation;
- Maintenance;
- Disposal.

Every stage will be analyzed to identify the activities that should be controlled to guarantee safety and quality for the SPES facility: starting from general guidelines the specific operating instructions for each area will be identified. Some of the aspects that will be analyzed for the phases of design and construction concern, for example, the collection of all technical draws, the identification of legal and technical requirements and the description of the techniques for hazards and risks analysis. Following this all the ordinary and emergency procedures for the last three phases (operation, maintenance and disposal) will be drawn.

The SPES QSMS will be implemented using a software tool built up with the aim to automate all the system procedures.

Special attention will be put on the creation of the software interface that must be user friendly and easily accessible to all the facility staff and users.

The QSMS is intended to demonstrate the will of LNL to adopt a policy of safety and quality that will result into concrete benefits for personnel and local area inhabitants.

For the purpose of the work described in this paragraph, it is important to remember that inside LNL an Environmental Management System is already operating, in agreement with the international guidelines ISO 14001:2004. The QSMS of SPES will be developed consistently with the structure of this existing management system so that it will be possible to guarantee a future easy integration of the two managing tools. During the design phase of the QSMS it will be necessary to asses which aspects may be common to both systems in order to avoid any duplication in management processes.

10.2.1 Planning phase of QSMS

The planning phase of QSMS starts with the definition of SPES quality and safety standards, these should be measurable and consistent with the policy established by LNL.

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1 Elements are all the equipment, plant and infrastructures in which the project SPES can be subdivided.

The modalities for the attainment of the established goals have to be described and transferred into specific procedures.

The ISO 9001 and OHSAS 18001 guidelines require a preliminary draft of more general documents setting the organizational basis of the system. A subsequent compilation of more specific documents will describe the correct operating procedures for managing all the SPES Elements.

Stages for the realization of QSMS:

1. Risk analysis and design;
2. Realization;
3. Implementation (Operation, Maintenance, Disposal…);
4. Review.

Table 10.1 shows a list of the main aspects, subdivided into the five phases of elements life cycle, that will be managed and regulated by specific procedures.

***Table 10.1**: Procedures of QSMS*

Design and Risk analysis	Experimental apparatus design	Mechanical drawings	
		Electrical and hydraulic diagrams	
		Operation analysis	
	Infrastructure design	Building design	
		Plant design	
	Risk identification	Risk analysis and risk assessment	Risk assessment of plant accidents (FMEA, HAZOP and FT Analysis)
			Operational risk assessment
			Radiological risk assessment
	Identification of legal and other prescriptions applying to the project	Prescriptions for radiation protection	
		Prescriptions for fire prevention	
		Prescriptions for mechanical design	
		Plant prescriptions	
	Identification of prevention and protection measures to eliminate or reduce risks and keep them under control	Definition of safety systems/ control systems/ prevention and protection systems. Eventual drawings upgrade	
	Management of competitive tenders	Competitive tenders for plant mechanical design. Competitive tenders for the design of buildings.	

Construction	Experimental plant – construction	Assembly	Components and materials certification
			Processing certification
		Processing	Final certification
	Infrastructure - construction	Buildings	Site management
			Materials certification
			Certification of energy performance
		Plant	Components certification
			Plant certification
	Safety systems / control systems / prevention e protection systems - realization		
	Identification of laws and other applicable standard (practices, requirements relating to facilities, tenders...)	Radiation protection authorization files	
		Fire prevention certificate files	
		Plant and equipment certification	
		Building files	
		Tenders for the construction of the equipment, the construction of the buildings etc	
	Preparation of documentation and data base	Drafting the manual and the procedures of the Management System	
		Drafting the plant manuals and the operative instructions for the use the equipment	
		Collection of external technical documentation (certifications, declarations of conformity, etc)	
		Data collection	
		Information system development	
Implementation – Operation	Implementation of operative procedures	Procedures for the operation of experimental apparatus	

(operational control)		Procedures for the plant operation	
		Procedures for the management of the measurement instrumentation	
		Procedures for the operation of safety systems and control systems	
		Procedures for surveillance and monitoring activities	
		Waste management, emissions management	
	Maintenance management	Maintenance planning	
		Maintenance report	
		Stocks	
	Suppliers management	Maintenance, materials, etc	
Implementation – System Activity	Training management	Training and update programs definition	
		Implementation of the training and update programs	Registers of training courses
	Personnel management	Work organizational aspects (working tasks, working hours,…)	
		Health surveillance	
		Personnel classification for radioprotection aspects	
	Emergency management	Emergency procedures	
	Document management		
	Managing accidents and near misses, nonconformity, corrective and preventive actions	Procedures	
	Audits management	Planning and making audits	
Implementation	Dismantling		

– Disposal	Waste management		
Review	Periodical review		

10.2.2 Risk Analysis Techniques

An important part of the design phase in facilities like SPES is the risk analysis. The techniques for the evaluation of all possible ways that can cause a plant accident are: Failure Mode and Effect Analysis (FMEA), HAZard and OPerability analysis (HAZOP) and Fault Tree analysis (FT). These techniques will be firstly applied to the most hazardous components of SPES such as the ISOL Front-End and the venting system of the target bunker.

The **FMEA** technique is a survey tool aimed to identify the failure modes of each equipment component and both their local and global effects. It consists in a grid where all failures are analyzed. In particular the likelihood of occurrence of the fault, the severity of its effects and the possibility of its detection by an operator are evaluated. The combination of these last three parameters identify a precise value, the Risk Priority Number (RPN), that indicates whether you need or not to take some countermeasure. The failure modes that have the highest RPN must have the highest priority for corrective action. Not always the failure modes with the highest severity value should be treated first, there may be cases with less severity but higher probability of occurrence and lower chances of detection.

The **HAZOP** technique is a structured and systematic examination of a plant in order to identify and evaluate problems that may represent risks for personnel or equipment. It is based on the use of “guide words” (less, more, no, reverse,…) tabulated with the process variables (pressure, temperature, flow…) in order to evaluate their potential deviations from the design values, their causes and possible solutions.

The HAZOP methodology is useful for the construction of accident sequences that, starting from failures of simple elements, may cause a malfunction of the whole system and then raise an accident (Top Event).

For the purpose of the next paragraph some important definition relative to HAZOP analysis are indicated below.

Node: specific section of the system in which the deviations of the design intent are evaluated.

Deviation: way in which the process conditions may depart from their design intent.

The last factor is created by combining “Guide words” with process parameters resulting in a possible deviation from design intent.

Guide Word + Process variable = Deviation

The **FT** is a failure analysis in which an undesired state of a system is studied using boolean logic to combine a series of lower-level events. This technique permits to evaluate the expected frequency of the Top Event individuated by HAZOP analysis.

In general the application of all these three techniques requires a preliminary detailed knowledge of the equipment considered.

10.2.3 An application of risk analysis techniques: the cooling system of the SPES target

A first application of the risk analysis techniques regards the study done for the cooling system of the SPES target. The circuit has the same layout currently used for the EXYCT facility at Laboratori Nazionali del Sud (LNS) of Catania.

The results of the safety analysis have permitted to make some considerations regarding the possible malfunctions of the plant in case of accident. The principal outcomes are:

- the individuation of the most critical components of the plant;

- the assessment of the major adverse events that can cause serious damage to system integrity;
- the study of the principal Top Events, in particular the evaluation of their major causes and the calculation of their frequency of occurrence.

The Figure 10.1 shows the layout of the cooling system analyzed.

The system is constituted by two closed circuits: the primary uses demineralized water with neutral pH for the cooling of the target, the secondary uses softened water for the refrigeration of the primary circuit.

FMEA Analysis has been conducted for all components of the cooling system, for each of these one or more failure modalities have been considered. The criticality of the failure modes of the components has been evaluated by using the index RPN (Risk Priority Number): an higher value of this parameter is sign of danger and potential damage in case of failure of a component. A critical element will be subject to a greater controls in terms of safety and reliability, as well as a specific maintenance policy aimed at maintaining and monitoring the component.

The Figure 10.2 shows the RPN values of several components of the cooling system.

***Figure 10.2**: RPN values calculated for each components of the plant*

The analysis of the graph shows that the highest RPN index has been obtained for the flow meter and pump power of primary fluid: these are the most critical components of the system, they should be handled with special care and attention both in terms of design and schedule of maintenance.

HAZOP Analysis has been made considering the following process parameters: pressure, temperature and flow. The safety study has been performed on two nodes of the system: the first node is inside the primary circuit at the output of the heat exchanger, the second node located inside the secondary circuit at the entrance of the heat exchanger.

For each parameter considered the possible causes of deviation and its consequences have been evaluated. In this way a global vision of all physical parameter variations can be reconstructed.

The most important parameter in terms of incidental sequence has been the temperature with the relative deviations “greater than” and “less than”, these both lead to the study of two Top Event (TE) that are two potential adverse events that can cause damage and bring serious consequence to the integrity of the system.

The first TE, the temperature increase of the target, concerns the structural integrity of the source and consequently the whole system examined. An increase of temperature may cause also significant problems to adjacent structures and thus to the working personnel.

The second TE, the temperature decrease, does not have an adverse effect either for the system or the staff but it only concerns a productivity problem, namely the failure to produce beams of exotic ions due to the reduction of the temperature of the source.

Only the first TE, more dangerous than the second, has been developed through the Fault Tree Analysis in order to identify the frequency of occurrence of accidental scenarios and determine which are the events which most contribute to the TE.

The Top Event studied may happen because of the occurrence of either of the following incidental situations:

- failure of the control systems of pressure and temperature;
- reduction of water flow in the primary circuit and failure of safety systems.

The FT analysis has given a result of the frequency of fault occurrence equal to 8.3E-4 per year.

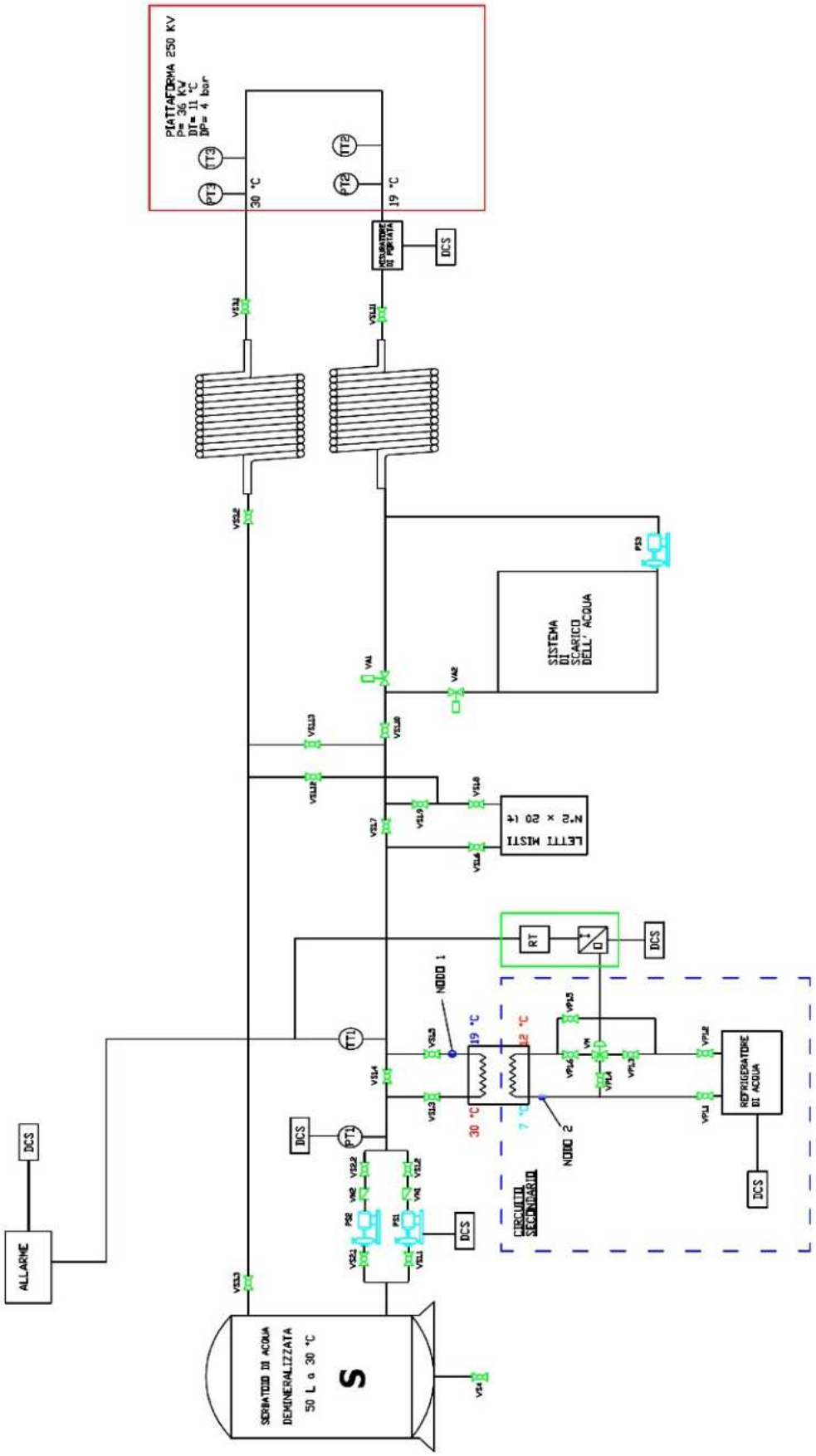


***Figure 10.1**: Layout of the cooling system of the SPES target*

10.3 The Software for QSMS

The QSMS will be made operational with the assistance of a custom software made of two parts:

1) A relational database for data collection;

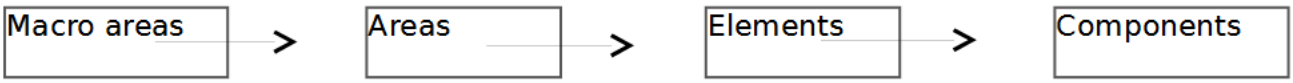
2) An interface that permits users interaction with data from the database and allows the automation of all procedures provided by QSMS itself.

Both the database and the interface should have the flexibility to ensure their adjustment with the development and the realization of the SPES facility.

The QSMS database will be created to catalog the following information:

- SPES Elements of these four main areas:
  - Experimental plant;
  - Laboratories;
  - Safety systems;
  - Infrastructures (buildings, plant);
- Personnel;
- Documents in general;
- Stocks;
- Suppliers and other contacts;
- Laws and technical standards;
- Procedures (operation of equipment, maintenance, emergencies, accidents,…);
- Audit.

An example of the database organization for the first point “Elements of SPES” is shown in Table 2; the modality of cataloguing follows this breakdown:



All Macro Areas (Experimental phases, Laboratory, Safety, Infrastructure) are subdivided in Areas, for each Area all the featuring elements are identified; eventually the elements are partitioned in Components.

***Table 10.2**: Example of database organization*

Macro Areas	Areas	Elements	Components
Experimental phases	Primary beam	Cyclotron	…
		Proton beam transport	…
		Cyclotron and magnets cooling system	…
		Pump cooling system	…
		Compressed air distribution	…
		Vacuum and air return system	…
		Radio Frequency	…
		Radioactive materials deposit and handling	…
	Direct beam	ISOL Front-End	…
		Target cooling system	…
		Ventilation system of the target chamber	…
		Ohmic heating power	…
		Vacuum and air return system	…
		Target system handling	
		60 kV Platform	…
		Service platform	…
		Pump cooling system	…
		Compressed air distribution	…
		Deposit and handling radioactive materials	…
	Secondary beam	…	…
	Reacceleration	…	…

10.4 Current state of the work

The realization of the QSMS explained in the previous paragraph requires a huge amount of work by different specialized figures. At the moment only some of the foreseen risk analysis have been finalized. In order to proceed and coordinate the various activities, a specific working group has been created and various collaboration have been established.

10.4.1 Safety working group for SPES at LNL

In the framework of the Task 1, the safety working group is intended as a sharing place among the various responsibilities concerning all the safety and quality issues about the SPES project. This group is coordinated by a group leader responsible of:

- QSMS development and implementation;

- supervising the work done among internal and external collaboration;
- the organization of regular working group meetings.

At these regular updating meetings, the followings figures are invited to participate:

- the SPES project leader;
- the responsible of SPES QSMS;
- the responsible of LNL Environmental Management System;
- a member of the Department Support Equipment;
- a member of the Task 3 ISOL target;
- a member of Accelerator Control System and Experimental Plant Service;
- a member of Radiation Protection Service;
- a referee common with the LARAMED project;
- the responsible of LNL Protection and Prevention Service;
- the responsible of LNL Radiation Protection Service;
- the responsible of LNL Divisions.

10.4.2 External Collaborations

The management of safety aspect of the project will be supported by the following contacts:

- Department of Nuclear Engineering, University of Palermo. The collaboration is based on the safety analysis for some components of the project SPES. It's expected to perform the following studies:
  - Risks analysis of the Front-End ISOL;
  - A thermo-hydraulic analysis of the target cooling system. This is carried out to verify if the plant is able to work according to the design expectation and which are the possible reactions in case of anomalous situations;
  - Analysis of the ventilation system that will keep the depression in the target bunker.

- ISOLDE, CERN. The similarity between ISOLDE and SPES facilities is useful to establish a comparison of the managing methods of all safety aspects that are adopted in the two facilities: ordinary and emergency procedures, safety systems, risks and accidents management, documents organization. Matter of particular interest for LNL is the current implementation of a "Safety File" for ISOLDE: a website platform for sharing documents and information about safety among all personnel. The software of the QSMS of SPES will be realized considering the general framework of the Safety File required at ISOLDE by CERN.

10.5 Work plan

The different tasks illustrated in the previous paragraph will be carried on in consequent working stages.

The first phase of the realization of QSMS for SPES will be the collection of the already existing safety documents and the definition of their cataloguing and organization.

In the following phase, the required general procedures for the satisfaction of ISO 9001 and OHSAS 18001 will be drawn.

Next, the specific procedures for each Element of the project SPES will be written; the work will be initially concentrated on the component of the ISOL Front End. This first application wants to be a test to verify the correct startup of the System until its general application.

In Table 10.3 the major objectives for the implementation of QSMS are shown.

***Table 10.3**: Schedule for the QSMS of SPES*

Goal	Dead line
☐ Cataloguing and management of documents already existing	
☐ Drafting of general procedures of QSM	
☐ Drafting of the specific procedures for the component Front End ISOL	
☐ Drafting of the specific procedures for all the other components of the project SPES	

10.6 Conclusion

The modalities chosen by LNL for the management of the SPES safety aspect underline its will of reaching a standardized method of work capable of guarantee Quality and Safety from the design phase of the project to the very end of the facility operation. A strategy of this kind needs a detailed study of all the aspects that will be regulated. This requires a considerable investment of time and manpower but this choice is necessary to achieve a correct and safe operation of a complex facility like SPES. The mail goal of the QSMS remains the realization of a useful and effective tool for safety and quality control, directed to all the personnel and external population.

10.7 Radiation Protection

Summary

The Radiation Protection aspects at the alpha stage of the SPES Project has been already faced. A technical report for licensing has been produced and the authorization of this stage of the project has been already given by the Minister Authority. The arguments contained in the report were:

- the evaluation of the radiation fields due to the interaction of the proton beam delivered by the cyclotron with the thick target used in the SPES – Phase Alpha;
- the shielding design of the irradiation bunker (considering the irradiation of a fissionable target as worst case) and of the cyclotron vault;
- the residual dose rates after an irradiation cycle in the irradiation bunker and in the cyclotron vault;
- the activation of air in the irradiation bunker and in the cyclotron vault;
- the activation of the concrete in the bunker shielding walls, at the presumed end of the facility lifetime;
- the activation of the target cooling water.

LICENSE AND PRESCRIPTIONS

Starting from the 21st of September 2012 the laboratory is authorized to operate the 70 MeV cyclotron satisfying the requests as formulated by the responsible of the SPES Project.

It is important to point out that at this stage of licensing is included the possibility to irradiate an UCx target with 40 MeV protons at the maximum current of 5 μA, extract the radioactive beam needed, re-accelerate it with the already existing Linac, and bring the beam to one of the experimental halls. This result makes the LNL facility one of the few structures in the world already authorized to re-accelerate radioactive beams (even low intensity ones) at the energy of some MeV/amu.

RIB GAMMA DOSE RATE

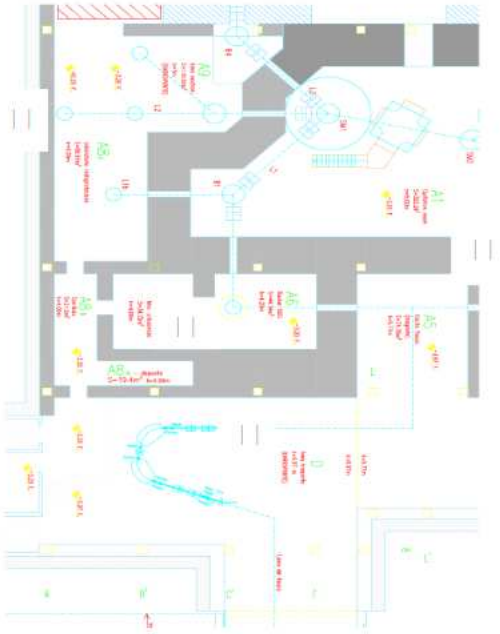
On the basis of the information already achieved, we proceed with the evaluation of the gamma dose rate along the beam line of the facility considering a particular radioactive ion beam.

The radioactive ion beam of interest for nuclear physics is obtained after different stages including extraction from the fissioned target, beam cooling, selection through a mass separator and charge breeding for the re-acceleration (Figure 10.2). In each of these steps there are beam losses, which cause a dose rate close to the beam line and the selection points.

A beam of 4x1011 isotopes/sec of mass number 131, 132 and 133 has been considered in order to analyze the production a 132Sn beam.

The map of the γ dose rate obtained with the Monte Carlo simulation shows that the dose rate at the end of 2 irradiation weeks is maximum 10 μSv/h in well-defined areas close to the beam cooler and the mass spectrometer (C). In the selection magnet area the contribution from the irradiated target is comparable to the dumped RIB (A), see Figure 10.3.

The outcome of this study is that the dose rate due to the transport and selection of the radioactive ion beam is relatively easy to manage: safety, from the radiation protection point of view, can be achieved using removable shields, where needed, and fence to avoid people to approach the beam line.



A: selection magnet
B: beam cooler
C: HRMS
D: charge breeder

***Figure 10.2**: Transport and Selection line of the radioactive beam*

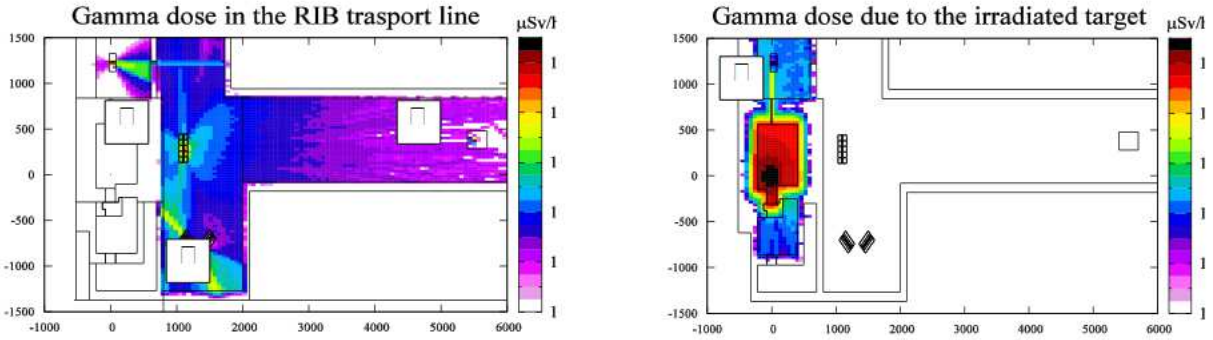


***Figure 10.3**: Gamma dose in the radioactive ion beam transport line (left) and gamma dose due to the irradiated target (left) in the target bunker and in the selection magnet room (right).*

RISK ANALYSIS

In the SPES facility radiation safety will be managed according to the principle of the defence-in-depth. This means that there are layers of safety provisions (structures, components, systems, procedures or combination of these) commensurate with the risk posed by the radiation source. In general, a lower overall probability of failure is achieved by combining independent protective layers, since the probabilities of failure of each successive layer of protection are multiplicative.

Technical layers of defence are organized in logical sequence, as:

1) design for minimum hazard
2) reduction of hazards through safety devices (e.g. interlocks)
3) safety warning devices (e.g. radiation alarms)
4) procedures and training for workers
5) identification of residual hazards for management review.

The practical application of the defence–in-depth principle involves both redundancy, where multiple copies or versions of the same protective layer are available in parallel, and diversification, where alternative modes of protection are available for a particular problem.

ACCESS TO CRITICAL AREAS

In order to avoid the exposure of personnel to high intensity proton beams, the access to the cyclotron vault and adjacent areas is strictly controlled and exclusively possible through interlocked doors. The beam is instantly stopped if someone attempts an entry during scheduled operation of an accelerator.

The cyclotron is shielded with 3 m concrete and the access is possible through a maze (made by movable shielding blocks) closed with an interlocked gate. The whole area (cyclotron plus irradiation bunkers) is accessible by two interlocked doors (A and B in Figure 10.4). An exchange key procedure must be followed to obtain an access key to A or B doors: the door key will only be released when the cyclotron is isolated and the beam cannot be accelerated.

The access to the irradiation bunker is possible through the interlocked doors E and F (or C and D). In particular the F door opening is triggered by the radiation monitor inside the bunker.

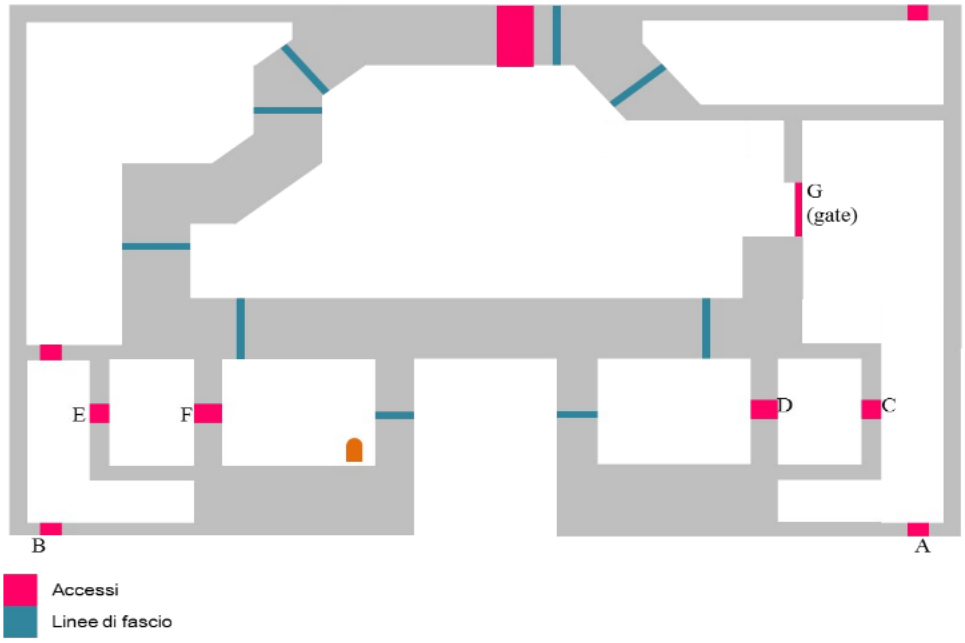


Figure 10.4: *layout of the cyclotron vault and the irradiation bunker with adjacent rooms. the access doors are identified by letters (A-G) and red squares.*

A first approach to the risk analysis has been made using an FTA (Fault Tree Analysis) considering as top event the overexposure of a person in the cyclotron vault or in the irradiation bunker.