CHAPTER IX - SAFETY AND RADIATION PROTECTION

1. OBJECT

This document presents the safety and radiation protection analysis of the SPIRAL 2 project. For many points studies are still in progress and will continue during all of 2005 (especially for the production hall and the existing GANIL facility).

A more detailed presentation is made in the DOS – *'Dossier d'Options de Surete'* – (ref. 1).

2. SPIRAL 2 FACILITY DESCRIPTION

The SPIRAL 2 project is an extension of the existing GANIL facility. It has to be considered as a modification of the GANIL INB "Installation Nucléaire de Base" (administrative denomination). The facility and building are described in the other chapters of this document.

The GANIL site is located in the Caen suburbs. The site is surrounded by industrial and technological sites, the Caen CHU hospital and the campus of the University. The surface of the GANIL site is 36000 m^2, and the surface of the INB zone is around 11 000 m^2.

The main uses of accelerated particles in the SPIRAL 2 facility will be:

- Production of radioactive ion by the indirect (or 'converter') method: deuterons of 5 mA, 40 MeV on a carbon target for production of fission products in a UC_x target, with a maximum production rate of 10^{14} f/s.
- Production of radioactive by the direct method: light ions on a U or similar target.
- Acceleration of ion beams to the maximum energy of 14.5 MeV/n and 1 mA intensity to interact with various target.
- Neutron irradiation with high neutron flux.

The radioactive ions produced in the two first cases can be transported after separation to the very low-energy experimental room (LIRAT) or accelerated by the CIME cyclotron and transported to GANIL's existing experimental areas.

In terms of safety, the critical point of the facility is the production hall where is located the 'plug' containing the UC_x target, the ion-source, the beam lines dedicated to the transport of the fissions product, the separator and the charge-breeder. A high quantity of radioactivity is produced (few 10^{14} Bq) in the uranium target with high radiotoxicity elements like alpha-emitters or iodine. The presence of this induced radioactivity gives rise to constraints for the SPIRAL 2 facility, but has also to be taken into account for the existing facilities (CIME and experimental areas).

2.1. Design criteria

In the present chapter we present the criteria relevant to safety and radioprotection. Some of these parameters could be adjusted according to the conclusions of the studies of the nuclear engineering company and of the project team. However, the order of magnitude should be correct.

2.1.a. Accelerator (source, RFQ, LINAC, Beam Dump)

For the accelerator facility (sources, RFQ and LINAC), the design criteria taken into account for radiation protection and safety are:

- beam intensity,
- beam energy,
- beam losses,
- voltages of the accelerating cavities, the RFQ, the ion source(s) and power-supplies.

The following parameters are used for the design of the radiation protection (shielding). Some of these parameters could be adjusted according to the conclusions of the study, with regard to beam losses, for example.

Table 1: design criteria for the accelerator hall.

Equipment	Energy (MeV/n)	Intensity (mAe)	Intensity (pps)	Losses (pps)	Tension (kV) or power (kW)
Ion sources	0.02	6	3.75×10^{16}	6.25×10^{15}	10 kW
LEBT	0.02	5	3.13×10^{16}	6.25×10^{15}	so
RFQ	0.75	5	3.13×10^{16}	9.4×10^{14}	100 kV
MEBT	0.75	5	3.13×10^{16}	3×10^{14} to 1.5×10^{15}; or 3.13×10^{16} if suppresser is used	so
Linac	From 0.75 to 20	5	3.13×10^{16}	From 8.4×10^{14} pps at 0.75 MeV/A to3.13×10^{13} pps at 20 MeV/n (1)	2000 kV
Beam dump	20	1	6.25×10^{15}	6.25×10^{15}	so
Converter-target	20	5	3.13×10^{16}	3.13×10^{16}	so

(1) According to ref. 2, maximum punctual beam losses in normal conditions do not exceed 200 W.

Other specific risks already identified around the linac are concentrated in the cryogenic plant. With respect to the normative requirements for such equipment, the followings points will be studied :

- Anoxic risk: the use of ventilation and detection is required.
- Cryogenic risk (the use of liquid helium).
- High-pressure equipment risk: security valves will be installed on tanks and periodically tested under pressure according to the normal rules.

2.1.b. Target station

In term of radioprotection, the “worst” case is the deuteron beam of 5 mA, 20 MeV/n on the carbon converter and the production of fission products with a maximum rate of 10^{14} fissions/s in a UC_x target which contains a mass of uranium (isotope 238) less than 5 kg. Only elements of fusion temperature lower than 2000°C are extracted from the target and ionised in the 1^+ source with an efficiency of 100%. (ref. 3). The value of 2000°C should be adjusted according to the real working point of the target.

Critical points are the remote handling of the plug for storage (while activity decays after irradiation) and the dismantling operations in the hot-cells.

The others possible uses of the target station (direct method of production) do not lead to any higher safety problem than the first. The incident beam intensity will be calculated to respect this assumption.

2.1.c. Transport of radioactive ion beams (ref. 3)

For the SPIRAL2 facility, all the elements injected in the 1^+ source will be ionised and transported in the separator with an efficiency of 100%. Only one mass (particle of interest and all isobars) will be transmitted by the separator.

An efficiency of 5% is assumed for the charge breeder.

For the existing GANIL facility, we have taken the maximum efficiency of the CIME cyclotron to be 40%.

The safety demand not to exceed a given maximum radioactivity in the existing facility may require limited modifications of the experimental area. To reach this goal, the safety studies will follow the following rules:

- A systematic analysis of all risks will be made.
- proposal of will be made for safety barriers, to reduce the consequences and the probability of the risks.
- Calculations of the consequences of accidents will be made. If this last result is not acceptable, new barriers will be studied in order to reduce the consequences and or the frequency.

The criteria chosen for "acceptable consequences" depend on each event, and introduce the notion of "reasonable" steps to be taken. This implies a multicriteria analysis in term of cost, consequences for safety and the security of the facility and the gain in term of dose for the proposed solution.

The radioactivity sent to or induced in the existing GANIL facility will be managed with the intensity of the beam as parameter (cf §3.2.c). This will be defined with radiological criteria such as equivalent dose rate, maximum impact of an accident, etc.).

2.2. Identification and quantification of dangers

In this chapter all known sources of danger are presented for each piece of equipment and, when possible, a quantification of the level is also given.

2.2.a. Direct radiation

Neutrons

Neutrons will be produced in the region between the deuteron ion sources and the irradiation station according to the energy of the ions and the deuteron beam losses.

Below 5 MeV (cf. ref. 4) the dominant reaction is the D-D one which produces neutrons of energy greater than 2 MeV from the energy of the incident particle. The phenomenon consists of implantation of a deuteron in a target with beam losses (e.g. in a faraday cup), which allow the D-D reaction to take place. It concerns the deuteron source, the LEBT, the RFQ and the first part of the LINAC.

For energies greater than 5 MeV, the dominant process leading to neutron production is the break-up of the deuteron in the target. The evaluation of the dose rate is given in the following table.

Around the linac, the shielding is calculated for normal losses of 200 W (at a given point). The interlock system should detect losses that exceed this level in a given time and then stop the beam The study (ref. 2) has shown that this goals could be reached, which then allows the construction of shielding with a thickness of 190 cm compared to 290 cm with 100% of losses.

The probability of an integrated dose of 4 µSv per year for a given number of beam losses in normal working conditions is smaller than 10^{-6}.

Gamma rays

The production of various radioisotopes will produce a risk of external exposure to high fields of gamma rays. The different sources are listed above and the evaluation of equivalent dose rate is shown in Figure 2.

Table 2: Prompt neutron dose rate and shielding for the accelerator hall.

Equipment	Energy of d ions (MeV/n)	Intensity (mAe)	Intensity (pps)	Losses (pps)	Equivalent dose rate without shielding at 1m (mSv/h)	Shielding required for 1 µSv/h (order of magnitude)
Ion sources	0.02	6	3.75×10^{16}	6.25×10^{15}	1.20 7.2 for 100% loss	25 cm 35 cm
LEBT	0.02	5	3.13×10^{16}	6.25×10^{15}	6	25 cm
RFQ	0.75	5	3.13×10^{16}	9.4×10^{14}	7.4	35 cm
MEBT	0.75	5	3.13×10^{16}	3×10^{14} to $1.5\times10^{15;}$ or 3×1310^{16} if beam stopper used	2.4 for 1% to 11.8 for 5% 246 for 100%	30 cm (1%) 35 cm (5%) 50 cm for 100%
Linac	From 0.75 to 20	5	3.13×10^{16}	From 8.4×10^{14} pps at 0.75 MeV/A to 3.13×10^{13} pps at 20 MeV/n (200 W)	6.7 at 0.75 MeV to 1.4×10^{4} at 20 MeV/n	35 cm at 0.75 MeV/n 190 cm at 20 MeV/n
Beam dump	20	1	6.25×10^{15}	6.25×10^{15}	2.8×10^{6}	310 cm at 0° 255 cm at 90°
C-converter	20	5	3.13×10^{16}	3.13×10^{16}	1.4×10^{7}	340 cm at 0° 290 at 90°

Note: The thickness of the shielding is given for concrete of density 2.4 g/cm^3.

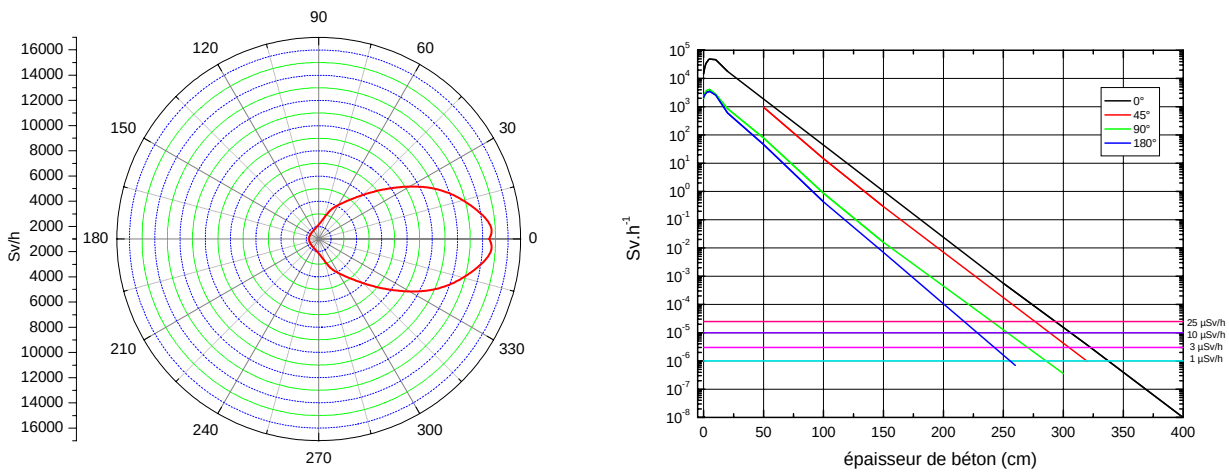

Figure 1: Neutron and prompt gamma dose rate at 1 metre from the converter for 5 mA of deuterons at 20 MeV/u, as a function of the diffusion angle and transmission curves through concrete of normal density (ref. 5).

Neutron activation of structures

All the structures and elements irradiated by high fluxes of neutrons will be activated and radioisotopes that emit β- and/or γ-rays will be produced. The total activity depends on the neutron energy and flux. The equipment and areas concerned are:

- Deuteron ion sources
- The beam transport lines (LEBT, MEBT and HEBT)
- The linac
- The irradiation target TARGET (i.e. beam dump and plug)

The very first evaluation of the neutron activation has been made. For the transport lines and the linac (ref. 6), the results show that, for conservative assumptions, the dose rate will not exceed 100 µSv/h at 1 meter (for 200 W of losses).

However, for the plug (ref. 7) and its direct environment, neutron activation will induce higher dose rates, i.e. 8 mSv/h at 1 metre of the top of the plug and 44 mSv/h at 1 metre from the wall of the tank; this result shows that the actual concept of a plug with a high quantity of stainless steel is not acceptable, and additional development is needed to find material less sensitive to neutron activation.

Fission products

The very great majority of fissions products produced in the UC_x target are βγ-emitters. The total activity produced in the UC_x target and the corresponding dose rates are presented in the figures below. These numbers were obtained with the codes LAHET MCNP and CINDER.

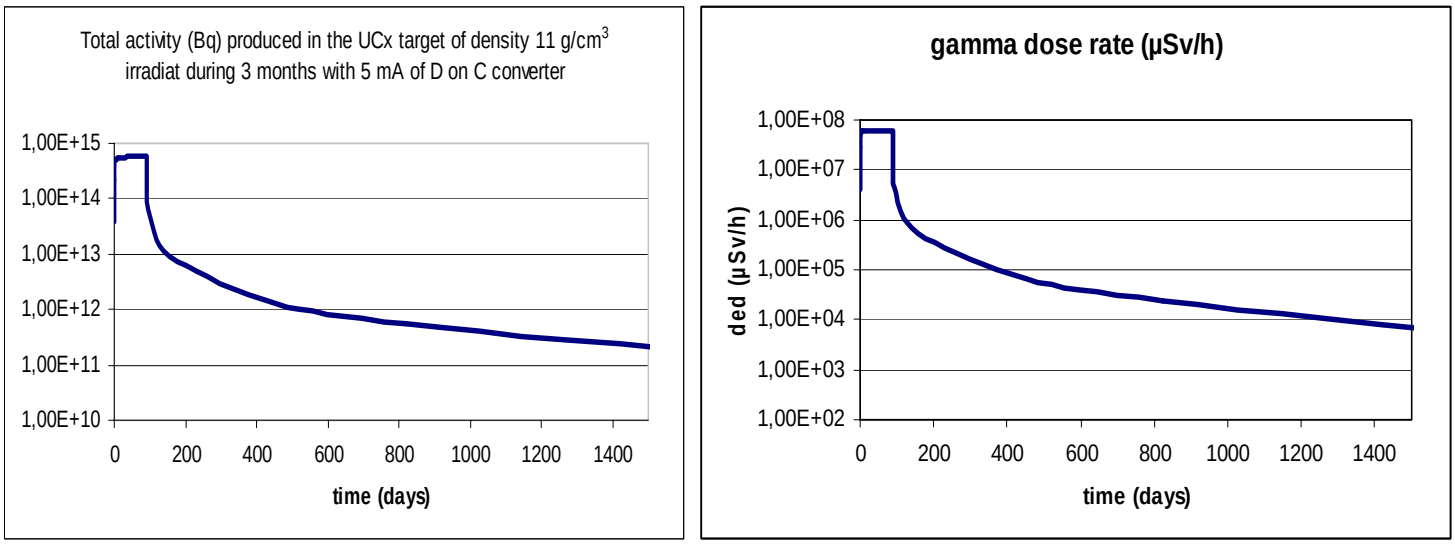

Figure 2: Total activity and equivalent γ-ray dose rate produced in one target, for 10^{14} fissions/s (ref. 1).

Table 3: Activity of various elements produced in the UC_x target (ref. 1).

Maximum total activity	6×10^{14} Bq
Total activity after 1 year of decay	2.2×10^{12} Bq
Maximum βγ-activity	5.9×10^{14} Bq
Maximum γ-equivalent dose rate at 1 m without shielding	6.12×10^{7}µsv/h
Maximum γ-equivalent dose rate at 1 m without shielding after 1 year of decay	1.1×10^{5}µsv/h

These values have to be considered as the source term of the plug. This radioactivity is very high and does not allow any access in the vicinity of the facility where this radioactivity is present without special precautionary measures.

- It has been shown (ref. 8) that this quantity of radioactivity requires the classification of the SPIRAL 2 facility as a "Nuclear INB" as opposed to the present GANIL facility which is an "Accelerator INB". The classification of SPIRAL 2 will be *"usines de préparation, de fabrication ou de transformation de substances radioactives et installations utilisant des substances radioactives sous forme de sources non scellées ou sous forme de sources scellées non conformes aux normes NF M 61-002 et NF M 61-003"*.
- For all operations around the plug (handling, dismantling in hot-cell, etc.), shielding will be required, even after a long decay time. The order of magnitude of the thickness is 52 cm of steel or 170 cm of concrete for a value of 10 µSv/h behind the protection without decay (ref. 9) and without any neutron-induced activation.

Taking into account the hypotheses presented in chapter 2, we obtain the following results for the other equipment of the facility (refs 10 and 11)

Separator:

All elements extracted from the target (i.e. elements with a melting point of less than 2000°C) are assumed to be transmitted to the 1+ source and extracted from the source and conducted to the separator with an efficiency of 100%. The corresponding activity is 3.10^{14} Bq which corresponds to a maximum γ-equivalent dose rate of 30 Sv/h at 1 m. The decay of the γ-equivalent dose rate around the separator is presented in Figure 3.

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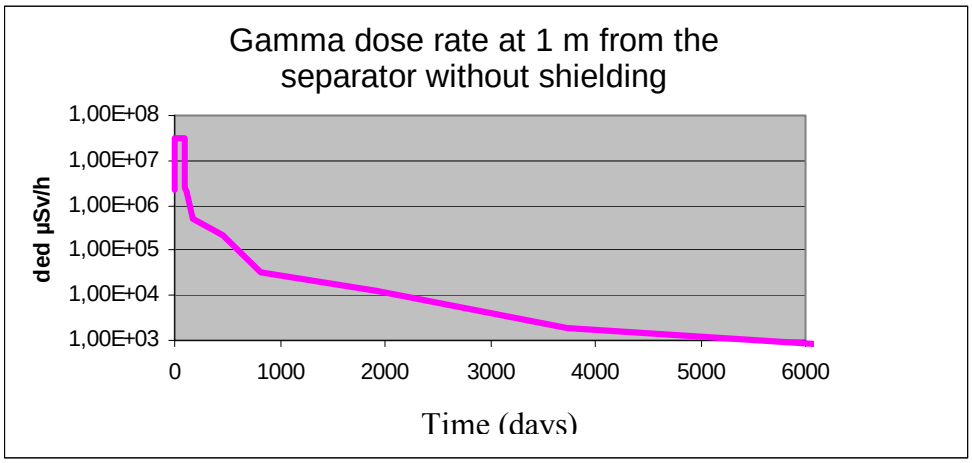

Figure 3: Equivalent gamma dose rate near the separator.

These results show that the radiological problem associated with the separator is almost the same as that of the plug. Constraints due to the use of the separator are not identical to those for the plug (no need for handling as often as for the plug, life-time far greater than for a plug).

<u>Beam lines after the separator</u>

For the lines after the separator (i.e. the charge-breeder with beam lines before and after it, where ions of the wrong charge are lost, the identification station and the low-energy experimental area), all elements presents with a given mass leave the separator and are transmitted.

Examples are:

mass 91: Y-91*, **Kr-91**, Sr91, **Rb-91.**
mass 140: Pr-140, **I-140**, Ba-140, **Xe-140**, **Cs-140**, La-140.

The order of magnitude of the activity is A ~ 10^{13} Bq and EDR = 2.6 Sv/h at 1 m. Special care has to be taken due to this level of radioactivity. We observe great differences between different isotopes even when they are very close in mass. With some masses, a short delay is sufficient for access. With particular bad cases, the delay can reach 100 days (see example of mass 140 below).

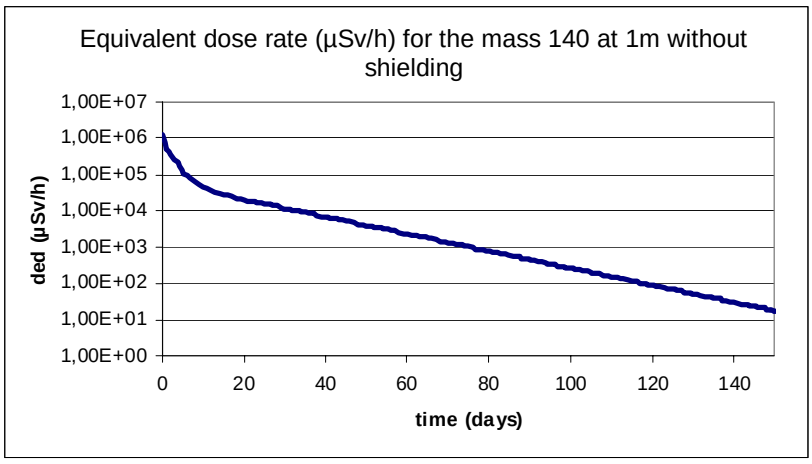

Figure 4: Equivalent gamma dose rate near the 1+ n+ source for mass 140.

Beam lines after the charge-breeder and CIME

Here we reach a critical point because it concerns a facility that already exists and for which modifications could be more difficult to realise. For all this existing equipment, work is still in progress to analyse the consequences of the presence of radioactivity. The following topics are being studied:

- The possibility of operating systematically with purification of the beam to retain as many of the ions of interest as is possible and to minimize the transport of isobars.
- The possibility of limiting beam losses to a few particular points, specially equipped with shielding.
- Monitoring of beam losses between these points to cut the beam when unacceptable beam losses are identified.

With a maximum efficiency of 5 % of the charge breeder for a given mass and charge, we find:

A ~ 510^{11} Bq, and
DeD = 2.6 10^{-2} Sv/h at 1 m.

After CIME (i.e. the existing GANIL facility and experimental rooms)

With a maximum efficiency of CIME of 40%, we find A ~ 10^{11} Bq, and DeD ~ 10^{-2} Sv/h at 1 m. Thus even for experimental areas, radiological constraints can be important. In several cases, access around detectors in the irradiation cave will be impossible for a long period (e.g. after 80 days of decay for mass-140 isotopes, the equivalent dose rate is still 500 µSv/h, corresponding to a yellow controlled area which cannot be considered as a permanent work place. The adoption of experimental setup safety constraints is an important point.

Beta radiation

The equivalent beta dose rate is very important (i.e more than 2 mSv/h, corresponding to a zone with access denied). However, the shielding required for the gamma rays will be enough to attenuate the beta rays. Specials care will be taken for dismantling operations if they are not realised in a hot-cell.

X-rays

Rf cavities, and ions sources will generate prompt X-rays when in operation. For the cavities, the maximum X-ray energy will be determined by the maximum voltages in the cavities: this will not exceed 2000 kV in the linac. Dose rate evaluation shows that the dose rate can exceed 2 mSv/h, which corresponds to a forbidden access area.

Shielding will be required on the outside of the RFQ and accelerator and personnel exclusion zones will be installed.

Measurements of the X-ray spectrum and corresponding dose rates will be performed with the RF cavity prototype in ORSAY at the beginning of 2005.

2.2.b. Radioactive material

When taking into account the radioactivity produced in the UC_x target (6×10^{14} Bq) and the dispersion of this radioactivity all along the beam lines and in the vacuum system of the facility, the quantity of material with a significant risk of contamination is important. If we look in detail at the spectrum of isotopes we find the following results:

Table 4: Activity of particular elements produced in one converter and UC_x target with 10^{14} fissions/s.

Maximum total activity (Bq)	6×10^{14}
Total activity after 1 year of decay (Bq)	2.2×10^{12}
Tritium activity (Bq)	3×10^{11}
Iodine (Bq)	2.7×10^{13}
Maximum βγ-activity (Bq)	5.9×10^{14}
Maximum alpha activity (Bq) without ^{238}U	4×10^{7}
Alpha activity (Bq) without ^{238}U after 1 year	3.5×10^{7}

It has been shown (ref. 12) that in case of an accident with the plug (dispersion of all the contamination) the contamination will follow the curve shown below. No ventilation and filters are taken into account. The LDCA means the maximum contamination acceptable (proportional to Bq/m^3) for each radioactive element. This result shows that vacuum chambers where radioactive beams are transported cannot be opened without special security measures. Ventilation systems will be an important part of the safety equipment.

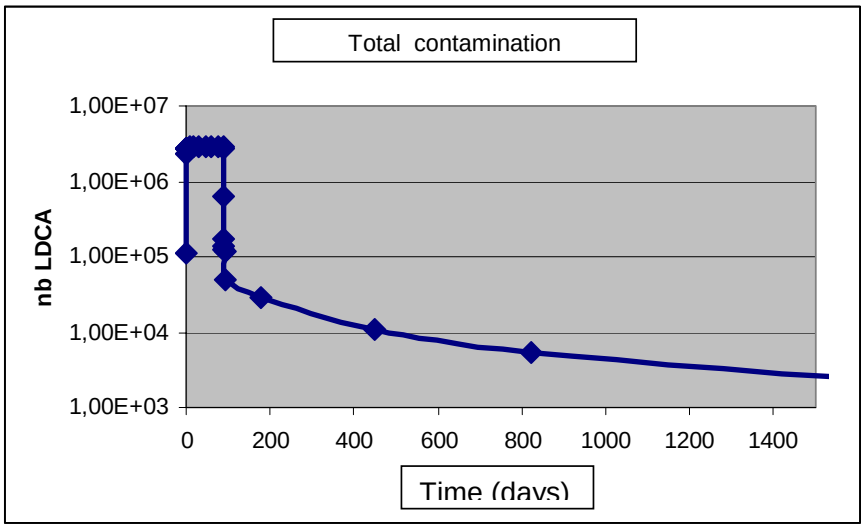

Figure 5: Contamination in case of accident of the plug.

2.2.c. Radioactive gases

It is true that of the various elements produced in the target, a significant number have a melting temperature less than 50°C and can thus be considered as gases. It has been shown in various facilities (e.g. ISOLDE at CERN) that these elements can be transported in the vacuum chambers for truly long distances, and are generally pumped by vacuum system. This will oblige us to consider all the gases pumped by the vacuum system as potentially radioactive. This concerns all beam lines where radioactive beams are transported (from production hall to experiments).

In the following figure is presented the activity of these elements.

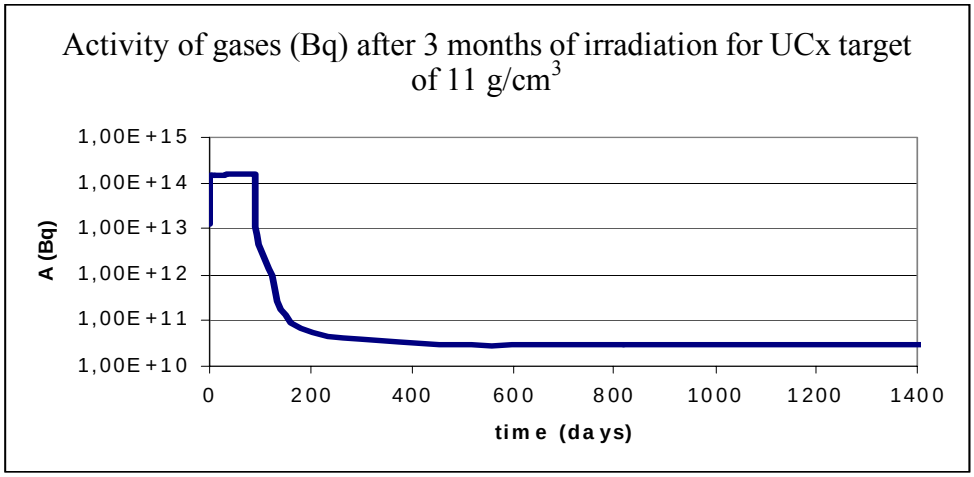

Figure 6: Total gaseous activity produced in one UC_x target with 10^{14} fissions/s.

Normal releases

After being pumped, the gaseous elements will be stored for a given time and then released into the atmosphere. If we take into account two very high-efficiency filters (efficiency = 10^3) for elements others than noble gases (i.e. 100 for iodine), the dose to the public can be evaluated by the GAZAXI code for external exposition and with GAZAXY for the ingestion (both codes from the CEA). A very first study of the radiological impact has been performed (ref. 13). More detailed studies for SPIRAL 2 and the whole GANIL site are still in progress under the responsibility of the SPR at GANIL (for the administrative document DARPE).

The dose is calculated for realistic atmospheric diffusion conditions and between 800 metres and 8 km from the emission point. The decay time will be defined by the radiological impact of the release for the population around the GANIL site. A first approach is the following: assuming three runs of three months each per year at the maximum intensity, the radiological impact is as shown in the followingtable.

Table 5 Dose to the public under normal conditions for 1 year.

Decay time (month) before release	1	3	12
Public Dose (µSv)	100	3	0.01

After a reasonable decay time the dose to the public is very low compare to the regulatory limit of 1000 µSv/year. The final dose impact will be validated after a study that will demonstrate the application of the optimisation concept. A value as small as possible but, in any case, smaller than 10 µSv/year should be the design goal. That has to be considered as a major point of the safety aspect of the SPIRAL 2 project because GANIL has to integrate into its authorisation procedure from the French authorities the possibility to operate radioactive releases. This procedure is very long for a facility classified as “INB”, such as GANIL. A public enquiry is needed.

Accidental released

Another critical point is the impact of radioactive release in case of accident. A first evaluation shows that, assuming that 10% of the aerosol elements and 100% of gases are released into the atmosphere, with the efficiency of filters taken into account, the dose for the public is evaluated at 100 µSv. **This result shows that the use of filters is a safety demand in case of accident.** The definition of number of filters will be done later. The failure modes of the 'nuclear' ventilation system should be studied carefully (ref. 14).

For the experimental areas, if we assume that an accident occurs in an experimental cave, we find that even if we release of all the radioactivity present inside the beam lines without filtering, the dose for the public is 100 µSv for mass 140. Work is still in progress to calculate the public dose for all the masses and to evaluate the maximum intensity acceptable according to radiological constraints.

2.2.d. Chemical and cryogenic substances

An exhaustive list of chemical risks has to be established for all activities within the SPIRAL 2 facility. For instance there is no major problem identified. The activity realised in the 'white' room dedicated to the superconducting RF cavities will not require the use a hazardous chemical liquid. The cryogenic plant will have high quantities of gases present, and the risk of anoxia has to be taken into account for this part of the facility.

2.2.e. Internal and external hazards

The exhaustive list of all hazards (of internal or external origin) has to be made. Such a list is presented below:

- Earthquake
- Fire
- Overflow
- Explosion
- Aeroplane crash

Owing to the high quantity of radioactivity produced in the SPIRAL 2 facility, it is necessary to construct a building that will withstand to an external hazard such as earthquake or explosion, etc. This means that buildings and any equipment that providing functions "important for safety" must survive such an event.

The studies (still in progress) will define the level of the magnitude of the earthquake and then the criteria that will be take into account for the construction of the building (for the new facility). For the existing one, the studies of civil engineering will evaluate the level of the modifications (cost, feasibility, etc.). According to the possible consequence of the hazard, the decision on possible modifications will be taken. If some part of the facility does not comply with this requirement, the radioactivity present must be reduced to a value that makes any consequences acceptable.

The same assumption means that the risk of severe fire should not result in unacceptable consequences to the environment. It requires a division of the facility into sectors including (a) halls with high radioactive risk and (b) other parts of the site. The following points needs to be taken into account for sensitive areas:

- Resistance to a major fire for twice the duration of a typical fire (at least two hours)
- Automatic extinguishing of fires if access is not possible (due to radiological atmosphere)
- Retention of all water used in case of fire (i.e. no possibility to direct release into the town storm-water system).

The risk of external hazard due to an explosion has been studied (ref. 15). It has been shown, that the risk of explosion due to transportation of liquid gas around the GANIL site must be taken into account. Calculation of the high pressure resulting from such an explosion is in progress. It will be one of the design criteria for the new buildings of the SPIRAL 2 facility. The consequences on the existing GANIL facility will also be studied in 2005.

The other risks already identified are the use of high-pressure equipment in the cryogenic plant. It has been shown (ref. 1) that in case of explosion, the impact cannot cause other problems in the building.

The risk of an airplane crash will be studied to determine if it has to be taken into account.

3. GENERAL SAFETY OBJECTIVES

3.1. Object

In this chapter are listed the different parameters that have to be take into account for the safety and radiation protection of the project, according to the data presented in this report, concerning both normal situations and accidents.

3.2. Normal Situation

3.2.a. External exposition

Exposure of workers

Legal limits are 20 mSv/year for directly exposed personnel, 6 mSv/year for others and 1 mSv/year for the public. We have to aim to keep doses well below these legal limits to apply the optimisation principle.

Dose objectives for normal conditions are less than:

- 2 mSv per year and 200 µSv per day of work.
- Collective dose: 5 man.month.Sv for a given activity and 30 man.month.Sv for the whole site.

For any permanent work-station the dose rate may not exceed 3 µSv/h. For a particular workstation it is possible to reach ‘yellow’ controlled area status, according to the dose objective and the application of the optimisation principle. For permanent workstations of experimental workers, the public zone limit is chosen.

To respect the radiological zone around the linac, beam losses must not exceed the limits presented in paragraph 2.1. A dedicated monitoring system has therefore to survey the beam losses on-line, and to cut the beam when loss limits are not respected.

Important shielding (cf section 2.1.) is required everywhere around points where there are radioactive beam losses, when the accelerators are in operation, and also when stopped, because of the induced radioactivity.

3.2.b. Management of the radioactivity and of the contamination

An important point is to manage the radioactivity transported in the facility and to minimize the total activity. Sufficient numbers of barriers have always to be installed between radioactivity and the environment to achieve proper containment.

For the production hall:

- Two static barriers
- Two dynamic barriers

Currently it will be the vacuum chamber and the building for the static confinement and the vacuum system itself and the ventilation system for the dynamic confinement. Fast-acting valves

will be installed in case of detection of an incident, to close the vacuum chamber and form the static barriers.

For the existing facility:

If the principle of two barriers is not respected, we must prove that any consequence for workers and the environment is acceptable. For the existing facility this means reducing the intensity of radioactive beams. To be accepted by the safety authorities, it has to be established that the modifications of the existing facility is not possible or that it would imply a major cost compared to the gain in term of consequences.

- Additional safety system

To minimize transfer of radioactivity through the vacuum chamber we have studied the possibility of using cryogenic traps to stop the diffusion of non-ionised elements. This equipment should be able to stop gases from diffusing all along the vacuum chamber, but still allow the radioactive beam to pass. It is composed of traps at different levels of temperature (80K and 20K) and active carbon, to stop the different radioisotopes element according to their properties. The efficiency has to be greater than 10^3. A prototype will be construct to measure the value of the efficiency and optimize its efficiency. (See ref. 16).

The place chosen for it is just after the separator, to decrease the contamination in the beam line after the equipment. Shielding is required near the cryotraps, which will be connected to the storage system for radioactive gases.

The work still in progress during the year 2005 will allow us to construct a prototype to measure the efficiencies of the traps for various chemical species.

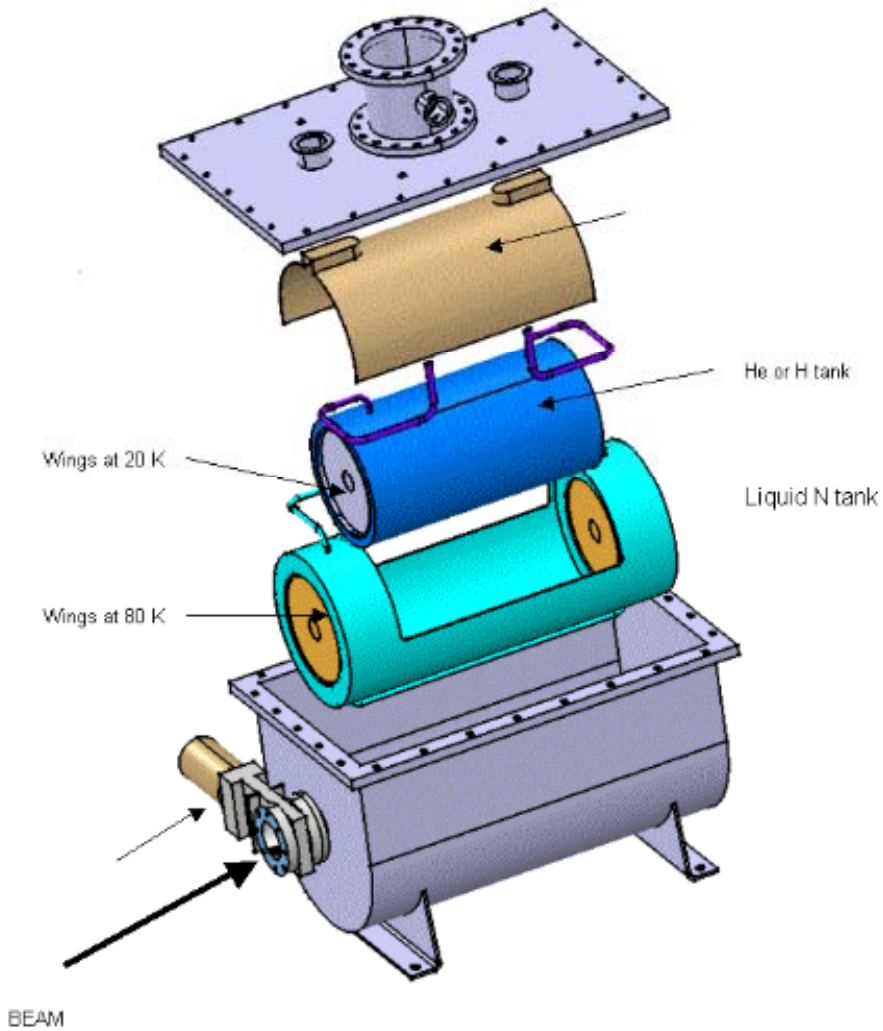

Figure 7: Schematic design of the cryotraps.

All gases (exhaust from vacuum pumps, cryotraps, etc.) will be stored in one or more tanks. After a decay time of 3 months, the radioactivity will be able to be released in atmosphere. Owing to the expected dose rate, shielding is required around the vacuum system, cryotraps and the storage tanks. Owing to the risk of contamination, the chance of any confinement break around the vacuum and stored system has also to be studied carefully.

3.2.c. Monitoring of radioactivity

An important goal is to manage the radioactivity that leaves the production hall to prove that the existing facility of GANIL (consisting of one system of confinement) can accept the secondary beams (ref. 17). The procedure involves calculation of the maximum intensity acceptable for each mass of radioactive beams. The working diagram is presented below:

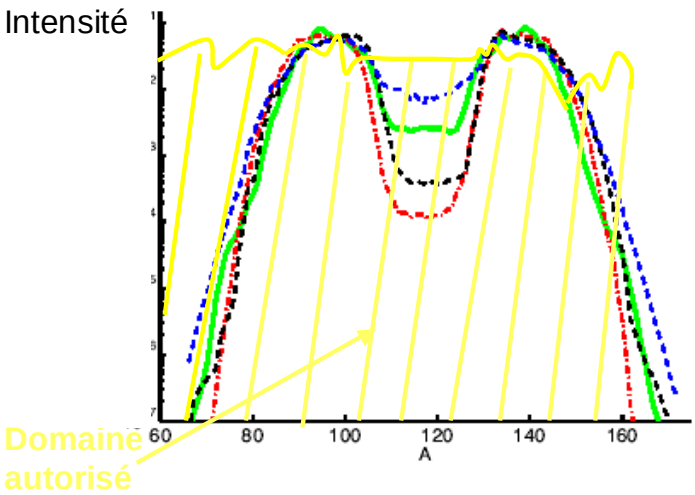

Figure 8: working diagram of the GANIL facility.

When needed, the beam will be reduced for each mass with dedicated equipment such as beam line "pepper-pots" or with a lower deuteron beam intensity on the UC_x target.

During operation, a monitor will measure the intensity of the radioactive beam on-line to show that authorised value is respected.

3.3. Safety level

The situations which define the nuclear safety level of the facility are:

- normal service of the installation;
- incidental situations;
- accidental situations.

- The incidental and accidental situations are the most penalising, concerning the radiological impact of the facility on its outside environment. The safety analysis of the facility must allow one to determine the exhaustive list of the situations in service other than normal, on the basis of a deterministic reasoning: it consist of listing the events which could lead to a dispersion of radioactive materials in the environment, in order to define the major accidents, meaning those which could lead to the more serious consequences outside of the facility. The determinist method of safety analysis sets scenarios based on initial events and on the supposed breakdown of components. The scenarios are defined so that they also include events of low probability. Then, the installation of barriers should be proposed to reduce the frequency of accident and or the consequences. Associated to the analysis principle, the dose will be evaluated for each events and then compare to admissible values. If the result is not acceptable, more safety barriers have to be installed to reduce the consequences or the frequency of the incident (ref. 18).

3.3.a. Incidentals situations

The incidental situations may have an impact on the inside of the facility but have no significant impact on the outside of the site. These situations are indicated on the table below:

Table 6 : Incidental situations (ref. 1)

Equipment	Item	Origin	Incidental situation
Linac	Measure of the beam losses	Dysfunction	Radiation levels higher than acceptable values
Converter	Cooling system	Leak	Dispersion of contaminated water
	Wheel	Breakdown	Possibility of affecting the target integrity
Target	Sublimation of the target	Loss of the converter	Dispersion of radioactive materials
	Vacuum system	Loss of the vacuum	Sublimation of the target: dispersion of radioactive materials
	Oven's cooling system	Leak	• Dispersion of contaminated water • Affects the oven's integrity
Plug	Pressurised water system	Leak	Dispersion of contaminated water
Separator	Vacuum chamber	Loss of containment	Dispersion of radioactive materials
CIME	Vacuum chamber	Loss of containment	Dispersion of radioactive materials
Transport lines	Beam-loss monitoring system	Breakdown	Radiation levels higher than acceptable values
Shielded cell	Fire	Short-circuit	Dispersion of radioactive materials
Nuclear ventilation	Stop	Loss of dynamic containment	Dispersion of radioactive materials

3.3.b. Major incident

The sublimation of the target is probably the major incident – in term of potential radiological consequences on the installation. The safety study of the installation will have to set the consequences associated with each incident by taking into account the systems designed to limit its consequences.

Sublimation of the target

Origin of the incident: breakdown of the converter (localised overheating, mechanical breakdown) associated with a malfunction of the system that protects the target (fusible wire).

Consequence: a beam of 200 kW directly on the target, which sublimates instantly.

Impact on the installation: contamination of the beam lines downstream from the target, up to the cryotrap system located beyond the separator, by radioactive aerosols. The activity injected into the existing GANIL facility is twice that expected (owing to a target efficiency of 100% instead of 50%).

Radiological impact on the environment: probably none, for all the gases located in the target are pumped by the vacuum system toward their storage-and-decay tanks. The activity of the gases

reaching the physicists is also twice that expected. These gases are also pumped and follow the same storage route.

3.4. Accidental situations

The accidental situation may cause a release of radioactive materials from the inside of the facility to the outside of the site:

Table 7: Accidental situations (ref. 1).

Equipment	Area	Origin	Accidental situation
Plug	Transport by crane	Fall	Dispersion of radioactive materials
	• Irradiation area • Storage area	Fire	Dispersion of radioactive materials
	• Irradiation area • Storage area	Earthquake	Dispersion of radioactive materials
Storage of the gases before released	• Storage tanks • Transfer system (lines to storage)	Risk of internal origin Earthquake	Uncontrolled release of radioactive gases
Experimental areas	Vacuum chamber	Earthquake	Dispersion of radioactive materials

3.5. Major accident

The destruction of the target inside the irradiation hall, due to the breakdown of the handling equipment of the plug is probably the most significant major accident – in term of radiological consequences to the outside of the facility. The safety study will have to determine the consequences associated to each accident by taking into account the systems designed to limit its consequences.

3.5.a. Material destruction of the target

Origin of accident: fall of a ‘plug’ during its handling by the crane.

Consequence: suspension of a great part of the activity of the target.

Impact on the installation: contamination of the atmosphere of the irradiation hall by aerosols and radioactive gases.

Radiological impact on the environment: the assumption is made that 10% of the aerosols’ activity contained in the target is put into suspension, and 100% of the gases’ activity. The radioactive aerosols put into suspension are captured and then filtered (at least 2 stages of very high-efficiency filters) by the nuclear ventilation of the building. All the gaseous elements are released outside the facility. The radiological impact for the neighbouring population is estimated to be 200 µSv, with 90% due to gaseous elements.

Consequence: the reliability of the handling system will have to provide a very low probability of occurrence of this kind of accident (at least less than 10^{-5} per year, which means less than 0.1% probability during the whole life of the facility, considering 5 handlings per year over some 20 year).

4. PRINCIPLES OF SAFETY AND ANALYSIS METHOD

4.1. Regulations

The SPIRAL 2 facility falls under the regulations applicable to the Nuclear Installations (INB), due to the quantity of radioactive materials located inside the facility, and it must thus comply with all safety rules and regulations laid down by the Nuclear Safety Authority, and recommendations of guides identified for their technical competences in nuclear safety.

The full list of regulations and guides is presented in the DOS (Safety Option File: ref. 1).

4.2. Safety functions

The safety functions identified on the SPIRAL 2 facility are:

- containment of radioactive materials;
- protection against ionising radiations.

The equipment that performs these safety functions is important for the safety of the facility, and subject to strict quality requirements (concept, use, maintenance, etc.).

4.2.a. Containment of radioactive materials

The safety of the SPIRAL 2 facility is mainly based on the minimisation of the risk of dispersion of radioactive materials inside the buildings, which would otherwise be likely to spread to the outside environment.

The activity of the maximum "source term" of each of part of the equipment and/or areas of the facility determines the number of containment systems between the source and environment (a system of confinement consists of at least one airtight barrier of static containment and one of associated dynamic containment.

The maximum activity which is calculated to be held in the SPIRAL 2 facility – for each piece of equipment or geographic area of the facility – is indicated in the table below:

Table 8: Maximum activity expected to be held in the facility.

Equipment	Maximum activity	% of activity produced	*Radiation associated with the naked source term (at 1m)*
Target	600 000 GBq - ~ 16 000 Ci	100%	*~ 60 Sv/h*
Ion source	300 000 GBq - ~ 8 000 Ci	50%	*~ 30 Sv/h*
Separator	300 000 GBq - ~ 8 000 Ci	50%	*~ 30 Sv/h*
Charge breeder	30 000 GBq - ~ 800 Ci	5%	*~ 3 Sv/h*
CIME GANIL	300 GBq - ~ 8 Ci	0.05%	*~ 30 mSv/h*
Downstream of CIME (up to the exp. area)	30 GBq - ~ 1 Ci	0.02%	*~ 10 mSv/h*

The containment systems for each piece of equipment (or geographic area) are the following:

Table 9: Containment systems (ref. 1).

Equipment	Containment system
Target	• 1st system: static containment (ECS) & dynamic containment associated (vacuum) • 2nd system: static containment (hall) & dynamic containment associated (ventilation of the hall)
Source	• 1st system: static containment (ECS) & dynamic containment associated (vacuum) • 2nd system: static containment (hall) & dynamic containment associated (ventilation of the hall)
Separator	• 1st system: static containment (ECS) & dynamic containment associated (vacuum) • 2nd system: static containment (hall) & dynamic containment associated (ventilation of the hall)
Charge-breeder	• 2nd system: static containment (hall) & dynamic containment associated (ventilation of the hall)
CIME cyclotron	• 1st system: static containment (ECS) & dynamic containment associated (vacuum)
Downstream of CIME (up to the exp. area)	• Containment system: static containment (lines) & dynamic containment associated (vacuum)

In normal service, the first containment system prevents the dispersion of radioactive materials used in the process toward areas accessible to employees.

Fast-acting valves will be installed in the vacuum chamber to complete the static containment. These valves will be closed on detection of an incident. The number and location of the valves are not yet fixed.

The second containment system provided for protection of the environment in case of any failure of the first containment system.

Remarks:

- The vacuum (primary/secondary) is a fully dynamic containment, because it ensures that the flow of air from the less (or non-) contaminated area (outside the beam line) to the more contaminated area (inside the beam line) even if the static containment barrier which is associated with it is damaged.
- Downstream from CIME, only one containment system exists because of the specificity of the existing GANIL facility. The possible loss of this containment system, associated with the more penalizing conditions, such as the occurrence of an earthquake (with which the present installations of GANIL are not designed to contend), does not generate unacceptable consequences for the neighbouring population (i.e. radiological impact much less than the recommendation of the CIPR60). The adaptation of the existing facility to the safety constrains is a major point of the project.

More detailed dispositions against the risk of dispersion are presented in the DOS (ref. 1).

4.2.b. Protection against ionising radiations

The protection of workers against the risk of external exposure is guaranteed by:

- correct sizing of the biological shielding (for all ionising radiation: neutrons, X, β, and γ. (cf. refs 1, 2 and 5));
- management of the access to the controlled areas (ref. 19);
- servo-control of the accelerator from the output of radiological monitors (ref. 2);
- use of remote-handling system for the more irradiating materials (shielded hot-cell, crane).

More detailed dispositions against the risk of external exposition are presented in the DOS (ref. 1).

5. CLASSICAL RISKS

A general method of risk analysis has been conducted for the SPIRAL 2 facility (called MES). It consist of a systematic analysis of all risks identified (electrical, fire, remote handling, etc.).The conclusions gives general directions for the use the facility (ref. 20).

6. WASTE MANAGEMENT

At the conception stage of the project, particular care is being taken concerning the management of waste produced by the SPIRAL 2 facility. The goal is to reduce both the quantity and toxicity. Indeed, the classification of areas which produce waste has to be defined, optimised and justified.

6.1. Waste classification

First, each area that produces waste must be identified, and the waste must be classified according to its nature:

- classical industrial waste;
- nuclear waste:
  - waste that contains a <u>very low quantity of radioactivity</u> (*Très Faiblement Radioactifs – TFA*): this waste comes from areas classified as *"contaminante"*, and for which their is no radioactivity detected, or only a very small quantity;
  - waste with a <u>low quantity of radioactivity</u> (*Faiblement Radioactifs – FA*) or moderately active (*Moyennement Radioactifs – MA*);
  - waste with <u>very high quantity of radioactivity</u> (*Hautement Radioactifs – HA*) – for SPIRAL 2, only the UC_x targets could be classified in this category

This classification of nuclear waste complies with the French regulations (*"arrêté du 31 décembre 1999"*).

6.2. Discharge fields

The ways of elimination will be identified in the waste study which will be conducted for the SPIRAL 2 facility. This document will describe the handling and/or discharge of all kind of waste: conventional or radioactive. A first study has shown that the most activate waste produced by the SPIRAL 2 facility should be accepted by the ANDRA (ref. 1).

7. REFERENCES

1. Dossier d'Options de Surete, SSR 003 A, EDMS: I-003663
2. Risque d'Exposition Externe Autour du Linac, SSR 009 A, EDMS: I-004210
3. Validation des Hypotheses de Calcul, SSR 2003.09, EDMS: I-002250
4. Rapport LINAC phase 1
5. SPR SAC SERD 2003 997, EDMS: I-004512
6. Activation Injecteur et Linac, SSR 2004.05, EDMS: I-004511
7. Activation Neutronique du Plug, to be published.
8. Classement INB de Spiral 2, SSR 2003.003, EDMS: 391444
9. Protection Plug, REF SSR 2004.002, EDMS: I-004520
10. Problemes Radiologiques du Separateur, REF SSR 2003.005, EDMS: 391456
11. Radioprotection Lignes Secondaires, REF SSR 2003.008, EDMS: I-002249
12. Accident de Contamination, REF SSR 2003.005, EDMS: I-002126
13. Etude de Radioprotection Spiral 2 Cible Haute Densite SPR Saclay, EDMS: I-004513
14. Modes de Fonctionnement de la Ventilation Nucleaire (Precisions), REF SSR010, EDMS: I-004295
15. Risque d'Agression Externe Par Explosion, REF SSR 011 A, EDMS: I-004344
16. Etude du Cryotraps Spiral 2 Rapport de Stage, EDMS: I-004180_A, I-004180_B, I-004180_C, I-004180_D, I-004180_E.
17. Domaine de Fonctionnment du GANIL Existant, REF 2004.004, EDMS: I-004510
18. Demarche de Surete, REF SSR008, EDMS: I-004213
19. Principes de Gestion des Acces, REF SSR 007, EDMS: I-004211
20. MES Spiral 2, EDMS: I-003543_A, I-003543_B, I-003543_C.