

*Training Course on Safety Assessment of Facilities and Activities
Using Radiation Sources*



IAEA

**PRACTICAL EXERCISE
INDUSTRIAL PRACTICE
(TEACHER'S BOOK)**

FOREWORD

These exercises are a complement to the presentations of the training course on “Safety Assessment of Facilities and Activities using Radiation Sources”.

The objective of the exercises is to help develop the basic knowledge necessary to perform a safety assessment.

The contents of a safety assessment should include the following topics:

LIST OF CONTENTS OF A SAFETY ASSESSMENT

1.- ASSESSMENT CONTEXT

1.1.- Introduction

Regulations and Standards.

1.2.- Description of the facility or activity

Site characteristics

Engineering design

Safety measures

Operational procedures

Management Systems

1.3.- Approach and scope of the Assessment

1.4.- Assessment criteria

2.- DEVELOPMENT AND JUSTIFICATION OF SCENARIOS

2.1.- Identification of Hazards

2.2.- Selection and Hazard Screening

2.3.- Identification and description of Scenarios

3.- SAFETY ANALYSIS

3.1.- Identification of Models and Data Needs

3.2.- Dose Calculations

3.3.- Risk Calculations

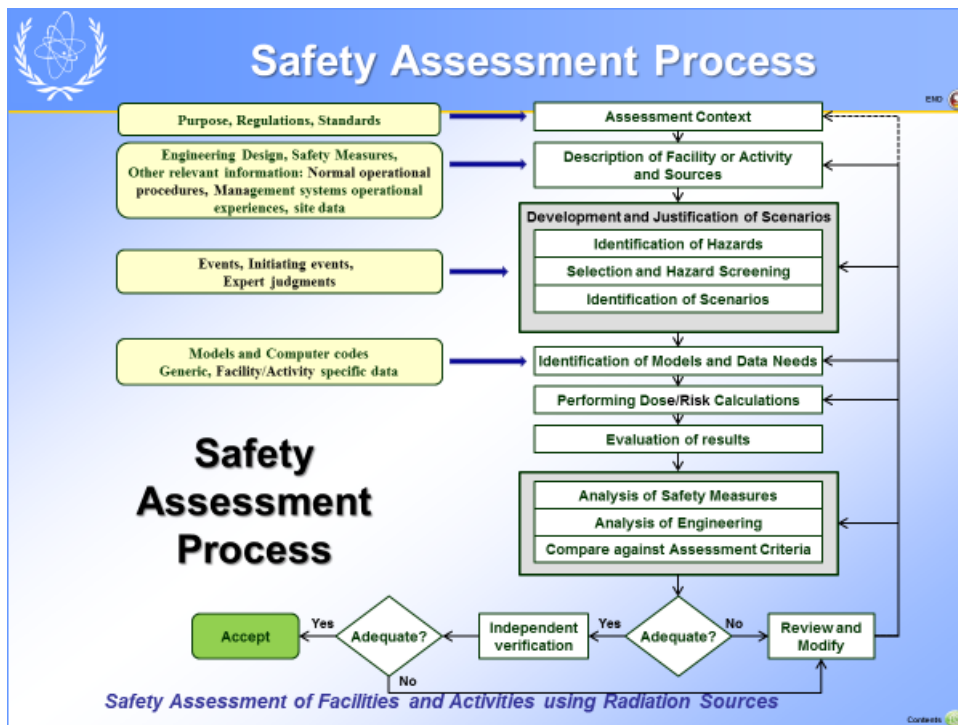
3.4.- Evaluation of results (uncertainty analysis)

4.- ANALYSIS OF ASSESSMENT RESULTS

4.1.- Comparison with assessment criteria

4.2.- Analysis and revision (if it is needed) of safety measures and engineering

Exercises are proposed for each of the sections. To facilitate understanding of the exercises, each section of the content list corresponds to a block of the safety assessment process diagram used in the course presentations:



EXERCISES PART 1.- ASSESSMENT CONTEXT

1.1.- Introduction

The safety assessment shall be in accordance with the requirements of the current National Regulations based on the criteria of GSR part 3 and GSR part 4.

The 24 requirements from GSR part 4 used in performing safety assessments are:

Requirement 1: Graded approach

A graded approach shall be used in determining the scope and level of detail of the safety assessment carried out in a particular State for any particular facility or activity, consistent with the magnitude of the possible radiation risks arising from the facility or activity.

Requirement 2: Scope of the safety assessment

A safety assessment shall be carried out for all applications of technology that give rise to radiation risks; that is, for all types of facilities and activities.

Requirement 3: Responsibility for the safety assessment

The responsibility for carrying out the safety assessment shall rest with the responsible legal person; that is, the person or organization responsible for the facility or activity.

Requirement 4: Purpose of the safety assessment

The primary purposes of the safety assessment shall be to determine whether an adequate level of safety has been achieved for a facility or activity and whether the basic safety objectives and safety criteria established by the designer, the operating organization and the regulatory body, in compliance

with the requirements for protection and safety as established in the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, have been fulfilled.

Requirement 5: Preparation for the safety assessment

The first stage of carrying out the safety assessment shall be to ensure that the necessary resources, information, data, analytical tools as well as safety criteria are identified and are available.

Requirement 6: Assessment of the possible radiation risks

The possible radiation risks associated with the facility or activity shall be identified and assessed.

Requirement 7: Assessment of safety functions

All safety functions associated with a facility or activity shall be specified and assessed.

Requirement 8: Assessment of site characteristics

An assessment of the site characteristics relating to the safety of the facility or activity shall be carried out.

Requirement 9: Assessment of the provisions for radiation protection

It shall be determined in the safety assessment for a facility or activity whether adequate measures are in place to protect people and the environment from harmful effects of ionizing radiation.

Requirement 10: Assessment of engineering aspects

It shall be determined in the safety assessment whether a facility or activity uses, to the extent practicable, structures, systems and components of robust and proven design.

Requirement 11: Assessment of human factors

Human interactions with the facility or activity shall be addressed in the safety assessment, and it shall be determined whether the procedures and safety measures that are provided for all normal operational activities, in particular those that are necessary for implementation of the operational limits and conditions, and those that are required in response to anticipated operational occurrences and accidents, ensure an adequate level of safety.

Requirement 12: Assessment of safety over the lifetime of a facility or activity

The safety assessment shall cover all the stages in the lifetime of a facility or activity in which there are possible radiation risks.

Requirement 13: Assessment of defence in depth

It shall be determined in the assessment of defence in depth whether adequate provisions have been made at each of the levels of defence in depth.

Requirement 14: Scope of the safety analysis

The performance of a facility or activity in all operational states and, as necessary, in the post-operational phase shall be assessed in the safety analysis.

Requirement 15: Deterministic and probabilistic approaches

Both deterministic and probabilistic approaches shall be included in the safety analysis.

Requirement 16: Criteria for judging safety

Criteria for judging safety shall be defined for the safety analysis.

Requirement 17: Uncertainty and sensitivity analysis

Uncertainty and sensitivity analysis shall be performed and taken into account in the results of the safety analysis and the conclusions drawn from it.

Requirement 18: Use of computer codes

Any calculational methods and computer codes used in the safety analysis shall undergo verification and validation.

Requirement 19: Use of operating experience data

Data on operational safety performance shall be collected and assessed.

Requirement 20: Documentation of the safety assessment

The results and findings of the safety assessment shall be documented.

Requirement 21: Independent verification

The operating organization shall carry out an independent verification of the safety assessment before it is used by the operating organization or submitted to the regulatory body.

Requirement 22: Management of the safety assessment

The processes by which the safety assessment is produced shall be planned, organized, applied, audited and reviewed.

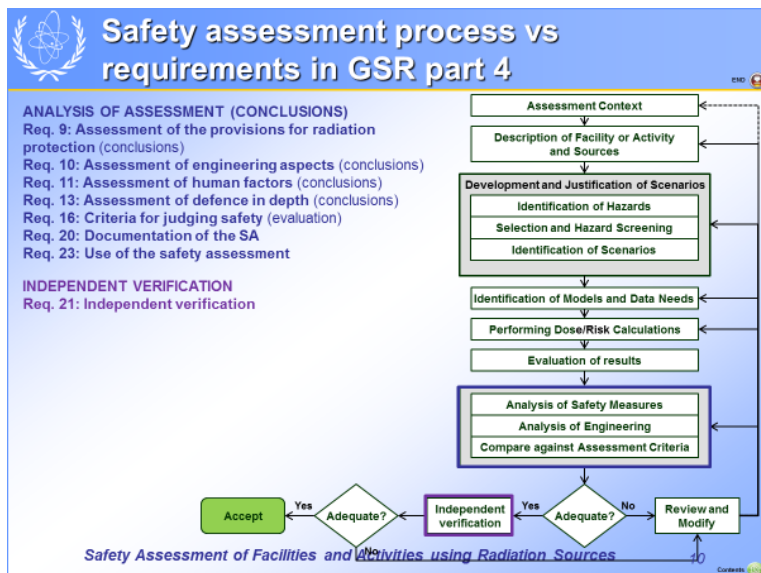
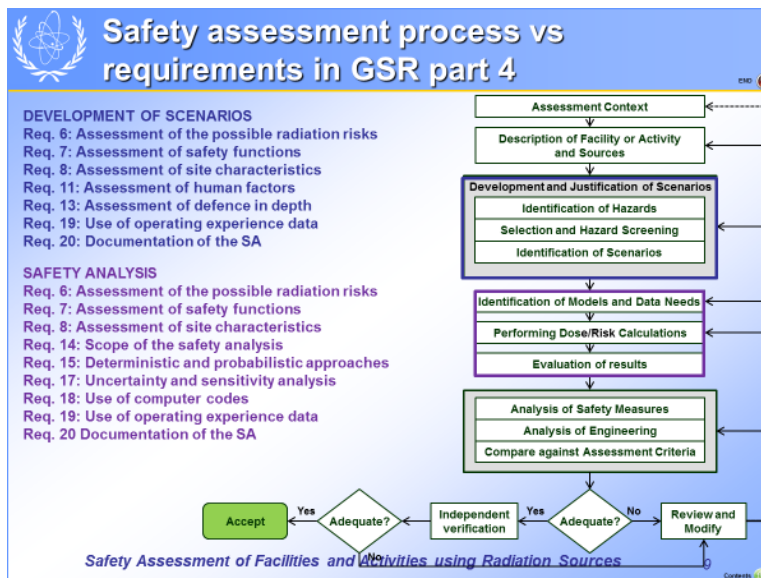
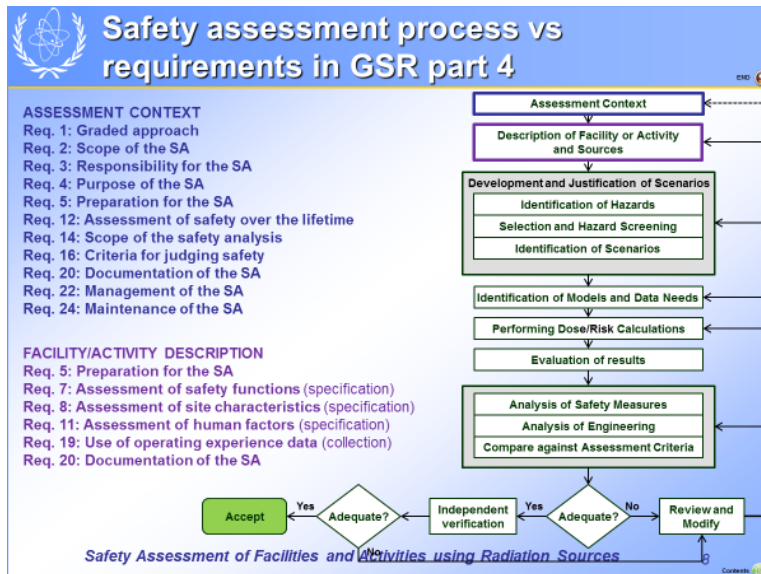
Requirement 23: Use of the safety assessment

The results of the safety assessment shall be used to specify the programme for maintenance, surveillance and inspection; to specify the procedures to be put in place for all operational activities significant to safety and for responding to anticipated operational occurrences and accidents; to specify the necessary competences for the staff involved in the facility or activity and to make decisions in an integrated, risk informed approach.

Requirement 24: Maintenance of the safety assessment

The safety assessment shall be periodically reviewed and updated.

In every step of the Safety Assessment Process, the requirements that are used are:



1.2.- Description of the facility or activity

Site characteristics

The company is dedicated to the applications of industrial scintigraphy in infrastructure works (in fieldwork conditions).

Work in field conditions is carried out in the areas assigned by the client. Working procedures and delimitation of areas are used as shown in figure 2.



Engineering design

The gamma radiography equipment has the following elements and characteristics:

- An encapsulated radioactive source coupled to a cable called a source holder.
- The activity, depending on the isotope contained in the source, does not exceed the following radiological activities:
 - Ir-192: 5 TBq (135 Ci).

The source holder is a cable that is coupled to the source and mechanism to and the connector mechanism to join it with the remote control.

The guide tube is a flexible tube that is used to guide the source holder out of the container to the exposure terminal. The exposure terminal is the device that houses the sealed source in the irradiation position. The flexible guide tube comprises a flexible tube that rolls up, made of braided stainless steel inside and with rubber sheathing outside

The Industrial Gamma radiography equipment is a shielded container where the source holder is accommodated. These containers usually have security devices that allow to lock the source holder inside the container, avoiding accidental exposure to the source. Most of these containers meet the requirements for a Type B (U) transport package as stipulated in the IAEA Regulations for Safe Transport of Radioactive Materials.

The radioactive source is taken out via the front of the container and moved to the exposure terminal through a guide tube by the operator using a crank-type remote control system. In this way, the operator remains at a distance from the source so as not to be exposed to high radiation doses. The radioactive source remains exposed for the radiography and when the radiographic exposure is terminated returns, using the same system, to the container into the position providing maximum shielding.

The collimators are fitted to the end of the exposure terminal. The radiation is collimated via a small opening through which a cone of radiation is emitted when the radioactive source is inside it. The use of collimators significantly reduces the controlled area to which access is restricted during industrial gamma radiography work. They are made of heavy metals, usually lead or tungsten.

The company's collimators allow the dose rate to be reduced around the point of radiography by a factor of 1/20 and can be used on 20% of the radiographs made by the company

Safety measures

The equipment used by the company complies with the ISO 3999-1 standard and has the following safety measures:

- Closing or locking mechanism, able to keep the source in safe position.
- Source position indicating mechanism (storage or exposure).
- Handles for transportation or other devices that facilitate lifting and transfer.
- Mechanisms for driving the source and indicating the position of the source in transit (odometer).
- Controls to prevent withdrawal of the source from the back of the container .
- Remote control Interlock that does not allow removal until the source is in the safety position.
- Visual display indicating that the source has not returned to the safety position .
- Use of direct reading dosimeter with alarm.
- Use of portable monitor with alarm.

Operational procedures

The company has procedures to perform the different stages of the gammagraphy process as shown below:

Acquisition.

There are procedures for the procurement of original supplies, equipment and accessories, which guarantees the supply of goods and services from authorized companies.

Permanent Storage.

The company's store has organizational measures, physical security and radiation safety that allows to maintain in good condition equipment, supplies and accessories.

The shielding is sufficient so that the dose received by the occupationally exposed personnel and the public is the established in the national regulation. The installation has a fixed area radiation monitor for radiological control.

The store has security barriers that prevent access by unauthorized personnel, such as perimeter fence, security alarm, door locks, CCTV and guards, among others.

The store is located in a place where possible adverse factors such as natural, external and social events that could jeopardize the safety of the radioactive material have been contemplated and the measures to attend an emergency case are foreseen.

Temporary storage (In situ).

The client must help for the location of temporary storage. The measures of radiation safety and security are coordinated with the client. It has the support and agreement of the client in case of having the need to execute the Radiological Emergency Plan.

Work preparation.

The company coordinates with the client before carrying out the work. Verify the elements that the client has to provide such as scaffolding, lighting, security conditions, among others. Equipment and accessories, radiological safety equipment, transport and storage are reviewed before the start of work. The company carries out the sealing and delimitation of the controlled area, it is signaled using the warning light and sound alarm before the execution of the scintigraphy works.

Transport of radioactive material.

The company complies with regulations for the safe transport of radioactive material (signage, package labeling, media, fasteners, emergency kit, planned routes, etc.) established by the regulatory authority.

Operation.

During the operation, all the operational procedures and of radiological protection are fulfilled, to develop the works in a safe way and to satisfy the requirements of the client.

There are in place the elements and devices to act in case of a radiological emergency. Emergency procedures are always available in the work area during the practice.

Periodic simulations of emergency procedures are performed to ensure the effectiveness of the response.

Maintenance of equipment and accessories.

The company carries out periodic maintenance of the equipment and accessories following procedures established by the manufacturer, using original accessories and authorized service personnel.

The replacement of the source is performed by service personnel, authorized for these activities, following the procedures pre-established and approved by the regulatory body.

The company manages the disused sources according to the regulations established by the regulatory authority. The spent radioactive sources are returned to the supplier.

There are written guidelines for not making any modifications to the equipment and accessories and not to render safety interlocks off, as well as not to use the equipment for situations not foreseen at the time of purchase and commissioning.

Tightness tests are performed on the sources, by an authorized company, the smears are taken following established procedures and with a frequency that correspond to the requirements of national regulation.

Dosimetry control of workers

The company analyzes the evolution of the worker's dosimetry in order to establish compliance with the dose restrictions.

Management Systems

The company has implemented a Radiation Protection Program for the practice of industrial radiography with written procedures and records, which includes occupational medical surveillance, which is part of the Management System, it is reviewed and audited periodically, Has an Operating License in force for the development of the practice.

The facility has sufficient operators, radiation protection officers and authorized supervisors.

There are guidelines from the license holder to ensure adequate training of operators, radiation protection officers and supervisors. In addition to training in the professional aspects, practices and experience are included, specific training in the equipment used, and lessons learned from accidental exposures.

It has a defined organization where the functions and responsibilities that correspond are clearly established.

There is an appropriate amount of radiation monitors and direct reading dosimeters, depending on the number of equipment and operators.

1.3.- Approach and scope of the Assessment

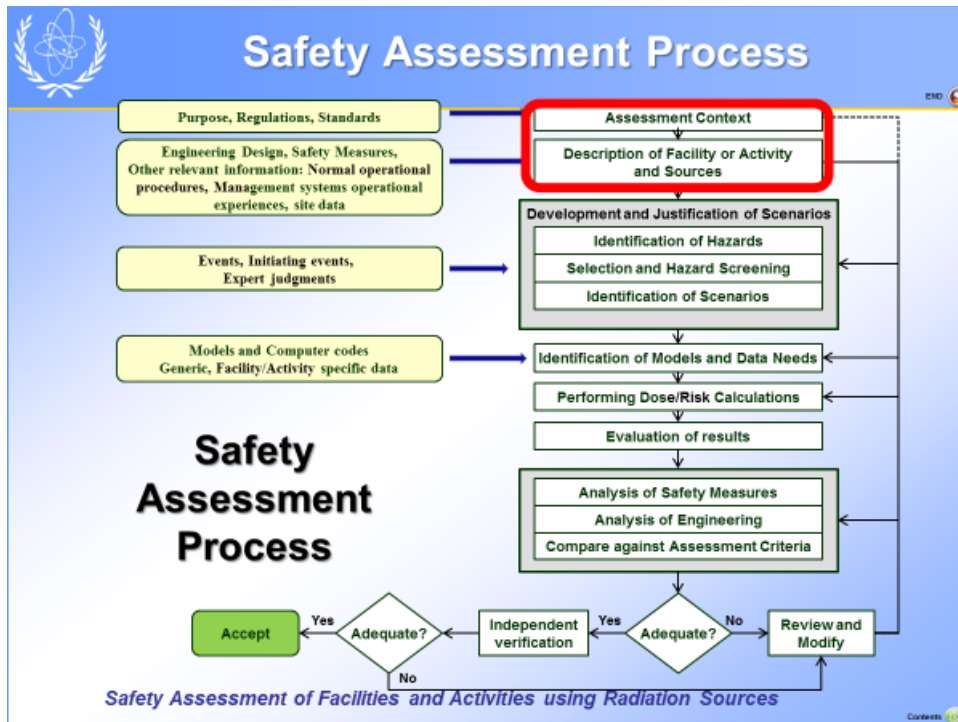
The safety assessment is focused on ensuring the radiological safety of workers, and the public during the performance of the industrial gammagraphy procedures. It includes all stages and substages of the gammagraphy process as well as the request, purchase, transportation and storage of the sources used in this practice.

1.4.- Assessment criteria

The criteria are based on what is established in the current national regulation according to IAEA recommendations, and are as follows.

- a) Dose limits. According to GSR Part 3
 - i. For workers: 20 mSv / year on average in 5 years and no more than 50 mSv in a year.
 - ii. For public: 1mSv / year.
- b) Dose Restrictions. According to applicable National Regulation .
 - i. For workers: 10 mSv/year.
 - ii. For public: 0.5 mSv/year.
- c) Acceptability of Risk. According IAEA-TECDOC 1685.
 - I. Accidental Sequences of "Very High Risk" (VHR). They are unacceptable, it is necessary to stop the practice since they are an imminent risk.
 - II. Accidental Sequences of "High Risk" (HR). They are unacceptable, it is necessary to implement a plan of measures to reduce the risk within a reasonable time since they are not an imminent risk.
 - III. Accidental sequences of "Medium Risk" (MR). Are Tolerable, a plan of measures to reduce the risk according to criteria of Cost-Benefit must be implemented.
 - IV. Accidental Sequences of "Low Risk" (LR). They are widely accepted, no risk reduction required.

These exercises cover first block of presentations.



EXERCISE PART 1 #1

GSR Part 3 Requirement 13: Safety assessment states: “The regulatory body shall establish and enforce requirements for safety assessment, and the person or organization responsible for a facility or activity that gives rise to radiation risks shall conduct an appropriate safety assessment of this facility or activity.

3.29. The regulatory body shall establish requirements for persons or organizations responsible for facilities and activities that give rise to radiation risks to conduct an appropriate safety assessment. Prior to the granting of an authorization, the responsible person or organization shall be required to submit a safety assessment, which shall be reviewed and assessed by the regulatory body.

3.30. The person or organization, as required under para. 3.9(d), or registrants and licensees, as appropriate, shall conduct a safety assessment that is either generic or specific to the practice or source for which they are responsible.

3.31. Safety assessments shall be conducted at different stages, including the stages of siting, design, manufacture, construction, assembly, commissioning, operation, maintenance and decommissioning (or closure) of facilities or parts thereof, as appropriate, so as:

(a) To identify the ways in which exposures could be incurred, account being taken of the effects of external events as well as of events directly involving the sources and associated equipment;

(b) To determine the expected likelihood and magnitudes of exposures in normal operation and, to the extent reasonable and practicable, to make an assessment of potential exposures;

(c) To assess the adequacy of the provisions for protection and safety.

3.32. The safety assessment shall include, as appropriate, a systematic critical review of:

(a) The operational limits and conditions for the operation of the facility;

(b) The ways in which structures, systems and components, including software, and procedures relating to protection and safety might fail, singly or in combination, or might otherwise give rise to exposures, and the consequences of such events;

(c) The ways in which external factors could affect protection and safety;

(d) The ways in which operating procedures relating to protection and safety might be erroneous, and the consequences of such errors;

(e) The implications for protection and safety of any modifications;

(f) The implications for protection and safety of security measures or of any modifications to security measures;

(g) Any uncertainties or assumptions and their implications for protection and safety.

3.33. The registrant or licensee shall take into account in the safety assessment:

(a) Factors that could give rise to a substantial release of radioactive material, the measures available to prevent or to control such a release, and the maximum activity of radioactive material that, in the event of a major failure of the containment, could be released to the environment;

(b) Factors that could give rise to a smaller but continuing release of radioactive material, and the measures available to detect and to prevent or to control such a release;

(c) Factors that could give rise to unintended operation of any radiation generator or a loss of shielding, and the measures available to detect and to prevent or to control such occurrences;

(d) The extent to which the use of redundant and diverse safety features that are independent of each other, so that failure of one does not result in failure of any other, is appropriate to restrict the likelihood and magnitude of potential exposures.

3.34. Registrants and licensees shall ensure that the safety assessment is documented and, where appropriate, that it is independently reviewed under the relevant management system.

3.35. Registrants and licensees shall perform additional reviews of the safety assessment as necessary to ensure that the technical specifications or conditions of use continue to be met when:

(a) Significant modifications to the facility or to its operating procedures or maintenance procedures are envisaged;

(b) Significant changes occur on the site that could affect the safety of the facility or of activities on the site;

(c) Information on operating experience, or information about accidents and other incidents that could result in exposures, indicates that the current assessment might be invalid;

(d) Any significant changes in activities are envisaged;

(e) Any relevant changes in guidelines or standards have been made or are envisaged.

3.36. If as a result of a safety assessment, or for any other reason, opportunities to improve protection and safety appear to be available and improvement seems desirable, any consequential modifications shall be made cautiously and only after favorable assessment of all the implications for protection and safety.

The implementation of all improvements shall be prioritized so as to optimize protection and safety.”

Question: Can you highlight the main recommendations of this requirement that would apply to the installation described in this exercise?

EXERCISE PART 1 #2

Split the students in 4 groups. Each group should identify the requirements that apply to the Safety Assessment parts:

- 1.- ASSESSMENT CONTEXT
- 2.- DEVELOPMENT AND JUSTIFICATION OF SCENARIOS
- 3.- SAFETY ANALYSIS
- 4.- ANALYSIS OF ASSESSMENT RESULTS

EXERCISE PART 1 #3

Split the students in small groups. Each group should review the information given in #1.2. (Description of the facility or activity) and identify if it contains enough information to fulfil the safety assessment requirements.

EXERCISES PART 2.- DEVELOPMENT AND JUSTIFICATION OF SCENARIOS

2.1.- Identification of Hazards

The following are the hazards that have been identified for this safety assessment:

- Fire in the work area where the equipment is used.
- Physical damage to the equipment during field work
- Overdose caused to persons due to the operation of the equipment, including:
 - Damages to the Worker.
 - Damages to the public.
- Uncontrolled use of sources.
- Robbery or theft of the equipment.
- Accidents during the transportation of equipment.
- Lack of training and/or experience of workers.
- Floods.
- Earthquakes.

2.2.- Selection and Hazard Screening

Considering the Approach and Scope of the Assessment, the following are the hazards that have been selected for consideration in this Safety Assessment:

- Fire in the work area where the equipment is used.
- Physical damage to the equipment during field work
- Overdose caused to persons due to the operation of the equipment, including:
 - Damages to the Worker.
 - Damages to the public.
- Uncontrolled use of sources.
- Robbery or theft of the equipment.
- Accidents during the transportation of equipment.
- Lack of training and/or experience of workers.
- Floods.

2.3.- Identification and description of Scenarios

2.3.1 Scenario for normal operation. Stages.

During normal operation, the Gammagraphy company performs the operations following the following steps and substeps of the process:

1. Acquisition.
2. Storage.
3. Temporary storage (in the field)
4. Transport.
5. Work preparation.
6. Operation.
7. Maintenance.

The **acquisition** comprises all the actions and procedures that the company follows for the acquisition of equipment, devices and radioactive sources that are necessary for the correct realization of the practice.

For these activities, the company ensures that the requests addressed to the suppliers are formulated and revised in a redundant manner, guaranteeing that a tender, including only internationally recognized suppliers, is made.

The **storage** of the equipment, sources and devices that are used is done in an existing warehouse in the company where there are shielded vaults for the sources with locks that prevent the free access to the sources and equipment of the people authorized to enter into the warehouse. The removal of equipment and sources is done only by authorized personnel and under the supervision of the Radiation Protection Officer who verifies that the established records are updated.

The warehouse has a physical security system capable of effectively detecting the intrusion of intruders.

Temporary storage is done when the company works several days in works that are located more than 20 kilometers away from the central warehouse. A written agreement with the client is formalized by selecting an appropriate area for the temporary storage of the equipment and sources and agreeing the appropriate physical security measures for the protection of these sources.

Each workgroup has a specially equipped **transport** for the transfer of the equipment of Gammagraphy from the warehouse of the company to the field where the Gammagraphy practices are realized. Each workgroup has adequate means of communication and design measures to guarantee the physical security of the equipment and sources in cases of traffic accidents or other unforeseen events that can occur during transport. Transport is carried out at pre-established schedules and routes and considering the weather conditions that may be foreseen.

Work preparation is a very important stage since the operator and the radiation protection officer can analyze the task entrusted and with this they select the equipment, sources and devices necessary to guarantee the radiological protection of workers and public.

The client must ensure that the technical and organizational measures that are planned are respected in order to guarantee the radiological protection and security during the execution of the job.

Operation is always performed with the presence of a certified operator (licensed by the regulatory authority) and a trained operator's assistant.

Each workgroup performs on average 1800 gammagraphies per year using an equipment that has the following characteristics:

- A) Source activity: 3700 GBq.
- B) Control cable distance: 10 meters.
- C) Length of the guide tube: 10 meters.
- D) Gamma constant of Ir-192: 0.135 mSv m² / GBq h).
- E) The company performs 36 gammagraphies per week, working 50 weeks a year.
- F) Average exposure time for 1 gammagraphy: 2 minutes.
- G) Rate of transfer of the source, through the guide tube: 1 m / s.
- H) 20% of the scans are performed using a collimator that reduces the dose received by the operator by a factor of 1/20 (0.05)

During the practice, the operator delimits the controlled area by monitoring the source when it is exposed to ensure that at the boundary of the controlled area a member of the public is not exposed to a dose rate greater than 2.5 µSv/h.

Considering that these works will be done at selected times, it is considered that the occupation factor of these areas for members of the public will not be greater than ¼.

Maintenance of the equipment is carried out according to an approved maintenance program and considering the workload of the Gammagraphy equipment and its accessories.

Simple daily maintenance activities are carried out by the operator while planned preventive maintenance activities are carried out by the equipment supplier.

2.3.2 Scenario for an accident situation.

Several possible scenarios in accident situations have been analyzed and are shown below:

- a) Disengagement of the source holder and the propulsion cable, after a gammagraphy, the source being exposed inside the had guide.
- b) Inadvertent entry of the operator's assistant to the work area while the source is exposed performing a gammagraphy.
- c) Inadvertent entry of a member of the public to the work area while the source is exposed performing a gammagraphy.
- d) Fire in the work area.
- e) Drop of a heavy object on the guide tube preventing the return of the source to the equipment.
- f) Theft of the scanning equipment and uncontrolled in the public domain.

All of these scenarios will be taken into account during the development of the safety assessment, particularly in the risk assessment. For the estimation of doses, in an accident situation, we have selected scenario (a), which was previously stated,

considering that it is an extreme and representative scenario of the doses that can be received by workers in an accident.

2.3.2.1 Description of the scenario “Disengagement of the source holder and the propulsion cable, after a gammagraphy, the source being exposed inside the had guide”

During normal operation of the gammagraphy unit, when attempting to return the gamma source to the working container, the operator notices that the interlocks of the unit's remote control and the container show that the source has not returned to the shield position. Based on these indications the operator uses the portable detector to corroborate, by observing the dose rate, that the source has disengaged from the drive wire and has stuck inside the guide tube.

In this situation, the operator tries to rescue the source. To do this, he enters in the controlled area and during 5 minutes it is positioned to 2 meters of the source analyzing the situation and designing an improvised procedure to return the source to the emergency container that is available.

Subsequently he sends the Operator's Assistant with a telescopic tool of 0.6 meters long to perform the operation of taking the source and place it inside the emergency container. Due to the lack of training in performing this procedure, the Operator Assistant unsuccessfully attempts to perform the indicated procedure and remains exposed for 10 minutes at an estimated distance of 0.9 meters from the source.

Considering the failure of the rescue attempt performed by the Operator's Assistant, the Operator of the gammagraphy team gives the order to withdraw from the controlled area and enters the controlled area for the second time, quickly, locates the position of the source, takes with his hand the source and inserts the source into the emergency container. This operation is done in just 15 seconds.

Following data are considered:

- a) Source activity: 3700 GBq.
- b) Gamma constant of Ir-192: 0.135 mSv m²/ GBq h.
- c) Fc, It is the factor of conversion of the absorbed dose rate, applied to the absorbed dose a soft tissue. (Table 14 y 15 EPR-D-VALUES 2006) (For the I-192 $F_c = 8.5 \cdot 10^{-15} \text{ Gy/Bq}\cdot\text{s}$).

These exercises cover second block of presentations.



EXERCISE PART 2 #1. Analyze the list of hazards shown in #2.1 (Identification of Hazards) and select those that are present in a gammagraphy activity.

EXERCISE PART 2 #2 Taking into account its radiological consequences, select the most important hazards that will be considered within the Safety Assessment.

EXERCISE PART 2 #3 Describe the most likely extreme scenarios that can trigger the hazards selected in question #2.

EXERCISES PART 3.- SAFETY ANALYSIS

3.1.- Identification of Models and Data Needs

For dose estimation under normal operating conditions, the following models and assumptions have been considered:

- a) Point source considerations.
- b) Law of the Inverse of the square of the distance.

For risk estimates, the "Risk Matrix" methodology has been considered. Publication IAEA-TECDOC 1685. The SEVRRRA INDUSTIA 3.0 software has been used. (Available on WWW.foroiberam.org).

3.2.- Dose Calculations

3.2.1 Dose estimates in Normal operation.

3.2.1.1 Occupationally exposed personnel.

Workers in the Industrial Gammagraphy company who are exposed to ionizing radiation during the practice are shown in the following table.

No.	Job position	Duties	Dose
1.	Operator	Work preparation	No
		Placement of radiographic plates on the parts to be tested.	No
		Manipulation of the equipment while the Source is in transit.	Yes
		Control of the gammagraphy process while the Source is in irradiation position.	Yes
2.	Operator's assistant.	Carrying of the equipment during the transport. In this case it is exposed to leak radiation from the container	Yes
		Monitor to prevent entry of members of the public to the controlled area. In this case it is exposed to the expected dose rate levels for members of the public	Yes
3.	Radiation Protection Officer.	Audits to the radiation protection program.	No
		Inventory of equipment and radioactive sources.	Yes
		Supervision of work under field conditions.	Yes

When analysing the working conditions in each of the positions described in the above table and considering the functions they perform, it is considered that the position of Gammagraphy Operator is exposed to higher radiation doses during normal operation. Esto es debido a que se expone a tasas de dosis significativas, fundamentalmente cuando tiene una alta carga de trabajo de gammagrafía.

Based on this analysis, we will perform the estimation of normal operating doses for the position of the Gammagraphy Operator in order to demonstrate that this worker does not exceed the restrictions and dose limits established in this facility:

- a) Dosage received by the Gammagraphy Operator.

The estimated Dose Rate values to which operators are exposed can be obtained from the isodose curves supplied by the equipment supplier, and taking into account the above considerations. If the isodoses curves are not available, the dose rate values to which workers are exposed can be calculated as follows:

- The dose rate at which the operator is exposed during transit (Htr) from the source to the irradiation position is:

$$\dot{H} = \frac{\Gamma \cdot A}{d^2},$$

Where

Γ is the gamma constant, for Ir-192: 0.135 mSv m²/ GBq h;

A is the Source activity,

d is the distance to the source.

In the calculation, two realistic assumptions are made:

- As the dose rate increases as the source approaches the equipment and decreases as the source moves away to the end of the guide tube we assume that the entire transit time of the source is located in the intermediate position of the guide tube, and therefore d = 15 m for calculations.
- Since the activity of the source decreases with its use and considering that the source is changed 2 times a year, A = Ai / 2 is taken to perform the calculation

With this in mind

$$H_{tr} = (0.135 \cdot 1850) / 15^2 = 1.11 \text{ mSv/h}$$

- The dose rate at which the operator is exposed while performing the gammagraphy (H_{ir}) is:

$$\dot{H} = \frac{\Gamma \cdot A}{d^2},$$

Where

Γ is the gamma constant, for Ir-192: 0.135 mSv m²/ GBq h;

A is the Source activity,

d is the distance to the source.

In the calculation, two realistic assumptions are made:

- It is considered the worst scenario when the gammagraphy is done without a collimator.
- Since the activity of the source decreases with its use and considering that the source is changed 2 times a year, $A = A_i / 2$ is taken to perform the calculation

With this in mind

$$H_{ir} = (0.135 \cdot 1850) / 20^2 = 0.624 \text{ mSv/h.}$$

When the collimator is used. the dose rate (H_{ir-}) is reduced by a factor 0.05 due to the shielding provided by this device, therefore.

$$H_{ir-} = 0.624 \text{ mSv/h} \cdot 0.05 = 0,0312 \text{ mSv/h}$$

The total annual doses for the implementation of the practice are shown in the following Table:

No.	Doses during the practice	Estimated Dose Rate	Average estimated time per practice	Number of practices per year	Annual dose for each type of practice
1	Dose received by the operator during the transit of the source of Gammagraphy to the position of irradiation.	1.11 mSv/h	0.0056 h (20 sec)	1800 scans per year	11,2 mSv/y
2	Dosage received by the operator during irradiation for each scan. WITH NO COLLIMATOR	0.624 mSv/h	0.033h (2 minutes)	1440 scans per year	29,6 mSv/y
3	Dosage received by the operator during irradiation for each scan. WITH COLLIMATOR	0,0312 mSv/h	0.033h (2 minutes)	360 scans per year	0,4 mSv/y
4	Total				41,2 mSv/y

b) Conclusions on the estimate total dose received by the Unit Operator under Normal Operation.

- The dose estimation shows that most of the dose received by the Gammagraphy operator are produced during the control of the equipment when the Source is irradiating. Particularly, when the working procedures do not contemplate the placement of the collimator, the dose is high enough to demonstrate the need for improvement of these procedures.
- It can be seen that the dose received by the operator during the transit of the source is not negligible and is directly dependent on the high workload that this company has.
- The dose received by the operator when using the collimator during the practice is comparatively low and fully justifies the use of the collimator.

3.2.1.2 Dose estimates in Normal operation. (For the public).

Next, we will estimate the dose received by this member of the public.

Parameters for the calculation of the dose:

- a) Dose rate at the periphery of the controlled area: 2,5 $\mu\text{Sv/h}$
- b) Occupancy factor in the peripheral area to the controlled area: 0.25.
- c) Number of gammagraphies performed by the company in a year: 1800.
- d) Exposure time during a gammagraphy: 2 minutes = 0,033 h.

The dose received by a member of the public at the periphery of the controlled area would be:

$$D_{\text{pub}} = 2,5 \mu\text{Sv/h} * 1800 \text{ gammagraphy/year} * 0,033 \text{ h/gammagraphy} * 0.25$$

$$D_{\text{pub}} = 37,125 \mu\text{Sv/year}$$

$$D_{\text{pub}} = 0,037 \text{ mSv/year.}$$

Conclusions on the estimate total dose received by the members of the public:

- The zone delimitation used by the gammagraphy company during the performance of its work is fundamental to guarantee the radiological protection of the public, since it guarantees that, despite the high workload, the public receives very small doses.
- It has been considered the most unfavorable scenario: members of the public have been supposedly located on the same periphery of the controlled area, so the results are overestimated

3.2.2. Dose estimates in accident situation.

3.2.2.1. *Dose received by the Occupationally Exposed Personal involved in the accident.*

- Operator of the Gammagraphy unit.
 - a) The first exposure of this operator occurs when approaching the source to assess the situation, so the dose received is estimated as follows:

$$\dot{H} = \frac{\Gamma \cdot A}{d^2}$$

- Γ , is the gamma constant for the radioisotope used (Γ , for I-192 is 0.135 mSv m²/GBq h).
- A, is the activity of the source. 3700 GBq
- d, is the distance between the source and the person irradiated. 2 m
- H, is the dose rate.

Substituting the data into the previous equation we obtain:

$$H = 124,875 \text{ mSv/h}$$

The total dose received by the operator in this action is obtained by multiplying the dose rate by the period of time spent to perform this action:

$$D_{o1} = H * t_{o1}$$

- t_{o1} is the time used by the operator to perform the first action: 5 minutes = 0,083 h

$$D_{o1} = 10,41 \text{ mSv.}$$

- b) This operator is exposed later, when taking the source with his hands, so the dose received is estimated as follows:

$$D_c = F_c * T_c * A$$

- F_c , Is the conversion factor of the absorbed dose rate, applied to the soft tissue absorbed dose. (Table 14 y 15 EPR-D-VALUES 2006) (For I-192 $F_c = 8.5 \cdot 10^{-15}$ Gy/Bq*s),
- T_c , Is the period of time the person keeps the source in contact: 15 s
- A, Is the initial Activity of the source (assuming conservative considerations): 3700 GBq = $3,7 \cdot 10^{12}$ Bq

Substituting the data into the previous equation we obtain:

$$D_c = 471,7 \cdot 10^{-3} \text{ Gy} = 0.4717 \text{ Sv.}$$

- Operator's assistant.

b) During the operation performed, it is exposed when trying to introduce the Source into the emergency container. Therefore, the dose received is estimated as follows:

$$\dot{H} = \frac{\Gamma \cdot A}{d^2}$$

- Γ , is the gamma constant for the radioisotope used (Γ , for I-192 is 0.135 mSv m²/GBq h).
- A , is the activity of the source. 3700 GBq
- d , is the distance between the source and the person irradiated. 0.9 m.
- H , is the dose rate.

Substituting the data into the previous equation we obtain:

$$H = 616,7 \text{ mSv/h.}$$

To obtain the total dose received by the operator's assistant in this action we must multiply the dose by the period of time used to perform the same:

$$D_{o2} = H * t_{o2}.$$

- t_{o2} is the time used by the operator to perform this action: 10 minutes = 0,17 h

$$D_{o2} = 102,8 \text{ mSv.}$$

- c) Conclusions on the estimation of total dose received by workers in accident situations.
- Actions in accident situations should be well planned in correspondence with emergency procedures. Note that the operator receives more than 10 mSv for the action performed aimed only to identify how to act in this scenario.
 - Emergency procedures should be systematically trained to ensure training and skills are available. Note that the operator's assistant receives a dose greater than 100 mSv because does not have enough skills in handling the accessories needed to use in the case of this scenario. Although it takes a lot of time to perform this task, he fails to place the source in the emergency container.
 - The action performed by the operator, which violates procedures taking the source with his hands, is unwise and brings with it a very high dose to the skin, ratifying the need to know and systematically train emergency procedures.

Table No 6. Dose thresholds for certain effects.

Tissue and effect	Total Dose Threshold received in a single brief exposure (Gy)
Testicles	
Temporary sterility	0.15
Permanent sterility	3.5-6
Ovaries	
Sterility	2.5-6
Lenses	
Detectable Opacity	0.5-2
Visual impairment (Cataracts)	5
Bone marrow	
Hematopoiesis depression	0.5

3.3.- Risk Calculations

3.3.1. The selection of the accident initiating events list has been made by adapting the Event List Recommended initiators for the practice of Gammagraphy in la publicación del FORO Iberoamericano de Reguladores disponible en la página WEB www.foroiberam.org by using the SEVRA3.0 INDUSTRIAL software (See Annex 1). The list of events analyzed included 76 events distributed along the different stages of the Gammagraphy process.

3.3.2. All selected events have been evaluated to estimate the applicable frequency level considering the following levels:

High: The initiating event occurs frequently, more than 50 events /year.

Medium: The initiating event occurs occasionally, greater or equal than 1 and equal or less than 50 events/year.

Low: Unusual or rare occurrence of the initiating event, less than 1 event/year and greater or equal than 5 events per 100 years.

Very Low: It is very rare that the initiating event occurs, less than 5 events per 100 years. There is no information the event ever occurred

3.3.3. Each event analyzed has been evaluated to accept the level of consequences proposed in SEVRRRA 3.0 INDUSTRIA. Consequences have been classified with the following levels:

- **Very high:** They are of catastrophic type, causing severe deterministic effects, are fatal, or lead to permanent damage or disability.
- **High:** They cause deterministic effects, but do not represent a danger to life and do not cause permanent damage.
- **Medium:** They provoke anomalous exposures that are below the thresholds of deterministic effects, manifested as an increase in the probability of stochastic effects.
- **Low:** no effects are produced on the workers or public. The level of defenses has decreased.

3.3.4. Each initiating event considered has been analyzed to identify the applicable defenses according to the principle of defense in depth. In each event, the Barriers and Reducers (Frequency and Consequences) were identified. Based on the quantity and quality of the existing defenses, SEVRRRA evaluates the variables of the risk equation and assigns the Risk Level corresponding to each accidental sequence.

3.3.5. Risk analysis conclusions.

Annex 1 shows the risk profile of this Gammagraphy company.

- None of the total 76 Initiating Events analyzed was evaluated with the Very High Risk (RVH) level or High Risk (RH) level.
- Annex 1 (Figure 3.2) below shows that there are 50% of accidental sequences evaluated with medium risk. The company should conduct a cost-benefit analysis to determine what measures may be proposed to reduce the level of risk.

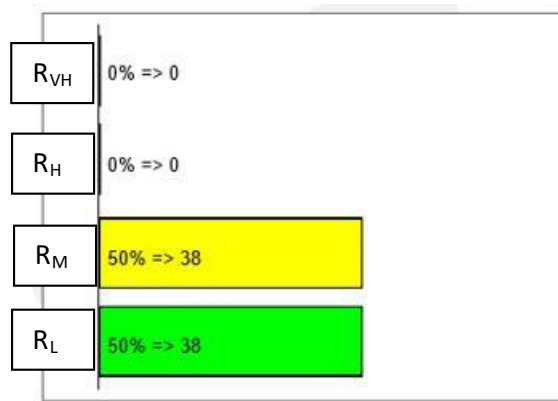


Figure 3.2.- Risk level of accidental sequences

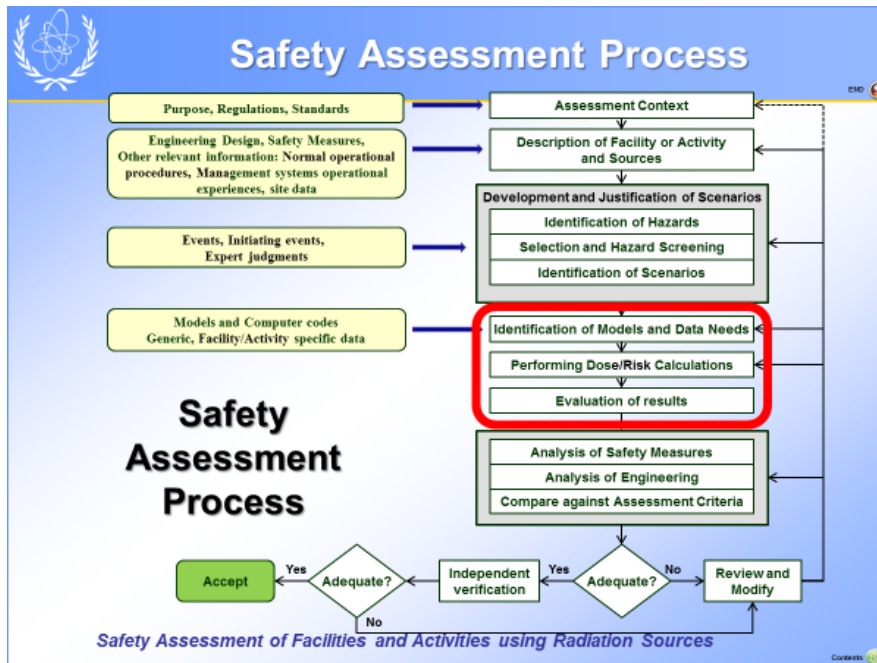
3.4.- Evaluation of results (uncertainty analysis).

The results of the safety analysis performed in point 3 have associated the uncertainties inherent to the methodologies and data used. These uncertainties are widely known because they are widely recognized internationally.

In spite of this, they have been applied under conservative precepts and considering the worst scenarios in such a way that if the results are accepted when comparing them with the evaluation criteria, it indicates that these uncertainties do not negatively influence the safety of the practice.

EXERCISES PART 3.- SAFETY ANALYSIS

These exercises cover the third block of presentations



DOSE CALCULATIONS

Using the information provided in part 3 and with the support of the presentations about dose calculations, solve the following exercises:

EXERCISE PART 3 #1 Fill the following table taking into account the job positions that are more exposed to ionizing radiation during the execution of their duties:

No.	Job position	Duties	Dose
1.	Operator	Work preparation	No
		Placement of radiographic plates on the parts to be tested.	No
		Manipulation of the equipment while the Source is in transit.	Yes
		Control of the gammagraphy process while the Source is in irradiation position.	Yes
2.	Operator's assistant.	Carrying of the equipment during the transport. In this case it is exposed to leak radiation from the container	Yes
		Monitor to prevent entry of members of the public to the controlled area. In this case it is exposed to the expected dose rate levels for members of the public	Yes
3.	Radiation Protection Officer.	Audits to the radiation protection program.	No
		Inventory of equipment and radioactive sources.	Yes
		Supervision of work under field conditions.	Yes

EXERCISE PART 3 #2 Estimate the dose received, in normal operating conditions, for the position of the Operator in order to demonstrate if this does exceed or not the restrictions and dose limits established:

No.	Doses during the practice	Estimated Dose Rate	Average estimated time per practice	Number of practices per year	Annual dose for each type of practice
1	Dose received by the operator during the transit of the source of Gammagraphy to the position of irradiation.	1.11 mSv/h	0.0056 h (20 sec)	1800 scans per year	11,2 mSv/y
2	Dosage received by the operator during irradiation for each scan. WITH NO COLLIMATOR	0.624 mSv/h	0.033h (2 minutes)	1440 scans per year	29,6 mSv/y
3	Dosage received by the operator during irradiation for each scan. WITH COLLIMATOR	0,0312 mSv/h	0.033h (2 minutes)	360 scans per year	0,4 mSv/y
4	Total				41,2 mSv/y

EXERCISE PART 3 #3 Estimate the dose received by the member of the public most exposed, in normal operating conditions (with the data from 3.2.1.2).

RISK CALCULATIONS

Using the information provided in part 3 and with the support of the presentations about risk analysis and SEVRRA software, practice with the following exercises:

EXERCISE PART 3 #4: Using SEVRRA software, analyze the events on the following stages:

- a) Transport.
- b) Operation

EXERCISE PART 3 #5: Analyze the results generated by SEVRRA after the assessment of the reference installation (Annex 1)

4.- ANALYSIS OF ASSESSMENT RESULTS

4.1.- Comparison with assessment criteria.

- The total annual dose received by the operator of the Gammagraphy equipment surpasses the dose limit (20 mSv / year as an average) established in the current national regulations and recommended in the GSR part 3. This situation is unacceptable as set out in point 1.4 and therefore technical and organizational measures should be taken to reduce the annual dose of the operator in accordance with the dose restriction and the dose limit established in the current national regulations.
- The total annual dose received by the member of the public in the worst conditions (from the point of view of radiation protection) is less than the dose limit (1 mSv / year) established in the current national regulations and recommended in the GSR part 3. This annual dose is, in turn, also lower than the dose restriction established at the Hospital (0.5 mSv / year).
- None of the total 76 Initiating Events analyzed was evaluated with the Very High Risk (RVH) level or High Risk (RH) level. In this sense, the company successfully fulfills the acceptance criterion defined in point 1.4 and does not require the implementation of new safety measures (barriers and reducers) to start the planned Gammagraphy work.

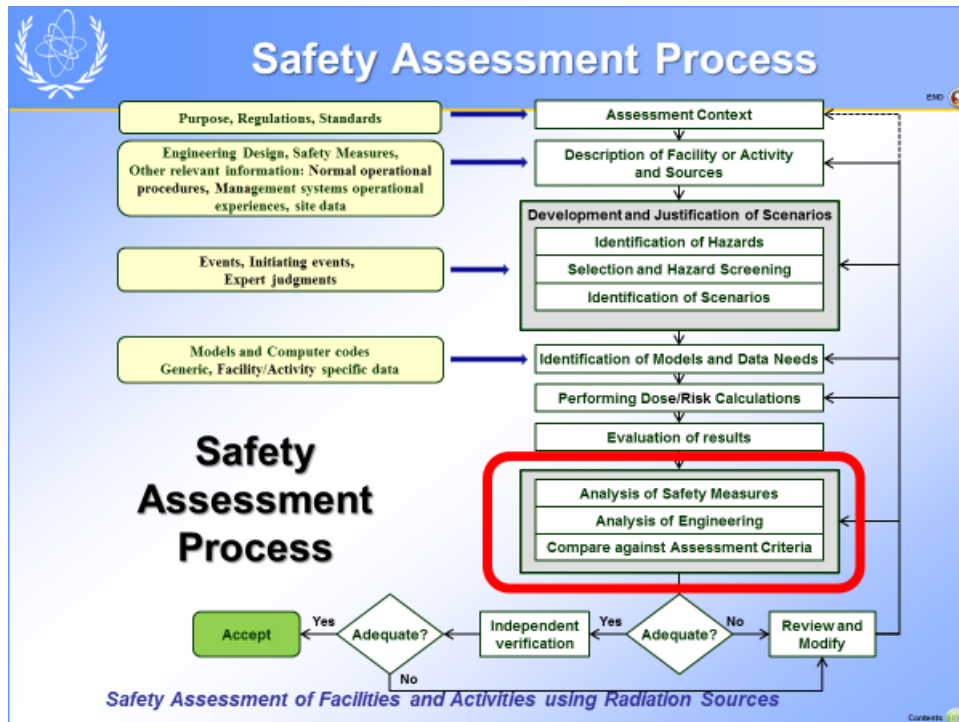
4.2.- Analysis and revision (if it is needed) of safety measures and engineering.

To reduce the doses received by the operator, that have been considered unacceptable, it is proposed to implement the following measures:

1. Modify the working procedures in order to reduce to a minimum the number of procedures of Gammagraphy that are performed without the use of the collimator. The international experience of companies that perform this practice shows that in more than 90% of cases the collimators can be used. This would reduce the dose received by the operator for irradiation from 30 mSv / year to 5.37 mSv / year.
2. Create two work shifts, so that the workload is uniformly distributed between 2 different operators. This measure is fundamental since the dose received by the operator for the transit of the source from the equipment to the piece to be tested and vice versa depends very closely on the number of gammagraphies performed.
3. In applying these two measures, the total dose received by each operator is reduced from 41.2 mSv / year to 8.29 mSv / year. This is in line with the restriction and dose limit criteria set out in point 1.4.

EXERCISES PART 4.- ANALYSIS OF ASSESSMENT RESULTS

These exercises cover last block of presentations



EXERCISE PART 4 #1: Use the result of dose calculations in exercises “part3 #1 and #2” and compare these results with the assessment criteria defined in paragraph 1.4 “Assessment criteria”.

EXERCISE PART 4 #2: Use the results of risk calculations with SEVRA software (Annex1), assess these results.