- GEOSAF -

International Intercomparison and Harmonization Project on Demonstrating the Safety of Geological Disposal

REPORT of the GEOSAF Working Group on Operational Safety

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I. INTRODUCTION

I.1 Background

During the course of the GEOSAF project, members have noted that, after decades of post-closure safety development, little work has been undertaken internationally to develop a common view on the safety approach related to the operational phase of a geological disposal facility.

General guidance in this regard can be found in e.g. *IAEA General Safety Requirements No.GSR-4, Safety Assessment for Facilities and Activities* [A], and *IAEA Specific Safety Requirements No.SSR-5, Disposal of Radioactive Waste* [B]. The guidance in those documents are however quite generic in nature and does not provide for detailed guidance on how to practically develop assessment of hazards occurring during operational phase and address interaction between operational and post-closure safety.

Thus, GEOSAF decided to launch a programme of work on this topic at the plenary meeting held on March 2010 and to establish a subgroup on operational safety.

I.2 Scope of the study

The specificities of a geological disposal facility in comparison with conventional underground facilities such as mines or tunnels are:

- the presence and handling of radioactive material (artificial RN and higher concentration than in mines…),
- the nuclear regulatory framework(s),
- the constraints on operations due to post-closure safety (e.g the preservation of the host formation characteristics) and the impact of operation on post-closure safety.

The subgroup on operational safety decided, in a first approach, to focus efforts on:

- operational hazards/safety issues specific to an underground nuclear facility (in terms of large scale, difficult access, concurrent activities…)
- how hazards/safety issues are addressed in the operation of mines (conventional or uranium) or underground facilities (tunnels…) and in the operation of existing nuclear facilities (including radioactive waste disposal facilities) ;
- the necessity of developing a specific safety approach for hazards/issues specific to an underground nuclear facility;
- the implications of these operational issues (including accidents) on post closure safety ;
- the recommendations with regard to the development and review of the safety case.

As considerable experience from the nuclear industry on design, construction and operation of surface facilities exists, the group decided to focus on the operation of the underground part of the facilities (including shafts and ramps).

This report presents the outcome of the GEOSAF Operational Safety Working Group as well as recommendations for continued work in this area.

I.3 Mode of operation

The work programme developed by the group involved visits to three different underground facilities to collect information on operational experience with special emphasis on management of hazards and/or risks;

- a conventional mine (the Moab Khotsong gold mine in South Africa),
- a high-grade uranium mine (Mc Arthur River, Canada), and
- a geological disposal facility for transuranic waste (Waste isolation Pilot Plant, WIPP, USA). A workshop was arranged in conjunction with the WIPP-visit in April 2011, to analyse and compile the conclusions.

A summary of the main conclusions from the visits are found in appendix I.

I.4 Common Terminology

It was found valuable by the group to start on common grounds with a terminology that fits with everyone's culture and practice. The following definitions are based on the two IAEA glossaries that are currently in use [C, D]:

Hazard: A hazard is something (e.g. an object, a property of a substance, a phenomenon or an activity) that can cause adverse effects

Hazard assessment: Hazard assessment is the process of analysing systematically the hazards associated with facilities, activities or sources in order to identify:

(a) Those events and the associated areas for which protective actions may be required;

(b) The actions that would be effective in mitigating the consequences of such events.

Event: An event is any occurrence unintended by the operator, including operating error, equipment failure or other mishap, and deliberate action on the part of others, the consequences or potential consequences of which are not negligible from the point of view of protection or safety.

Initiating event: An initiating event is an identified event that leads to anticipated operational occurrences or accident conditions.

Risk: Risk is a multi-attribute quantity expressing hazard, danger or chance of harmful or injurious consequences associated with actual or *potential exposures*. It relates to quantities such as the probability that specific deleterious consequences may arise and the magnitude and character of such consequences.
Note: this definition may be subject to various interpretations.

Scenario: A scenario is a postulated or assumed set of conditions and/or events.

II ASSESSMENT METHODOLOGY

II.1 General Context for the Methodology

Safety must be demonstrated for all the operational states of the facility (normal operation, accidental situations). For nuclear facilities, defence-in-depth is one of the main principles to rely on when demonstrating safety (SSR-5, requirement 6). Regarding operational safety, it should be emphasised that there is no major difference in the approach to demonstrating safety through the safety case whether it is dedicated to a disposal facility or another nuclear facility. Assessment of operational safety is an integral part of the process described in SSR-5, i.e. assessment of operational hazards should be integrated in the safety case development for a disposal facility.

The basic safety functions of a geological disposal facility are:

- containment of the radioactive material and protection of workers, public and the environment during the operational phase,
- isolation and containment of the radioactive waste during the post-closure phase.

In addition to conventional underground safety, operational safety of a geological disposal facility is dependent on the design of the containment barriers and the radioprotection measures in normal and abnormal conditions, while post-closure safety of a geological disposal facility is dependent on proper performance of technical barriers and of the host rock environment. Thus, proper design and construction (including closure) of the facility, as well as safe operations, are of special importance to provide for post-closure safety. Considering operational safety and post-closure safety of a geological disposal facility, special emphasis should therefore be put on identification of hazards associated with the construction and operation of the repository.

The safety approach should be based on verifying the compliance with technical performances of the protection provisions against all concerned hazards, derived from the hazard analysis. In this regard, safety functions and associated technical requirements have to be defined. The quantitative assessment of radiological consequence from any postulated hazards is only considered as a means of verification.

Hazard assessment requires identifying and analysing i) plausible hazards and ii) elements or “targets” to be protected regarding nuclear safety (radioactive materials, containment systems of these materials, evacuation pathways and access to equipments to handle the hazard and thus maintain the facility in a safe status…). The provisions adopted on the basis of this analysis, organized in successive and independent levels according to defence in depth, aim at (INSAG 10):

- prevention of abnormal operation and failures,
- control of abnormal operation and detection of failures,
- control accidents within the design basis,
- control of severe facility conditions, including the prevention of accident and mitigation of the consequences of severe accidents,
- mitigation of radiological consequences of significant releases of radioactive materials.

An approach on how to address hazards associated with operation of the facility is described below, and schematically illustrated in figure 1.

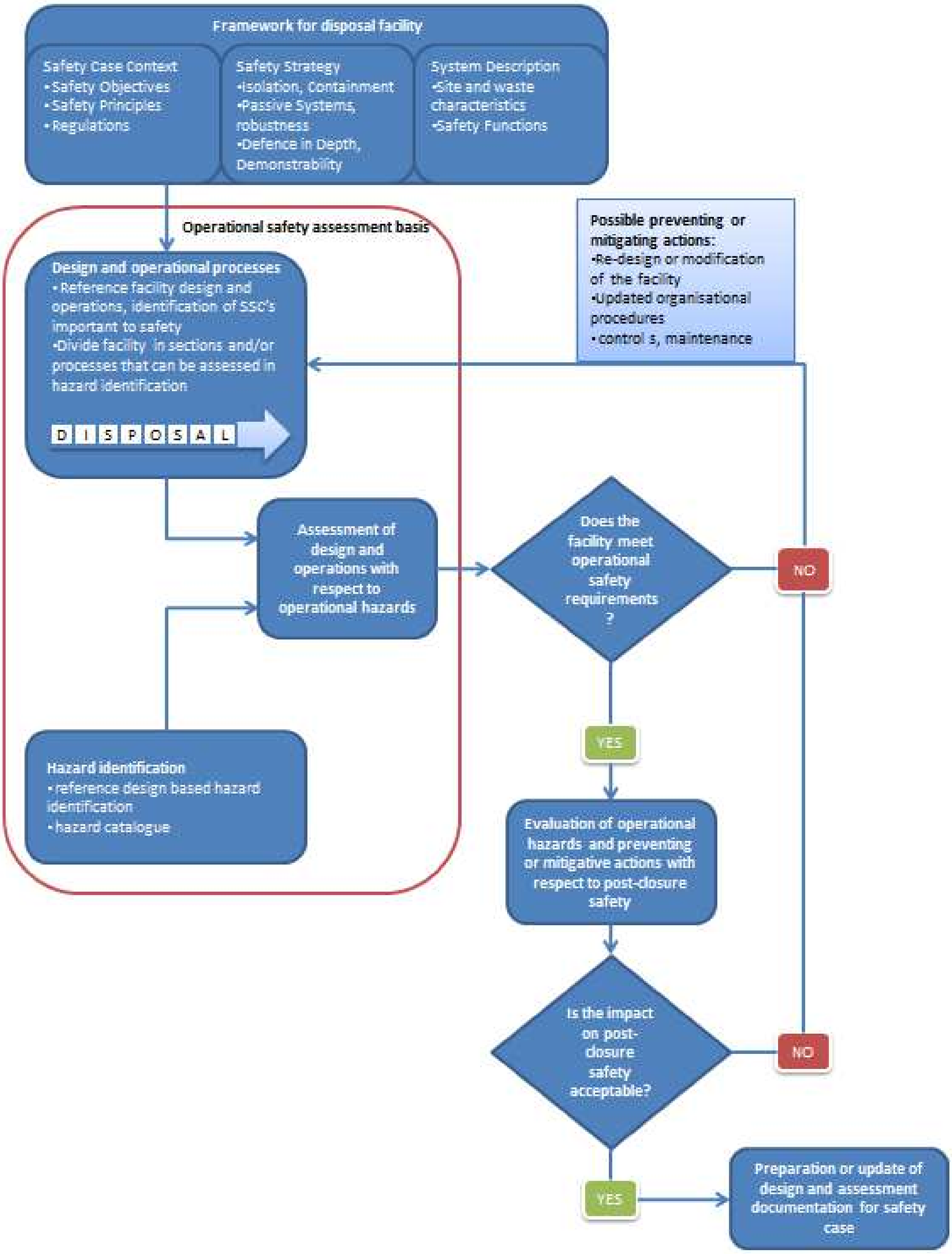


Figure 1 : Hazard assessment in operational safety context

In a first step, **the framework for the disposal facility** will guide the initial design of the facility, which might take into account some standard hazards that are defined through regulatory requirements – all or not nuclear – or through a preliminary analysis of hazards. In order to perform the hazard assessment, the reference **design and operational processes** should be described, and divided into assessable compartments and/or stages. Based on this and maybe on other sources such as hazard catalogue or matrices, the **hazards** of the facility are identified.

Then, identified hazards are assessed against the design and operational procedures in order to judge whether their consequences and/or the associated risks are acceptable, taking into account preventive and mitigation features.

- If **not acceptable**, adaptations should be made of the preventive and mitigation features, which could be on the level of design (re-design or modification) or operational procedures. Facility re-design or design modification requires iteration of hazard identification and assessment with regard to updated features.
- If **acceptable**, an evaluation is made on the impact of hazards and the preventive and mitigation features on the **post-closure safety**.

The same process of judgement is then applied to post-closure safety.

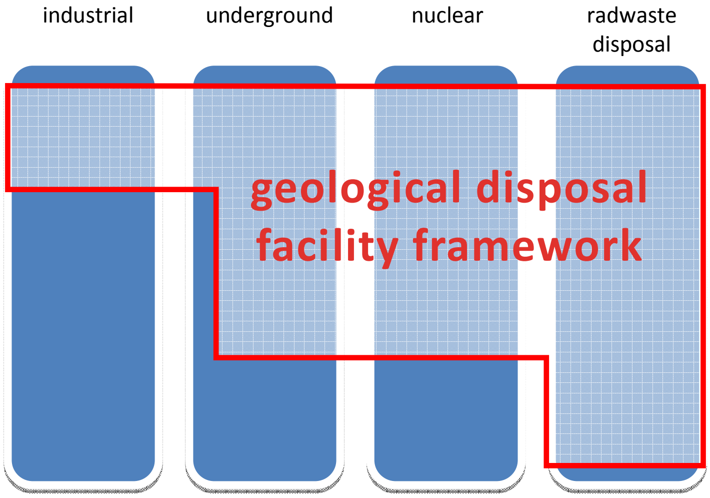
- If **not acceptable**, preventive and mitigation features should be adapted, which could be on the level of design (re-design or modification) or operational procedures. Facility re-design or design modification requires iteration of hazard identification and assessment with regard to updated features.
- If **acceptable**, the design and operational processes and the preventive and mitigation features can be finalized or updated, together with the final documented operational safety assessment.

A pilot study on the fire hazard was performed to check the consistency of this methodology. An example of the approach for fire hazard analysis at the WIPP facility is presented in Appendix III. Moreover, a presentation of the French approach on the fire hazard analysis was made to the GEOSAF group and is given in Appendix IV.

II.2 Framework for a geological disposal facility

With regards to operational safety, the framework for a geological disposal facility is established on the basis of inputs from surface nuclear facilities, conventional underground facilities such as mines and tunnels, and the specific features of a geological disposal facility.

For instance, the regulatory basis will be composed of regulations for surface nuclear facilities and for conventional underground facilities:



As an example of this scheme, the Canadian nuclear safety authority (CNSC) uses regulations from nuclear facilities and mining facilities to regulate the operation of high-grade uranium mines.

II.3 Design and Operational Processes

The design of an underground disposal facility should be developed according to the framework as defined in the previous step (e.g. requirements on operational safety and post-closure safety). However, post-closure safety may set constraints that are in conflict with requirements for operational safety and as a consequence, the design needs to be optimized. For example it can be beneficial for post-closure safety to have only few surface connections (access ramps, shafts) and small cross-section tunnels to avoid disturbance on site properties. Whereas for operational safety and emergency purposes a design should avoid dead-end tunnels and be in favor of safe exit. Examples of this kind of design constraining issues are given in Appendix II.

The reference design should be checked against the facility's safety functions and ability to ensure safety during the operational and the post-closure phases.

For the purposes of hazard identification and evaluation, it may be necessary to break out the overall facility operational process into various operational sections based on for example waste handling areas and the activities performed in those areas.

II.4 Hazard Identification

The identification of hazards inherent in waste activities is necessary to provide a sound basis for identifying potential accident events and performing a hazard evaluation in order to define the preventive and mitigative controls. Following the same approach as for the establishment of the framework, hazards are identified based on regulations, analysis and feedback of experience from various types of facilities: industrial, underground, mines, surface nuclear facilities and waste disposal facilities. Furthermore, a "Features, Events and Processes" (FEP) list or a hazard matrix can be used (see appendix II) or a pre-defined list of hazard, as underlined by the WIPP operational experience.

The hazards defined can be of different nature and amongst others result from:

- ✓ waste handling processes,
- ✓ natural phenomena (e.g., earthquakes, lightning, tornadoes, snow/hail buildup and high wind impacts),
- ✓ human induced external events (e.g., aircraft and vehicular impact),
- ✓ co-activity (construction and operation in parallel).
- ✓ Fire, loss of ventilation (active, containment), criticality…

II.5 Hazard Evaluation

The hazard evaluation is the process of analysing systematically the hazards associated with the facility in order to identify the initiating events that would need protective or mitigating controls. Approaches for evaluating hazards and defining preventive and mitigative controls may differ between countries. The next sections will develop the different steps that can be undertaken when performing a hazard evaluation.

II.5.1 Scenario Description

The hazard evaluation includes a brief description of initiating event that is representative or envelope for the type of hazard considered. The scenario includes a hazardous condition being postulated, general location of the event, the systems, structures and components (SSC) affected, especially those relevant to safety, the radioactive materials, the release mechanism (e.g. fire, pressurized release, spill).

II.5.2 Consequence evaluation

The consequences, radiological and/or non radiological, of identified scenarios should be evaluated. In doing so, credit is given neither to already identified preventive nor to mitigative controls. Also, margins should be taken into account for the evaluation, and uncertainties should be identified. It might be necessary to also consider plausible combinations of events.

Some countries adopting a risk based approach will rank the hazards further according to the risk they pose and according to the methodology developed in the next section. Other countries do not adopt this risk ranking and define the preventive and mitigative controls purely based on the consequence analysis.

II.5.3 Risk Ranking

The goal of risk ranking is to focus attention on those hazards that pose the greatest risk. Some countries that adopt a risk based approach rank the identified hazards with respect to the risk they cause, that is the combination of the unmitigated consequence levels of the hazard with the levels of frequency of its appearance. In this process of qualitative ranking, events with an unacceptable risk ranking or marginally acceptable risk ranking are analyzed to provide appropriate features of prevention or mitigation.

II.5.4 Determination and evaluation of controls

In order to cope with hazards that have unacceptable consequences (all or not radiological) or pose an unacceptable or high risk, the next step consists of identifying and selecting controls to be put in place in order to prevent hazards or mitigate their consequences. This should lead to the reduction of the frequency of the hazard or the exclusion of its occurrence in case of preventive controls, or the reduction of its consequences in case of mitigative controls. The controls can be a combination of both.

In any case, care should be taken to prevent as much as possible the occurrence of hazards or to keep the risk as low as reasonably achievable.

<u>Preventive Features</u>

Preventive features might include engineered features (structures, systems and components, etc.), administrative controls (procedures, policies, programs, etc.), natural features based on laws of physics (ambient conditions, buoyancy, gravity, etc.), or inherent features (physical or chemical properties, location, elevation, etc.) operating individually or in combination.

Mitigative Features

Mitigative features must be capable of withstanding the environment of the event. These might include the same kind of features as for preventive controls, operating individually or in combination. Mitigative features should to the extent possible rely on passive features.

II.6 Operational Safety Assessment

The goal of operational safety assessment is to assess the safety of the facility during the operational phase and to identify normal operation of the facility, as well as the anticipated operational occurrences (abnormal and accidental conditions) that might be the result of initiating events based on hazards, and the means put in place to cope with these conditions, in line with the safety principles such as defence in depth and optimization.

When it comes specifically to hazards, the operational safety assessment demonstrates that in the first place, sufficient effort is done to reduce the probability, or to prevent the appearance of hazards that might impact operational safety. In particular, operational safety assessment demonstrates that, possibly for different initial conditions, the consequences of the initiating events based on these hazards are mitigated through system design or procedures such that they do not give rise to unacceptable consequences (radiological or others) or pose an unacceptable risk. It should be demonstrated that if the postulated initiating events associated to hazards give rise to abnormal conditions, the controls in place should be able to put the facility back into its normal operation envelope. It should also be demonstrated that if those initiating events give rise to accidental conditions, the controls in place should be able to keep the facility in a safe state.

The assessment of the acceptability of preventive and mitigative controls can be done through the postulation of events and the development of a propagating scenario of this event into an incident or accident. In these scenarios, the facility is usually put at its most penalising state and conservative assumptions are made. This assessment can be performed through a purely deterministic or a risk-based approach as described in sections II.5.3 & II.5.4.

An example of a deterministic approach has been proposed by the Institut de Radioprotection et de surete nucleaire (IRSN) as part of the technical review of the “Dossier 2009”, the French geological disposal project under development. The review considered the possibility of a fire starting on a waste handling system being within a disposal cell for waste packages that contain flammable material. It was supposed that the fire on the waste handling system was not extinguished by the selected controls developed in the actual design. The reviewers considered that this event could lead to severe consequences, being a fire which is impossible to extinguish once it has started. Based on these consequences and in spite of the very low probability of occurrence of such an event (as it requires a multiple failure scenario), the assessor recommended a strengthening of the preventive and mitigative measures in place. In this example, neither risk ranking nor radiological consequences were a tool to judge the acceptability of the current measures.

II.7 Relationships between Operational Safety and Post-closure Safety

As described above, post-closure safety puts constraints on design and operation of a geological disposal facility, e.g. on use of foreign materials or other actions that are in favor of long term performance or geological properties. In the underground facility this can mean restrictions on use of construction materials, amount or type of rock reinforcement or grouts, ventilation, fire protection, etc.

In the same way, the operation of such a facility and the proposed measures to ensure operational safety may also have some impact on post-closure safety, as well as the consequences of incidents or accidents on the engineered or natural barriers.

Therefore it has to be verified that normal operation and anticipated operational occurrences (postulated incidents or accidents), and the measures (controls) put in place to ensure safe operation, as well as all monitoring systems put in place during operation and beyond, will not have an unacceptable effect on post-closure safety.

The impact or consequences of incidents or accidents on post-closure safety needs to be further investigated (both the requirements for the investigation in the safety case and the investigations to perform after the incidents/accidents have occurred).

III CONCLUSIONS

During the course of the GEOSAF project, members have noted that, after decades of focus on mainly the post-closure safety of geological disposal facilities, little work has been undertaken internationally to develop a common view on the operational safety of such facilities. As many member states are coming closer to licensing of geological disposal facilities, continuing efforts, such as the one presented in this report, should be undertaken in the forthcoming years in order to further develop international consensus on how to address operational safety issues for geological disposal facilities.

The conclusions in this report is limited to operational hazard assessment, which was the main focus of work during the one year of activity of the operational safety working group of GEOSAF.

The operational safety work group gained experiences from several field trips, amongst others to a conventional mine, a high grade uranium mine and a geological disposal facility of transuranic wastes. These visits, together with the consideration of different practices in different countries and numerous discussions and analysis led the group to the following conclusions:

- In general, the framework for a geological disposal facility is based on inputs from different sources: practices, experiences and regulations from nuclear surface facilities, conventional underground facilities (mines, tunnels…), standard industrial facilities and specific features unique to a geological disposal.
- The basis on which operational safety assessment (including hazard assessment) will be performed consists of an identification of all structures, systems and components together with their safety functions, an identification of the activities and processes that will be conducted within the facility, as well as the identification of all hazards that can impact the facilities' safety.
- A general methodology for hazard assessment could be developed, based on the experience in different countries. The final objective of the application of this methodology is to ensure that measures taken by the operator to manage hazards are adequate to ensure the safety of the facility, as well during operations as with respect to post closure safety. It was noted that all countries share the same basic principles of hazard assessment:
    - The identification of the design, including all SSC's and their safety functions, and of the operations and processes that will take place in the facility (and dividing the facility/and or processes into parts or phases that can be assessed)
    - The identification of the hazards by several possible means
    - The assessment of the possible (unmitigated) consequences (all or not radiological) of the hazards
    - The identification of preventive and mitigative controls
    - The assessment of the acceptability of these controls
    - The type of actions to take in case controls are assessed being insufficient or not acceptable

- The assessment of the consequences of the hazards, and preventive and mitigative controls on long term safety and the type of actions to take in case the consequences are not acceptable.

- Such methodology is specific to a geological disposal facility, compared to other nuclear installations. But the unique character lies in the fact that the assessment is performed in the frame of an underground installation, which has its own particular set of hazards (see Appendix II) which differ from considered for surface facilities. This underground environment also set some particular boundary conditions to the way one can cope with these hazards. Another aspect, common with surface disposal facilities, is the necessity to consider also the effect of hazards and their preventive and mitigative controls on the post-closure safety of the facility.

- The practical implementation of this methodology can vary significantly between member states (e.g. risk based or deterministic).

- A pilot study on fire hazard was conducted by different countries. This study showed that the general methodology was applicable and applied in the different cases. The study also underlined in a certain case the difficulties associated to the assessment of hazards in the specific configurations of a geological disposal facility, exposing the necessity to develop new models, to search for experience feedback from installations with similar configurations and to develop new assessment tools.

- Strong relationships between operational safety and post-closure safety were outlined. Post-closure safety puts constraints on requirements for the operation of a geological disposal facility, such as the choices of materials or the techniques that can be used for construction. In the same way, the operation of such a facility also has some impact on post-closure safety. It has therefore part of the safety demonstration to ensure that operations in general, and more specifically :
    - all normal operations
    - anticipated operational occurrences (postulated incidents or accidents),
    - the measures (controls) put in place to ensure safe operation, as well as
    - all monitoring systems put in place during operation and beyond,

  will not have an adverse effect on post-closure safety.

IV NEED FOR FUTURE WORK

The working group collected some recommendations for future work, based on their experiences and on discussions with member states at the GOESAF plenary meeting from may 2011.

Development of guidelines

GEOSAF made strides in providing tools and guidelines for operators and regulators to build and/or assess the safety of a geological disposal facility through the use of the safety case with a strong focus on post-closure safety. However, operational safety assessment shall be included in the safety case as well, but few guidelines exist that are specifically addressing geological disposal facilities to help operators and regulators in doing so. A good start could be the identification of detailed contents of the safety case for the topics related to operational safety and the adaptation of tools (questionnaire,…) developed during the GEOSAF project for the specific part on operational safety.

Operation states of a geological disposal facility

The definition of normal operation (normal operation envelope) and anticipated operational occurrences (incidents and accidents), and the associated set of safety margins and limits to get from one state to the other, is an area of knowledge that needs to be developed. As few experience feedback is available from existing geological disposal facilities, efforts could be made to gain as much as possible experience from other (nuclear) facilities.

Safety Evaluation Report and the Safety Case

The way how to develop a safety evaluation report of a geological disposal facility and its relation to the safety case, is an issue that has not been dealt with before. It will, however, become important as several member states are moving towards a license application.

Here one could start for example with a questionnaire to the different member states in order to see the different approaches that are currently foreseen for the development of a safety evaluation report.

Especially the fact that construction and filling-up of the facility are activities that are performed throughout the lifetime of the facility is challenging, as a safety evaluation report is aimed at always reflecting the current state of the facility. The challenge is here to take into account an ever-changing environment, with potential variations of the hazards & risks induced by these ever-changing activities.

Inputs for the implementation of hazard assessment in the safety assessment

As for a lot of member states, the consideration of operational safety of a geological disposal facility is relatively new and very particular, there is a need for a better development of know-how on the practical assessment of hazards, such as the quantification of their effects, the determination of performance criteria (temperature, pressure, size, position…), the development of scenarios involving incidents, accidents, failures of safety systems or controls and their modelling.

Co-activity

A geological disposal facility is built, equipped and operated at the same time. As a result, different processes, nuclear (emplacement of waste packages, handling…) and non-nuclear (mining, civil engineering…) are likely to take place in the facility at the same time. The consideration of this co-activity in the operational processes and also more particularly when looking at hazard identification and assessment, is an area that needs further development.

Relationships between operational safety and post-closure safety

Impacts of post-closure constraints on the design and implementation of the geological disposal facility and its safety envelope for the operational phase is something that has already been identified in many programs. In contrast, the impact of operations (in its largest meaning, including construction) on post-closure safety is something that should be more developed.
One could clarify or study for example the way in which the consideration of anticipated operational occurrences (incidents and accidents) shall relate to the post-closure safety assessment.

Relationships between operational safety and closure

The closure of the facility will consist in a set of processes that will take place at the end of the operational phase. Therefore, the consideration of operational safety issues during the closure processes are identified as a potential domain that could be developed.
The impact of partial closure both on operational safety and on post-closure safety could be identified as a particular issue to address for future work as well.

Reversibility/Retrievability

REFERENCES

[A] IAEA General Safety Requirements No. GSR Part 4, Safety Assessment for Facilities and Activities.

[B] IAEA Specific Safety Requirements No. SSR-5, Disposal of Radioactive Waste

[C] IAEA safety glossary. Terminology used in Nuclear Safety and Radiation Protection. 2007 edition. STI/PUB/1290; ISBN 92–0–100707–8. June 2007.
Link: http://www-pub.iaea.org/MTCD/publications/PDF/Pub1290_web.pdf

[D] Radioactive waste management glossary. 2003 edition. IAEA publication STI/PUB/1155; ISBN 92–0–105303–7. July 2003.
Link: http://www-pub.iaea.org/MTCD/publications/PDF/Pub1155_web.pdf

APPENDICES

I Observations made in underground facilities
II General Hazards Matrix
III A generic example from WIPP (US)
IV Presentation made by IRSN on fire

APPENDIX I: Observations made in underground facilities

McArthur River facility, Canada and the Moab Khotsong, South Africa

In particular, the group had the opportunity:

1. To tackle ventilation issues with operators (both during the Saskatoon and South African meetings), including maintenance and dimensioning of ventilation systems. The operators underlined the absence of limitation in terms of air flow, however the maximum capacity of the air intake and outflow have to be determined at the shaft design, prior to the construction of the first drifts. In fact, the dimensions and number of shaft can be impacted by such constraints, and the ventilation systems have to be dimensioned to allow for the extension of the underground areas. They also stressed the functions that can be assigned to the ventilation systems, such as radon rate control, and the way these functions can be implemented in the mine. For example, at the McArthur River facility, every underground area has to be ventilated to allow for works, therefore specific doors equipped with radon sensors prevent ventilated areas to be mixed with un-ventilated areas.

2. To gain experience in the Canadian approach to Uranium mining regulation. The Saskatoon meeting underlined the risks related to exposure to radiation, including the radon risk. Both the regulator and the operator explained the importance of sensible tele-operated mechanical devices for the mining operations: the extraction process itself is designed to prevent human presence in the vicinity of the uranium ore, and the lorries and skips are equipped with radio controlled systems in order to prevent workers from operating close to the extracted ore.
   At every step of the process, the regulator underlined the need to either design barriers or allow enough distance between the sources of radiation and the workers. The exposure time factor had to be taken into account in the least possible cases in the underground areas, thus the safety case had to provide sufficient controls with regard to radiation screening or distance from sources. Radon risk was controlled mainly by ventilation systems and security measures (locked doors…).

3. To stress the need for adequate fire protection systems. The South African meeting and the discussions between the group and the gold mine operator put light onto the way such a hazard might be taken into account in underground works. The gold mine operator introduced the group to the method developed by his fire protection experts, in order to prevent fires to lead to unacceptable consequences. This method mainly relies on an occurrence/gravity matrix that is often used in reliability management, for instance. The group was interested to discover the whole set of constraints that the operator includes in this matrix: security, but also environmental issues, social issues, etc. For instance, a fire leading to human casualties has consequences on the production, but also on the population acceptance of the operator in the area of the facility, or on the stock price of the parent company. All these variables are taken into account in the fire hazard analysis provided by the operator.

Waste Isolation Pilot Plant, Carlsbad, New Mexico – USA

Tour of WIPP.

1. Bulkhead and Airlock operations in the underground:

During the IAEA-GEOSAF Operational Safety Working Group tour of the Waste Isolation Pilot Plant, the group noticed that the drifts were separated by large metal doors that were air operated to permit passage of workers and equipment from one drift to another without disrupting the underground ventilation supply air. The underground ventilation system serves the WIPP underground to provide acceptable working conditions and a life-sustaining environment during normal operations and off-normal events including waste handling accidents. In the event of a breach of waste containers, the underground ventilation system provides confinement of radioactivity. The underground ventilation system is designed as an exhausting system that maintains the working environment below atmospheric pressure The design and operation of the underground ventilation system meets or exceeds the criteria specified by the Mine Safety Act (30 CFR 57) and also the New Mexico Mine Safety Code for All Mines. The underground mine ventilation is designed to supply sufficient quantities of air to all areas of the repository. Coupled with the need to maintain airflow requirements, operation of diesel equipment in the underground is subject to minimum airflow requirements for each piece of equipment operated.

The ventilation system in the underground is divided into four separate flow paths supporting the construction area (mining); the waste disposal area; the north area (URL/Experimental Activity); and the waste shaft station. The waste disposal, construction, and the north areas receive their air supply from common sources; the air intake shaft and the salt handling shaft. The purpose of the Airlocks and bulkheads is to separate waste shaft station ventilation from the other three circuits. The four air circuits combine near the exhaust shaft, which is the common discharge from the underground. The pressure differential maintained between the construction circuit and the waste disposal circuit ensures that air leakage is toward the disposal circuit. The pressure differential is produced by the surface fans in conjunction with the underground bulkheads and air regulators. Pressure differentials across selected bulkheads between ventilation circuits are monitored from a location called the Central Monitoring Room. The underground ventilation system consists of six centrifugal exhaust fans (three main fans in the normal flow path and three smaller fans in the filtration flow path), two identical HEPA filter assemblies arranged in parallel, isolation and back draft dampers, filter bypasses, and associated ductwork.

Normal operation of the main fans provides an approximate underground flow of 425,000 standard cubic feet per minute (scfm). The smaller filtrations fans provide approximately 60,000 scfm each and are located at the Exhaust Facility Building on the surface. During filtration operations, only one filtration fan operates, while the main fans do not operate. Any one of the three filtration fans is capable of delivering 100% of the design 60,000 scfm flow rate with the HEPA filters at their maximum pressure drop. Two of the three filtration fans can also be operated, with the HEPA system bypassed, to provide underground ventilation requirements, when needed.

There are two modes of operation:

- **Normal mode**. During normal operation, five different levels of ventilation can be established to provide five different airflow quantities.
    - **a. Normal ventilation**. Two main exhaust fans operating to provide an approximate flow of 425,000 scfm unfiltered.

b. **Alternate ventilation.** One main exhaust fan operating to provide an approximate flow of 260,000 scfm unfiltered.
c. **Reduced ventilation.** Two filtration fans operating as ventilation fans provide an approximate flow of 60,000 scfm each unfiltered.
d. **Minimum ventilation.** One filtration fan operating as a ventilation fan to provide an approximate flow of 60,000 scfm unfiltered.
e. **Maintenance ventilation.** Simultaneous operation of one or two main ventilation fans

- **Filtration mode**. This mode mitigates the consequences of an underground waste handling accident by directing the underground effluent through HEPA filters located on the surface in the Exhaust Fan Building. This mode also reduces the airflow in the underground. Filtration is activated automatically on a high radiation signal from one of the Continuous Air Monitors in the exhaust of the active disposal panel or manually by the Central Monitoring Room operator. During shift to filtration, the main exhaust fans are shut down and their associated isolation dampers close slowly, between 60 and 90 seconds, to minimize the effects of any pressure pulse back through the system. In filtration mode, the underground exhaust air passes through two identical HEPA filter assemblies located in the EFB. The filters remove airborne radioactive particulates that may result from a breach of waste containers before the air is discharged to the atmosphere.

2. Use of Vehicle Horns in the underground to alarm individuals of approaching vehicles

The IAEA-GEOSAF Operational Working Group also noticed that vehicles approaching corners, intersections, etc. use a horn to notify other operators/personnel that they are coming to the intersection. This is a safety feature that suffices to alert unknowing individuals in the area that a vehicle is approaching. Using this methodology as a safety feature greatly reduces risk of collision and/or injury in the underground environment. Electric carts are used for transportation, and a formal training program exists to ensure that individuals meet qualifications rand requirements to operate the electric carts at WIPP. Also, when parked, the cart must be chocked by placing a metal braking block on a wheel. This prevents an unmanned vehicle from movement to prevent a collision or rolling onto a worker resulting in an accident or injury.

3. Dry Chemical Fire Suppression in the underground at the location of the fuel depot

The group also discussed the fuel depot located in the underground with specific reference to the dry chemical fire suppression system in that area. The fire suppression system uses a dry chemical to suppress the fire until the fire brigade can be on seen to fight the fire. The overall philosophy of fire suppression at WIPP is a system to keep small fires from becoming large until the fire brigade can come on scene to extinguish the fire. The dry chemical system can be manually or automatically operated and is tested per U.S. fire protection practices.

APPENDIX II: General Hazards Matrix

Hazards & safety issues are identified through various sources relevant to a GD: industrial facilities, underground facilities such as mines or tunnels, and nuclear facilities. The OPS working group worked extensively to identify those hazards.

For instance, the group consolidated the following matrix after gaining feedback from mine operators (AngloGold Ashanti from RSA and Cameco from Canada) and a regulatory body (CSNC from Canada):

Hazards	Conventional Mines (e.g. Moab Khotsong)	High grade Uranium Mines (e.g. Mc Arthur River)	Control and mitigation measure in Mines	Nuclear facilities (waste management)	Relevance to Deep Geological Repositories
Radiation	Not applicable	Sources: radon, dust, gamma exposures	Ventilation, mining methods, shielding, freezing,	Waste packages Spent fuel → shieding and ventilation → procedures	Handling of used fuel containers towards emplacement constitutes radiation hazard
Criticality				Package design Facility design Administrative controls	Package design Facility design Administrative controls
Stability of shafts and galleries	Yes. Ore bodies are usually associated with fractured rocks with relatively high in-situ stress	Yes. Ore bodies are usually associated with fractured rocks with relatively high in-situ stress	Ground control measures: bolting, meshing, arches, shotcreting Monitoring for rock deformation	Not relevant	Ground instability would be less of a problem. DGR are usually associated with competent and sparsely fractured rocks. However, there is a need to control damage zones induced by excavation, and subsequent heat loss. For LT safety : optimize use of foreign materials for reinforcement→ balance operational safety and LT safety
Internal Flooding	Yes in general, since ores are associated with fractured rocks. However at Moab Khotsong, not an issue, since the rock is not saturated .	Yes. High water inflows rates associated with fractured rock.	Pumping capacity; freezing; grouting.	Breach on circuit Fire extinction	Less of a hazard. Most of DGR are located in low permeability rocks but non controlled inflow can cause flooding (granite site)
External flooding				Depending on site → siting, site protections (fences, dams)	Need to be addressed in selecting site or in designing the accesses to disposal (shafts or acces ramp)
Fire	Yes. Sources: flammable gas, blasting operations, electrical and fuel sources,	Yes but not as significant. Sources: burning vehicles, electric cables.	Refuges; ventilation; personal equipment, sectioning with fire resistant walls, fire extinguishers, good housekeeping, use of low toxicity and fire retardant cables, more than one shaft for escape, emergency drills, etc…	flammable gas, electrical and fuel sources. (risk handled through : limitation of burning load + fire detection system+ fire fighting systems + fire compartments)	Fire hazard could be as relevant to DGR. Sources could be comparable to UG mines. Same protection and mitigation measures as UG mines could be applied. Optimization between Operational Safety and post-closure safety wrt number and location of accesses to surface

Explosion	Blasting operations,	Blasting operations,	Blast resistant walls, strict procedures for handling explosives,	Gazes from waste (control of materials in WP)	If excavated in phases, proper procedures for separation of disposal and excavation activities Natural flamable gases + gazes generated by waste
Earthquake	Mining at great depths in high in-situ stress environment can trigger movements of faults, that generate earthquakes. Also, if mine is located in seismic zones, earthquakes can also occur naturally and affect mine stability.	Not as relevant, since depths are less important, and rock is less brittle. For Mc Arthur, the mine is located in a low seismic zone.	Control the mining rates; try to configure the tunnels so that mining does not get too near a fault,… Depending on the epicentral distance, usually underground structures are less vulnerable to seismic activity.	Siting, system and structure design	Excavation induced seismicity would be relevant for granite compared to sedimentary rocks. Depth of a repository should be chosen with due considerations of isolation and containment functions versus magnitude of in-situ stress . In most countries, repositories would be sited in low seismic zones. Design repository to resist earthquakes.
Hoisting equipment failure / elevator blocking	Yes, potential hazard	Yes, potential hazard	Prevention: Handling procedures, single failure proof hoisting machinery; maintenance/good housekeeping.	Prevention : : Handling procedures, single failure proof hoisting machinery; maintenance/good housekeeping. And mitigation : ventilation	Yes, both conventional and radiological in case WP is handled. In this case: mitigation: ventilation/procedures/section closure, refuges…
Ageing	Yes, long operation, infrastructure degrades as function of time	Yes, long operation, infrastructure degrades as function of time	Maintenance, inspection, repair/replacement	Maintenance, inspection, repair/replacement	Yes, operation for possibly more than century. Should be addressed
Decomissioning and impact of operational activities (including e.g. utility infrastructure) on post-closure safety	Reduce impact of mining activity on environment, so decommissioning is relevant	Reduce impact of mining activity on environment, so decommissioning is relevant	Surface infrastructures should be dismantled; mine wastes should be managed with consideration of post-closure environmental impact; underground openings should be backfilled to reduce likelihood of surface subsidence,etc.		Yes, all related to post-closure safety. Mining technique, ventilation,… has impact on post-closure safety. Backfill/buffer. Dismantle operational infrastructure and impact of remains on post-closure safety. Should be addressed in Safety assessment.
Breach of security	Arson, sabotage, theft of valuable materials and equipments,…	Arson, sabotage, theft of valuable materials and equipments,…	controlled access; security screening of workers and visitors		Arson, sabotage, theft of valuable materials and equipments, … are all relevant. In addition, needs security and safeguards measures wrt radioactive materials. Sabotage of LT term site properties

APPENDIX III: A generic example from WIPP (US)

GENERIC EXAMPLE OF THE WIPP PROCESS OF HAZARDS IDENTIFICATION, EVALUATION, AND CONTROL APPLICATION PERTAINING TO A FIRE IN THE UNDERGROUND

Methodology

At the Waste Isolation Pilot Plant located near Carlsbad, New Mexico – USA, fires in the underground have been identified as one of many hazards. Standard Industrial Hazards are identified also, however particular to the operation of a deep geologic repository, waste is emplaced for disposal by diesel powered equipment that requires combustible fuel. One event postulated is a fuel pool fire as a result of several accident scenarios and is the topic of this writing.

Table 1, below identifies hazards commonly expected for waste operations for deep geologic repositories and surface waste preparation facilities. The fire event described in this writing has a hazard source and material group identified in the first 7 groups under fires in the Hazard Sources and Potential Events in Table 1.

The listing in the table below represents major hazard sources and material groups that *could* be potential initiators for specific accident events to be discussed in the safety report. Wherever these hazards are present in a given waste operation an analysis must evaluate the applicability of the corresponding accident event(s). It is important to note that hazards identified in above table do not always result in accidental release of radiological materials or hazardous chemicals. Depending on the location and specific characteristics of the hazard, it may be considered a Standard Industrial Hazard. Standard Industrial Hazards can be defined as a hazard that is:

> *. . . routinely encountered in general industry and construction, and for which national consensus codes and/or standards exist to guide safe design and operation without the need for special analysis to design safe design and/or operational parameters/*

It is not the intention of the safety report to provide analysis of SIH type of hazards. Rather, hazards in the table above are evaluated to the extent that they act as initiators and contributors to accidents that result in a radiological or chemical release. Applying appropriate levels of hazard screening during the hazard identification process can be helpful in distinguishing between SIH and those that must be evaluated by the safety report.

Now that the source is identified, the hazard identification process progresses to a particular mode of operation that involves a diesel powered vehicle such as a transport vehicle, forklift, etc. that is involved in an accident that results in a spillage of fuel from the fuel tank and that fuel pools under the vehicle or can spread to the material at risk (waste). Once the event is identified and a comprehensive identification of all known hazardous material and energy sources coupled with diesel powered equipment operated in the underground is completed, the hazard evaluation process and accident analysis can be performed. This effort includes the event categorization, identification of event cause(s), assignment of event frequency and unmitigated consequence level, and identification of potential mitigative and preventive features.

Table 1

Hazard Sources and Potential Events

Hazard Source and Material Groups	Potential Accidents
Electrical	Fires - In combination with combustible/flammable material Explosions
Thermal	Fires - In combination with combustible/flammable material Explosions In combination with explosive material. Criticality Increased concentration
Pyrophoric Material	Fires - Pyrophoric fire; may serve as ignition source for larger fires and explosions when in combination with explosive material
Spontaneous Combustion	Fires - May serve as ignition source for larger fires Explosions - In combination with explosive material
Open Flame	Fires - In combination with combustible/flammable material Explosions (Events 5-8) - In combination with explosive material
Flammables	Fires - In combination with ignition source
Combustibles	Fires - In combination with ignition source
Kinetic Energy (Linear and Rotational)	Loss of Confinement/Containment - Impacts, acceleration/deceleration, missiles Criticality - Loss of configuration or spacing
Potential Energy (Pressure)	Loss of Confinement/Containment - Impacts, missiles Criticality - Loss of configuration or spacing
Potential Energy (Height/Mass)	Loss of Confinement/Containment - Impacts (falling objects), dropping Criticality - Loss of configuration or spacing
Internal Flooding Sources	Loss of Confinement/Containment - Ground/surface water runoff Criticality - Increased moderation
Physical	Loss of Confinement/Containment - Puncture, dropping
Radiological Material	All Events - Potentially releasable material
Hazardous Material	All Events - Potentially releasable material
Ionizing Radiation	Direct Exposure - Direct exposure to worker
Non-Ionizing Radiation	Direct Exposure - Direct exposure to worker Other - May interfere with equipment operation
Fissile Material	Criticality
Non-facility Events	External Initiated Event
Vehicles in Motion (external to facility)	External Initiated Event
Natural Phenomena	Natural Phenomenon Hazard (NPH) Events

However, before beginning the evaluation, the *initial conditions* for the facility in question are postulated. Initial conditions are specific conditions that are a part of facility operations or parameters used in the analysis. Initial conditions may include assumptions, inventory information and specific passive features (i.e., no mechanical or human involvement) such as the facility construction.

Once the initial conditions are known, a hazard evaluation process begins by investigating the *unmitigated* results and then *mitigated* (controls). The scope of the hazard evaluation in this scenario includes the following:

- Performed in an *unmitigated* manner to determine the risks (frequencies and/or consequences) involved with the facility and its associated operations without regard for any safety controls or programs. *Unmitigated refers to the determination of the frequency and consequences without credit given for preventive or mitigative features other than the specified initial conditions and assumptions regarding facility inventory*.

During the hazard evaluation process the material at risk reflects the available hazardous inventory that can be acted upon during the postulated event and no credit is taken for any controls; however, the laws of physics are applied.

This particular hazard evaluation and accident analysis identified several additional events that were similar to the primary pool fire event, and thus are added to the evaluation and analysis. The identified hazardous events are then binned into like events using the minimum set of events using Table 2 below as a guide. The hazard evaluation with the highest risk ranking from each event bin is selected as the ***bounding*** event for the event bin and is assigned a unique alpha-numeric designator and as the HE event scenario. The other events were retained as representative events for the event bin. When the event required further analysis and possible control selection, the bounding hazardous event is evaluated first for further evaluation and control selection.

Now we select our controls to mitigate the event. The controls are then evaluated for completeness by evaluating their effectiveness to reduce the likelihood or consequences of any representative events in the bin that also had an unacceptable risk rank or a public high consequence level. If the controls are determined to be inadequate to reduce the risk of the representative events, additional controls are selected to reduce the risk rank of the events to an acceptable level.

The hazard analysis and hazard evaluation of events are collected and organized into a single hazard evaluation table that represents both the waste handling processes as well as other facility process areas. For these events the following are included:

- ✓ **Event number** is a unique identification number provided for tracking the event through analysis and also for easily identifying the event when in reference to a specific accident scenario under consideration.
- ✓ **Event description** includes a brief description of a postulated HE event
- ✓ **Initiating frequency level** is a qualitative or semi-quantitative process that involves assigning a frequency level to each event in the HE table
- ✓ **Unmitigated consequence level** are evaluated at the following receptor locations to assess health effects associated with the postulated event
- ✓ **Preventive features** are features expected to *reduce the frequency* of a hazardous event
- ✓ **Mitigative features** are any features expected to *reduce the consequences* of a hazardous event

Table 2

Minimum Waste Activity/Hazard Evaluation Event Matrix

Hazard Evaluation Event[1]	Character-ization	Container Handling[2]	venting &/or Abating/ Purging	Staging and Storage	Retrieval and Excavation	Waste Repack-aging	Container Loading/ Unloading
Fire Events							
Fuel Pool Fire		X		X	X		X
Small Fire	X	X	X	X	X	X	X
Enclosure Fire	X		X			X	
Large Fire	X	X	X	X	X	X	X
Explosion Events							
Ignition of Fumes Results in an Deflagration/Detonation (external to containe		X			X	X	X
Waste Container Deflagration)	X	X	X	X	X		
Multiple Waste Container Deflagration	X	X	X	X	X		
Enclosure Deflagration	X		X			X	
Loss of Confinement/Containment							
Vehicle/Equipment Impacts Waste/Waste Containers		X	X	X	X	X	X
Drop/lmpact/Spill Due to Improperly Handled Container, etc.		X			X	X	X
Collapse of Stacked Containers		X	X	X			
Waste Container Over-Pressurization	X	X	X	X	X		
Direct Exposure to Radiation Events	X	X	X	X	X	X	X
Criticality Events	X	X	X	X	X	X	
Externally Initiated Events							
Aircraft Impact with Fire	X	X	X	X	X	X	X
External Vehicle Accident	X	X	X	X	X	X	X
External Vehicle Accident with Fire (Combustible or Pool)	X	X	X	X	X	X	X
External Explosion	X	X	X	X	X	X	X
External Fire	X	X	X	X	X	X	X
NPH Initiated Events							
Lightning	X	X	X	X	X	X	X
High Wind	X	X	X	X	X	X	X
Tornado	X	X	X	X	X	X	X
Snow/lce/Volcanic Ash Build-up (Event 23)	X	X	X	X	X	X	X
Seismic Event (Impact Only)	X	X	X	X	X	X	X
Seismic Event with Fire	X	X	X	X	X	X	X

The result of this effort is a table such as Table 3 below which describes the event and associated events. In this case, we identified three possible accident scenarios that involve a fire in the underground.

1. Fuel Pool Fire (Event 1)
2. External vehicle accident with fire (combustible or fuel pool) (Event 17)
3. If vehicle impact is the initiator of this event, controls from vehicle/equipment impacts with waste/waste containers (Event 9) must be added.

Minimum control functions are determined and listed. Three minimum control functions are identified: 1) limit the fire size, 2) separate the material at risk from the fuel, and 3) minimize releases. The preferred control to limit the fire size (item 1) is to ensure an automatic fire suppression systems is in place OR limit the amount of fuel permitted in the vehicle. The material at risk can be separated from the fuel bu grading and sloping berms in the underground or providing vehicle barriers (stop vehicles from close proximity to the material at risk). Item 3 minimizing releases can be addressed by ensuring an operational confinement ventilation system.

However, alternative controls are also identified and recommended. In this case, alternative fire protection controls, which are approved by a qualified fire protection engineer, are implemented to reduce the fire size such as limiting flammables and combustibles. Also, to separate the material at risk from the fire, rerouting vehicles, creating a stand off distance, and establishing refuelling locations away from the material at risk. Spacing and fire breaks are used to minimize releases and also limiting of the fuel and material at risk.

The final area that needs addressed is to provide reference to relevant criteria and discussion such as; regulatory requirements, standards, national safety codes, and a discussion if necessary concerning systems for clarification.

***General Example* of Methodology concerning a Fire Event in the Underground**

Accident	Minimum Control Functions	Preferred Controls	Alternative Controls	Relevant Criteria/Discussion
Fuel Pool Fire (Event 1) External Vehicle Accident with Fire (Combustible or Pool) (Event 17) If vehicle impact is the initiator of this event, controls from Vehicle/Equipment Impacts Waste/Waste Containers (Event 9) must be added	Limit fire size (P)	Automatic Fire Suppression System (FSS) OR Vehicle Fuel limit	Alternate fire protection controls approved by qualified fire protection engineer (e.g., flammables and combustibles limit)	DOE O 420.1B Note 1: FSS is not applicable to outside pool fires. Facilities with potential for indoor pool fires should consider both Preferred Controls. Note 2: These controls are expected to be supplemented by the overall Fire Protection Program suite of controls to prevent or mitigate accidents (e.g., flammable and combustible limits).
	Separate the MAR from fuel (P)	Grading and sloping; berms; vehicle barriers	Control vehicle route; stand off distance; establish refueling location;	
	Minimize releases (M)	Non-combustible containers AND	Spacing, fire breaks	
		Confinement Ventilation System (CVS)	MAR limit and/or vehicle fuel limit	CVS defined in DNFSB 2004-2 (Indoor activities only)

APPENDIX IV: Presentation made by IRSN on fire

IRSN
INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE
Faire avancer la sûreté nucléaire

IAEA Technical meeting GEOSAF

16 to 20 May 2011

IRSN approach on fire safety analysis of nuclear facilities

Yannick ORMIERES

IRSN approach on nuclear fire safety analysis

- **Position on the management of fire safety analysis in nuclear installations by specifying:**
  - the fire risk analysis process
  - the demonstrative elements expected in terms of nuclear safety

Fire safety analysis for nuclear facilities IRSN 2

Bases of reflexion

- **Take into account the whole of the effects of the fire**
  Effects of the fire often restricted at the temperature of gases
  - Smoke:
    - Dysfunctions of equipments
    - Toxicity, visibility…
  - Thermal radiant flux
  - Variations of pressure related to fire (~daPa)…

- **Evolution of the state of the art in the field of fire analysis**
  - Performance-based approach
    - Evolutions of French legislation
    - National or international standards (AFNOR, ISO…)

Fire safety analysis for nuclear facilities IRSN 3

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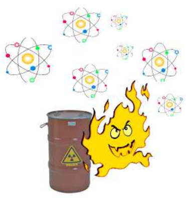
Process for fire safety analysis

Fire and Nuclear safety considerations

- **Fire could damage structures, systems and components (SSCs) important for safety**
- **Fire could spread out radiological materials**

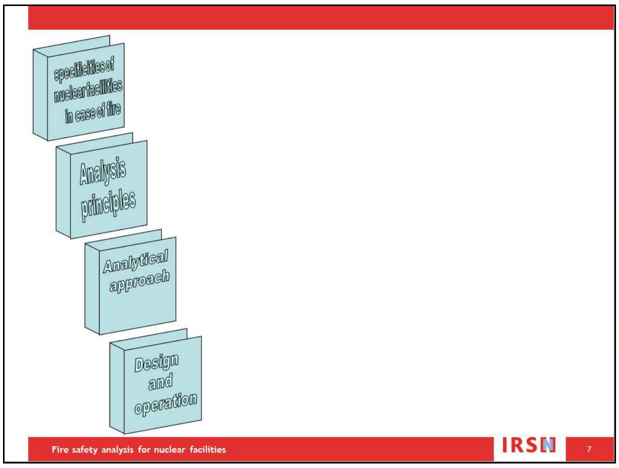


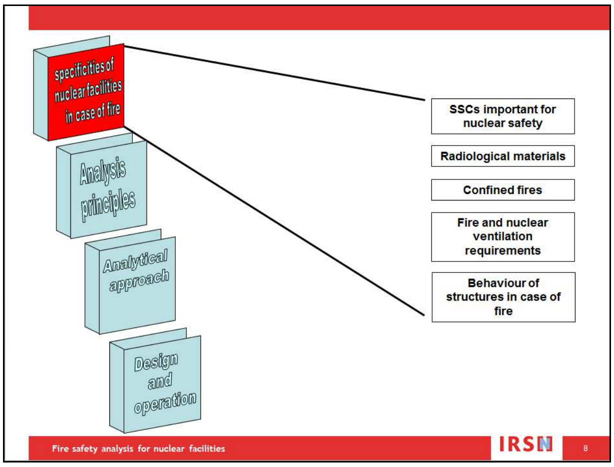
Fire safety analysis for nuclear facilities IRSN 5

Fire safety analysis of a nuclear facility

- **The fire analysis aims to achieve the highest possible level of safety**
  1. Take into account safety goals specific to the studied facility (to maintain functions important for safety, to protect SSCs…)
  2. Identify fire hazards
     - By a deterministic method
     - Probabilistic method is used for external hazards that the operator does not control: industrial environment of the nuclear facility, external road or railroad hazards (e.g. LPG truck explosion on an external road)…
  3. Justify the adequacy of fire protection measures in case of fire
  4. Estimate consequences on facility safety in case of fire for degraded situations

Fire safety analysis for nuclear facilities IRSN 6





Specificities of nuclear facilities

SSCs important for nuclear safety
- Fire can damage nuclear risk (criticality, irradiation…) protection measures
- Fire smoke is toxic and could affect staff with safety actions to achieve

Radiological materials
- Dispersion hazards
  - Fire could cause an airborn release of radiological materials
  - Liquid extinguishing agents could be contaminated
- Criticality

Fire safety analysis for nuclear facilities IRSN 9

Specificities of nuclear facilities

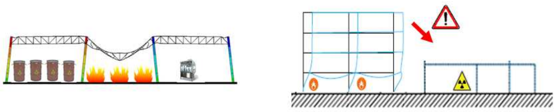
Confined fires
- The prevention of risks involving the uncontrolled dispersion of radioactive materials in the atmosphere is based on containment systems
  - These systems can amplify the effects of fire
  - The production of unburned gas generated by under-ventilated fire, due to containment, is a significant risk of smoke explosion and fire spread by ignition of unburned gas (in particular by ventilation system)

Nuclear ventilation in case of fire
- The pressure and temperature, increase together with the smoke produced by fire, can disorganize air circulation in the facility and destroy the ventilation filters. Release to the environment could then ensue.

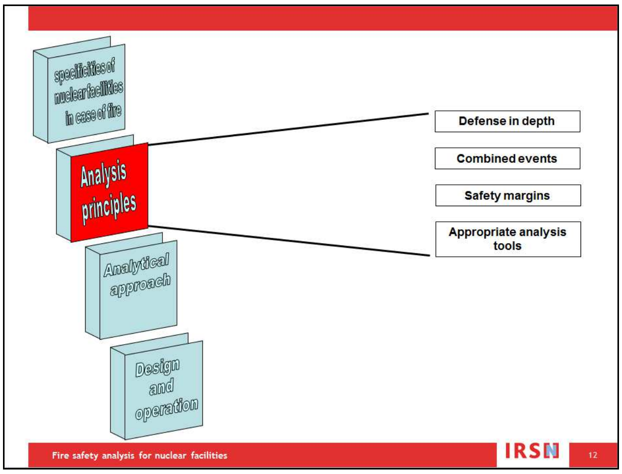
Fire safety analysis for nuclear facilities IRSN 10

Specificities of nuclear facilities

Behaviour of structures in case of fire
- Fire stability of structures housing or supporting safety targets must be guaranteed for the duration required to implement and maintain the facilty in a safety state
- This stability means for a fire occurring within or outside safety buildings, considering the consequences of possible interactions due to a fire developing in adjoining buildings.



Fire safety analysis for nuclear facilities IRSN 11



Principles to include in a safety demonstration

Defense in depth (1/2)

- Defence in depth is implemented primarily through the combination of a number of consecutive and independent levels of protection:
  - prevention of abnormal situations
  - preventing their degradation
  - limitation of their consequences
- Fire defence in depth levels:
  - Preventing fires from starting
  - Detecting and extinguishing quickly those fires which do start, thus limiting the damage;
  - Preventing the spread of those fires which have not been extinguished, thus minimizing their effects on essential plant functions

Principles to include in a safety demonstration

Defense in depth (2/2)

- It is a deterministic method, since a certain number of incidents and accidents are postulated
- When properly implemented, defence in depth ensures that no single technical, human or organizational failure could lead to harmful effects, and that the combinations of failures that could give rise to significant harmful effects are of very low probability [IAEA SF-1]

Principles to include in a safety demonstration

Combined events

- Occurrence of events that affect an installation in the same time interval. If there are no link between these events, they are know as independent :
  - Fire and other dependent events
    - » Earthquake and fire,
    - » Explosion and fire…
  - Fire and other INdependent events is postulated
    - in conjunction with each event with a high frequency rate that is likely to affect fire protection measures:
      - » winter conditions (freeze, snow…)
      - » Lost of offsite power…
    - after an event durably degrading the safety of the installation without compensatory provisions

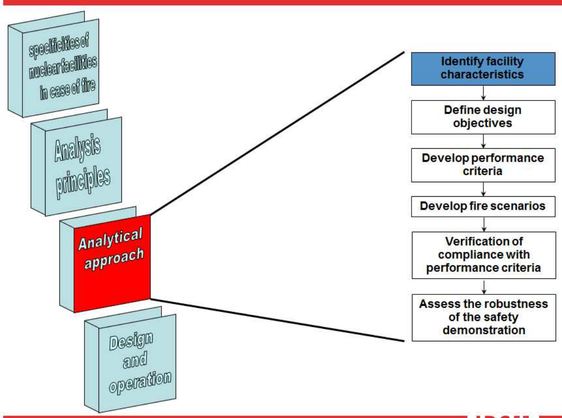
Other principles

Appropriate fire model depend on:

- Studied fire scenario
- Available input parameters
- Expected outcomes

Take into account margins and uncertainties on

- Input data or parameters
- Outcomes



Identify facility characteristics

Basic characteristics

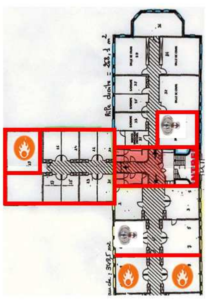
- Type of construction
- Number of floors
- Processes
- etc.

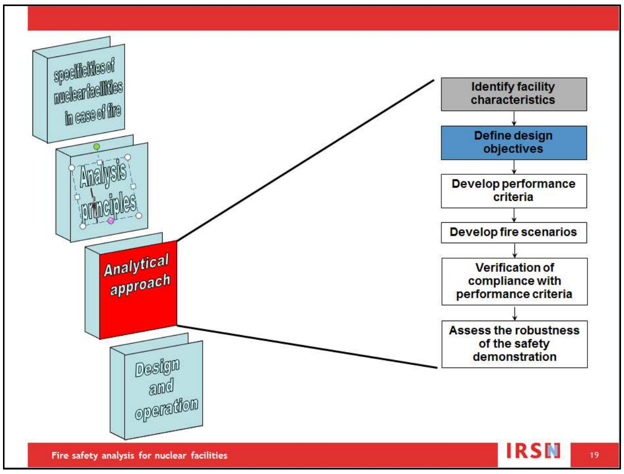
Identify fire loads

- Electrical rooms
- Flammable liquids
- Transient fire loads
- etc.

Fire protections measures

- Fire detection systems
- Fire compartments/walls
- Sprinklers
- etc.




specificities of nuclear facilities in case of fire
Analysis principles
Analytical approach
Design and operation
Identify facility characteristics
Define design objectives
Develop performance criteria
Develop fire scenarios
Verification of compliance with performance criteria
Assess the robustness of the safety demonstration
Fire safety analysis for nuclear facilities
IRSN
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Define safety targets in case of fire
Identify objectives
Nuclear safety
Radiation release
Life safety
Interruption
Define « targets » to be protected from the fire to achieve these objectives:
Radiological materials
nature and physical status (gas, liquid, solid)
quantity
Structures, systems and components important for safety
identification of equipment taking part of safety functions
redundancy identification
Personnel
etc.
Fire safety analysis for nuclear facilities
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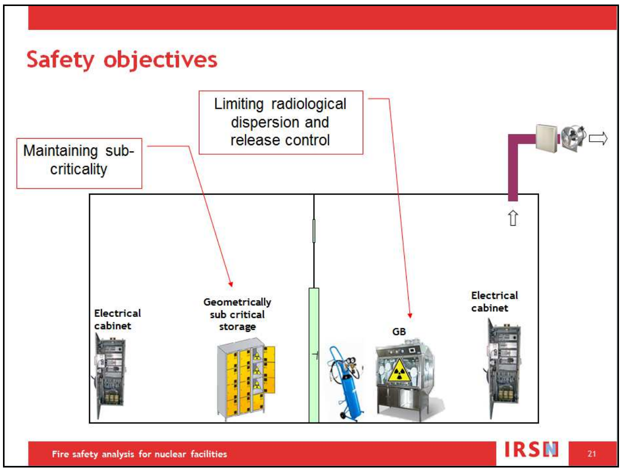
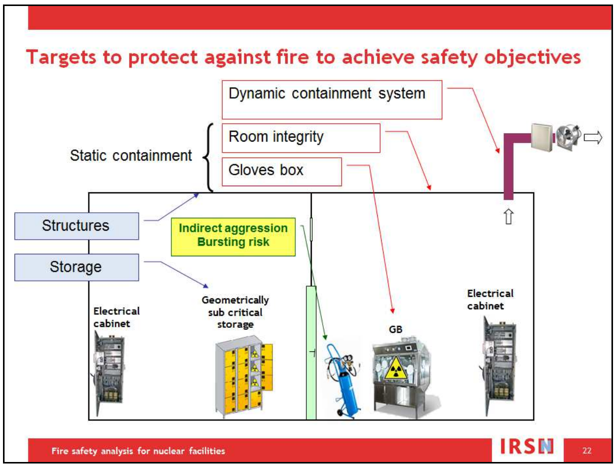
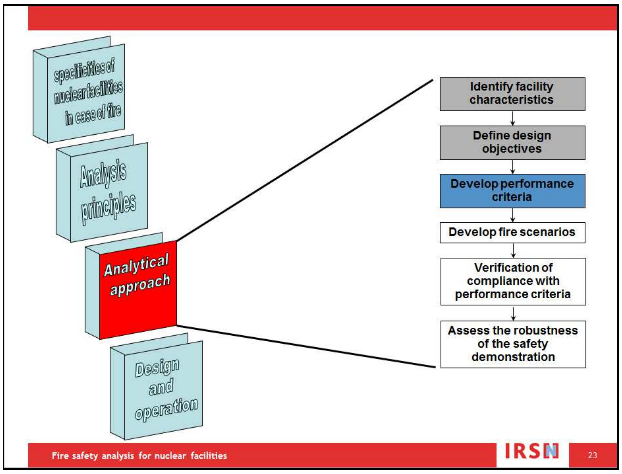

Safety objectives
Limiting radiological dispersion and release control
Maintaining sub-criticality
Electrical cabinet
Geometrically sub critical storage
GB
Electrical cabinet
Fire safety analysis for nuclear facilities
IRSN
21


Targets to protect against fire to achieve safety objectives
Dynamic containment system
Static containment
Room integrity
Gloves box
Structures
Indirect aggression
Bursting risk
Storage
Electrical cabinet
Geometrically sub critical storage
GB
Electrical cabinet
Fire safety analysis for nuclear facilities
IRSN
22


specificities of nuclear facilities in case of fire
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Define design objectives
Develop performance criteria
Develop fire scenarios
Verification of compliance with performance criteria
Assess the robustness of the safety demonstration
Fire safety analysis for nuclear facilities
IRSN
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Performance criteria
To adapt fire protection measures to the vulnerability of the safety targets
Vulnerability
Fire safety analysis for nuclear facilities
IRSN
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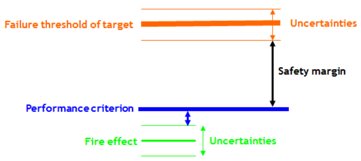
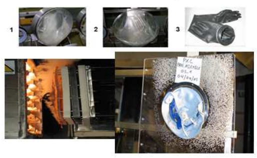
Performance criteria

- Definition of performance criteria is based on goals and given the vulnerability of targets to the effects of fire. For example, performance criteria might include values for thermal radiation exposure (kW/m²) or air temperature.
- These criteria will be used to evaluate the designs proposed by the operator.
- These criteria are associated with meeting the safety objectives, they are determined with margins.

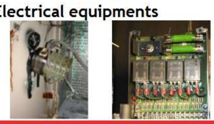


Result of real tests

- Glove box componants



- Electrical equipments

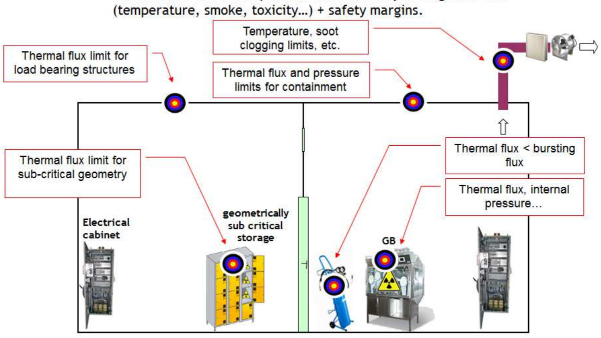


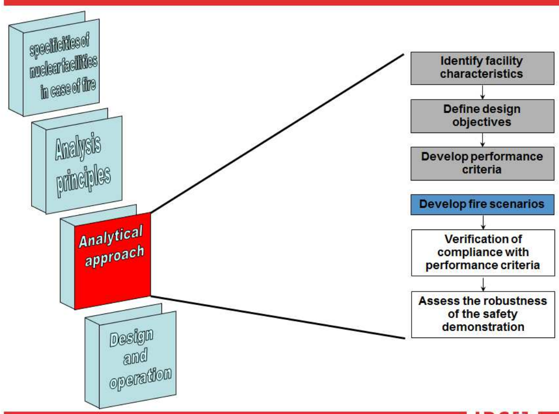
- HEPA filters

- Drums

Performance criteria

- Performance criteria depend on the sensitivity of targets to fire (temperature, smoke, toxicity…) + safety margins.





Identification of possible fire scenarios

Ignition is postulated

- A fire is by definition an accidental event that occurs only in abnormal operating conditions. It makes no sense to say that nothing can burn because it refers only to normal operation.
- The feedback shows that the risk of a fire is important

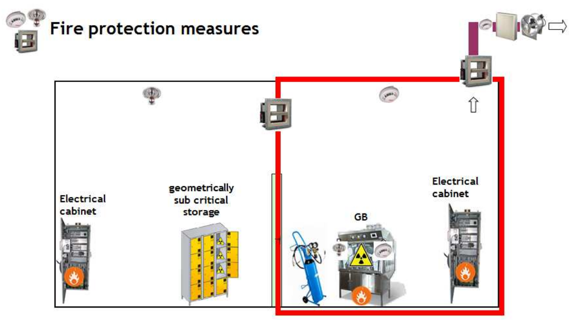
Consider operating conditions of the facility

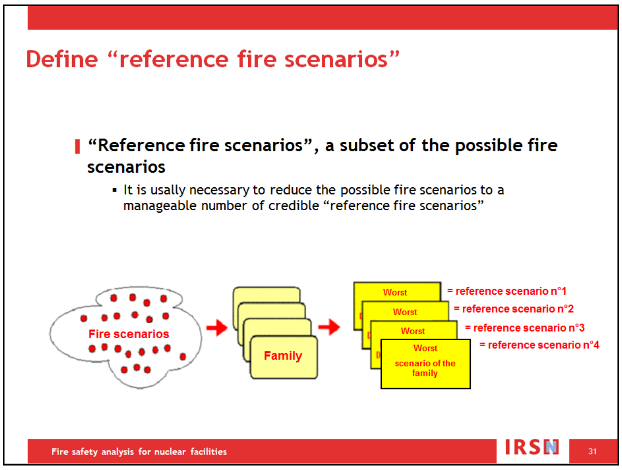
- Normal operating conditions
- Reduced power operation
- Scheduled maintenance or shutdown
- etc.

Take into account combined events with fire

Fire Scenarios

- Hazard fire sources
- Fire protection measures




Define “reference fire scenarios”
“Reference fire scenarios”, a subset of the possible fire scenarios
It is usally necessary to reduce the possible fire scenarios to a manageable number of credible “reference fire scenarios”
Fire scenarios
Family
Worst
= reference scenario n°1
= reference scenario n°2
= reference scenario n°3
= reference scenario n°4
Worst scenario of the family
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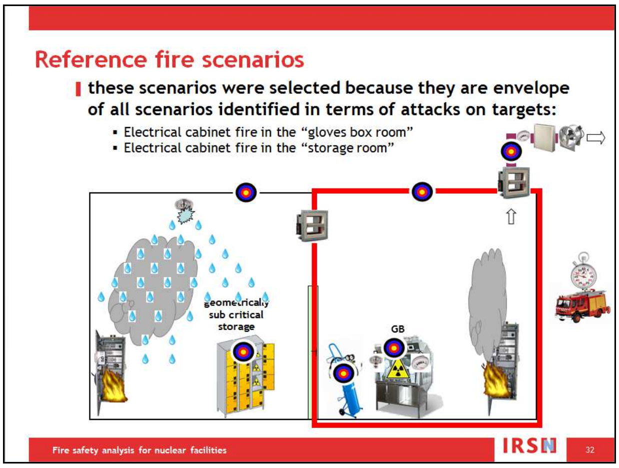
Reference fire scenarios
these scenarios were selected because they are envelope of all scenarios identified in terms of attacks on targets:
Electrical cabinet fire in the “gloves box room”
Electrical cabinet fire in the “storage room”
geometrically sub critical storage
GB
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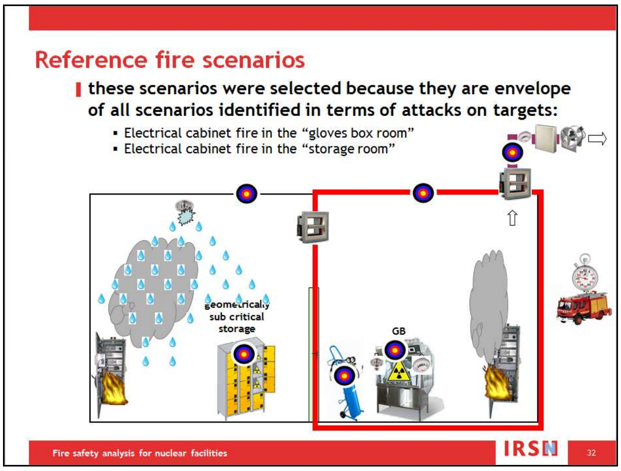
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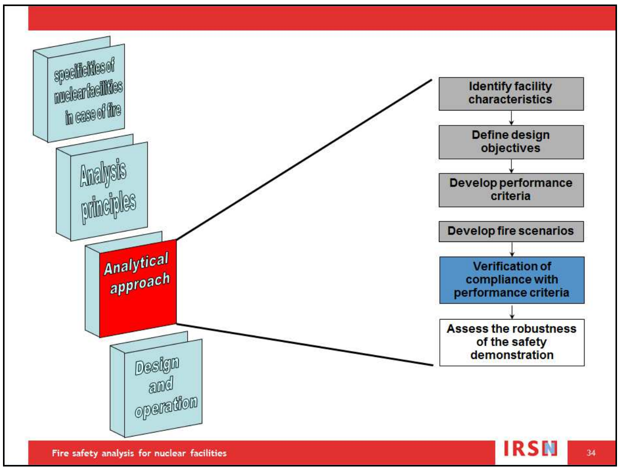
specificities of nuclear facilities in case of fire
Analysis principles
Analytical approach
Design and operation
Identify facility characteristics
Define design objectives
Develop performance criteria
Develop fire scenarios
Verification of compliance with performance criteria
Assess the robustness of the safety demonstration
Fire safety analysis for nuclear facilities
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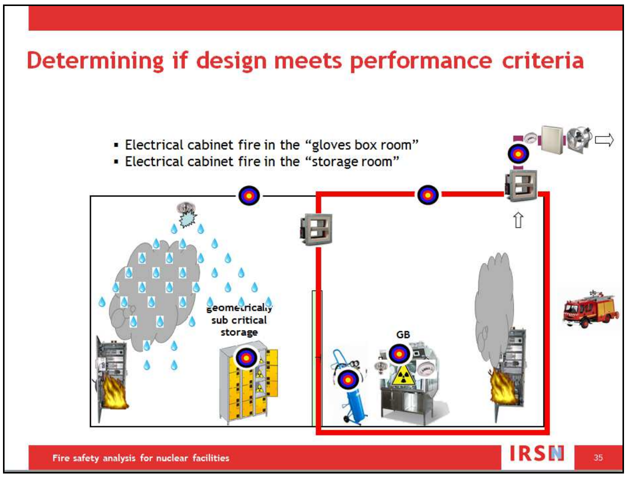
Determining if design meets performance criteria
Electrical cabinet fire in the “gloves box room”
Electrical cabinet fire in the “storage room”
geometrically sub critical storage
GB
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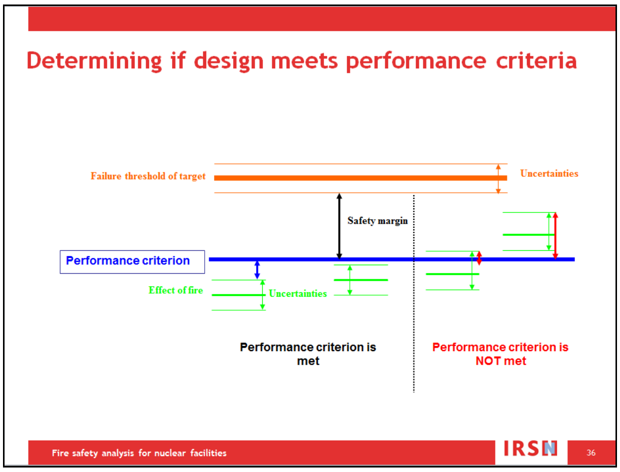
Determining if design meets performance criteria
Failure threshold of target
Uncertainties
Safety margin
Performance criterion
Effect of fire
Uncertainties
Performance criterion is met
Performance criterion is NOT met
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Determining if design meets performance criteria

Storage room

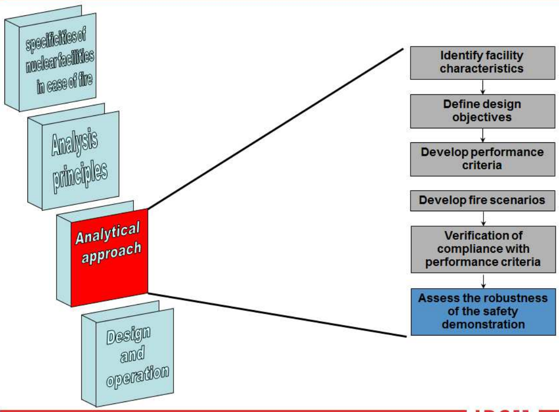
- Performance criteria
  - Sub critical storage
    - 400 °C : safe geometry
  - Room structure
    - (T°, t) : structure resistance
- Fire scenario effects = 50 °C :
  - performance criteria are met

Glove box room

- Performance criteria
  - Target 1: gloves box (nuclear containment)
    - 100 °C, 2 kW/m²
  - Target 2: dynamic containment system
    - 180 °C, ΔP(filter)=1800 Pa
  - Target 3: room structure
    - fire thermal flux < walls thermal flux resistance
- Fire scenario effects
  - 70 °C ; 0,5 kW/m² -> GB performance criteria are met
  - 150 °C (fire code) ; 1000 Pa (test) -> DC performance criteria are met
  - Structure performance criteria are met

All performance criteria are met

For studied reference fire scenarios, it is demonstrate that fire protection measures protect targets.



Assess the robustness of the safety demonstration

The failure of fire protection measures can lead to fire scenarios more severe than design fire scenarios.

- So, performance criteria could not be respected.

"When properly implemented, defence in depth ensures that no single [...] failure could lead to harmful effects, and that the combinations of failures that could give rise to significant harmful effects are of very low probability" [IAEA SF-1]

This stage consists in checking the robustness of the safety demonstration by making sure that the consequences for safety remain acceptable in spite of:

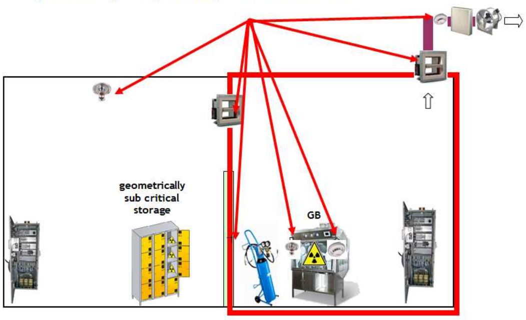
- failure of a fire protection measure
  - Deterministic approach
  - Probabilistic approach
- "Maximum possible fires" = both automatic systems fail and the fire brigade does not respond.

Assess the robustness of the safety demonstration

- Deterministic approach
  - Study the consequences of a fire with each passive or active fire protection system individually rendered ineffective
    - Check that none of these failures lead to a fire whose effects would generate a questioning of performance criteria.
    - If necessary (if performance criteria are not meet), it is advisable to assess the consequences for the safety of this resulting fire and to check that they don't lead to unacceptable consequences.
- Probabilistic approach
  - probabilistic assessment of fire protection failures
    - Assess the total frequency of fire protection failure
    - Assess the contribution of each fire protection measure on the total frequency
    - Radiological consequences

Assess the robustness of the safety demonstration

- Study the consequences of a fire with each passive or active fire protection system individually rendered ineffective



Assess the robustness of the safety demonstration

Storage room

- **Performance criteria**
  - Sub critical storage
    - 400 °C : safe geometry
  - Room structure
    - (T°, t) : structure resistance
- **Fire scenario effects** = 300 °C (sprinkler failure) :

Performance criteria are met despite fire protection failure

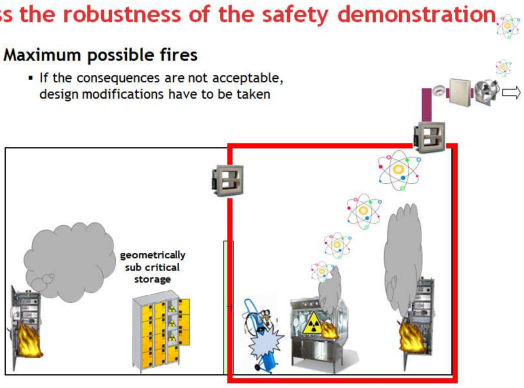
GB room

- **Performance criteria**
  - Dynamic containment system
    - 180 °C, ΔP(filtre)=1800 Pa
  - Gloves box (containment)
    - 100 °C, 1 kW/m²
  - Room walls
    - (T°, t) : walls integrity
- **Fire effects in case of one fire protection failure**
  - 180 °C (fire tools), 1000 Pa (test) : « dynamic containment » criteria are meet
  - 300 °C : « GB » criteria are not meet (GB extinguishing system failure)

If the consequences are not acceptable, design modifications have to be taken

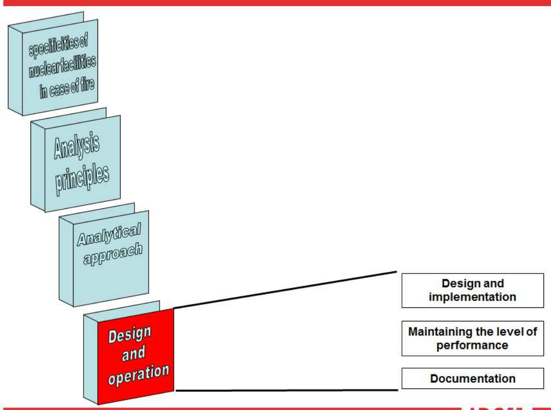
Assess the robustness of the safety demonstration

- **Maximum possible fires**
  - If the consequences are not acceptable, design modifications have to be taken



Process for fire safety analysis

- **There is a progression in our analysis process**
  - Basic fire scenarios
    - References fire scenarios
  - Degraded fire scenarios
    - Failure of fire protections measures
    - Maximum possible fire scenarios
- **Defense in depth approach**
  - Several levels of protection => several levels of analysis



Fire protections design and implementation

- **Check that fire protection measures are designed to meet**
  - the requirements determine in the safety demonstration
  - the fire protection design brief (given the combination of events to take into account)
- **The design should take into account the effects of aging, the life cycle of the facility and the environmental conditions**
- **Putting-into-service tests must be realized**
- **Feasibility and operational effectiveness of organizational measures have to be validate**

Operations and maintenance

- **Ensure that the performance of the fires protections in place are sustainable (availability, integrity…).**
  - Testing plan includes testind criteria and procedures
  - equipment maintenance (preventive and corrective maintenance)
  - maintaining the skills of people (training, exercises…)
    - The frequency and nature of controls, periodic tests and exercises are based on the particular importance of the relevant fire protection measures in the demonstration of safety, resistance to stress and vulnerability to aging.
- **Countervailing measures in case of unavailability of the fire protection measures (failure, maintenance …)**
- **Managing facility changes**

Documentation

- **The fire risk analysis requires a single dossier that contains the following elements in particular to be created:**
  - a description of the installation,
  - the safety principles retained,
  - the safety requirements to be respected,
  - the list of targets and their functional requirements,
  - the performance criteria* of the fire protection measures,
  - the fire hazards during the installation's various operating states,
  - the organizational measures (management of combustible loads, etc.)
  - the fire protection measures and their qualification dossiers,
  - the ventilation procedures during a fire,
  - the justification of the installation's organization on which the safety demonstration is based in terms of operability and lead times,
  - the reference scenarios retained and their selection process,
  - the presentation of the reference scenario simulation results together with input data groups and associated uncertainties (data, results) and their comparison with the performance criteria* desired,
  - verification of the robustness of the safety demonstration by studying aggravated fires and flashovers and calculating their consequences for safety, people and the environment,
  - justification of the suitability of the calculation tools' conditions of use with the scenarios considered,
  - periodic maintenance and test measures that concern the fire protection measures,
  - presentation diagrams of the installation showing at each level the targets, fire hazards and fire protection measures (fire detection and extinction systems, access routes, hydrants, fire compartmentation elements, etc.).
- **A summary of this document must be included by the operator in the installation's safety report**
  - With regard to the fire scenarios studied, the summary must recall the hypotheses and boundary conditions used so that it can be understood by a third party

CONCLUSION

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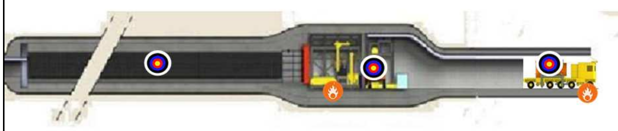

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CONCLUSION

- Fire protections measures should be implemented according to a defense in depth approach
- Principles to include in a safety demonstration:
  - Defense in depth approach
  - Consider all the states of operation of the facility
  - Safety margins
  - Consider combined events
  - Use appropriate models
  - Etc.

The prediction of fire phenomenon is complex

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Thank you for your attention