SAFETY SERIES No. 118

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safety series

Safety Assessment for Spent Fuel Storage Facilities

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1994

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SAFETY ASSESSMENT FOR
SPENT FUEL STORAGE FACILITIES

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FOREWORD

The spent fuel resulting from operation of nuclear reactors to produce electrical energy must be safely stored and managed pending its reprocessing or disposal. The IAEA recognizes the increasing need for such interim spent fuel storage and has consequently established a programme to provide guidance to its Member States on the key safety aspects of safe storage. This programme complements the IAEA's Nuclear Safety Standards (NUSS) programme.

The IAEA has prepared a series of three related Safety Series publications addressing (i) the design, (ii) the operation, and (iii) the safety assessment of interim spent fuel storage facilities. This Safety Practice addresses the management of all relevant issues concerned with the safety of the storage of spent fuel from nuclear power plants.

This Safety Practice was developed through a series of Advisory Group Meetings, Technical Committee Meetings and Consultants Meetings from 1991 to 1994. It describes accepted international approaches for maintaining fuel subcritical, removing residual heat, providing radiation protection and containing radioactive materials for the lifetime of the facility.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

This Safety Practice has been prepared as part of the IAEA's programme on the safety of spent fuel storage. It reflects the standards of the IAEA NUSS programme related to nuclear power plants and is a companion publication to two Safety Guides which treat the subject of spent fuel storage at interim spent fuel storage facilities, namely, Design of Spent Fuel Storage Facilities [1] and Operation of Spent Fuel Storage Facilities [2].

1.2. OBJECTIVE

The purpose of this Safety Practice is to provide details on how to assess and document the safety of a spent fuel storage facility.

1.3. SCOPE

This Safety Practice is primarily intended to provide details on the safety assessment of interim spent fuel storage facilities that are not an integral part of an operating nuclear power plant. Such an interim storage facility may be either co-located with other nuclear facilities (such as a nuclear power plant or reprocessing plant) or sited independently.

If the spent fuel storage facility is an integral part of an operating nuclear power plant, there will be additional considerations not dealt with in this Safety Practice but which can be found in the Safety Guide on Fuel Handling and Storage Systems in Nuclear Power Plants [3]. Similarly, publications on the design of high level waste and spent fuel disposal facilities are included in the Radioactive Waste Safety Standards (RADWASS) series.

The type of spent fuel considered in this Safety Practice is typically that derived from water moderated reactors. This Safety Practice can also be applied to other fuel types such as those from gas cooled reactors, as well as fuel assembly components. Some items, such as canistered failed fuel, may also be considered if an adequate safety analysis is prepared.

Transport requirements are provided in IAEA Regulations for the Safe Transport of Radioactive Materials [4], and in related IAEA publications (e.g. the TECDOC entitled Interfaces between Transport and Geological Disposal Systems for High Level Waste and Spent Nuclear Fuel [5]). The interface between storage and transport is discussed in this Safety Practice.

1.4. STRUCTURE

This Safety Practice has five sections. Following this Introduction, Section 2 provides general guidance on the safety assessment process, discussing both deterministic and probabilistic assessment methods. This section may be used to identify those events and sequences which need to be analysed and the appropriate analysis method to be used.

Section 3 describes the safety assessment process for normal operation and anticipated operational occurrences. Guidance is provided on how to categorize these operational states and determine the appropriate design requirements.

Section 4 describes the safety assessment process as it relates to accident conditions. The discussion covers both design basis accidents and those considered beyond design basis.

Section 5 describes the purpose and contents of the Safety Analysis Report and its relationship to the licensing process.

The Annex contains an example of a Safety Analysis Report, and the Bibliography suggests some useful reading.

2. SAFETY ASSESSMENT

2.1. GENERAL

Interim spent fuel storage facilities are required for the safe, stable and secure storage of spent nuclear fuel after it has been removed from the reactor pool and before it is reprocessed or disposed of as radioactive waste.

Various designs of wet and dry storage facilities are in operation or under consideration in Member States. Although designs differ, all consist of relatively simple, often passive systems, which are intended to provide adequate safety over several decades. Associated handling and storage operations are relatively straightforward.

Spent fuel is usually transferred to interim spent fuel storage facilities only after an initial period of storage at the reactor station. This initial period of storage allows a considerable reduction in the quantity of volatile radionuclides, the radiation fields and the production of decay heat. Hence, the development of conditions which could lead to accidents in interim spent fuel storage facilities will generally occur comparatively slowly, allowing ample time for corrective action before limiting conditions may be approached. The safety of spent fuel handling and storage operations can thus be maintained without reliance on complex, automatically initiated protective systems.

The safe operation and maintenance of spent fuel storage facilities, as with other engineered systems, depends in part on adequate design and construction. The most important design features of such facilities are those which provide the necessary assurances that spent fuel can be received, handled, stored and retrieved without undue risk to health and safety, or to the environment.

To achieve these objectives, the design of spent fuel storage facilities must incorporate features to maintain fuel subcritical, to remove spent fuel decay heat, to provide for radiation protection, and to maintain containment over the anticipated lifetime of the facilities as specified in the design specifications. These objectives must be met in all anticipated operational occurrences and design basis accidents in accordance with the design basis as approved by the Regulatory Body. The most important purpose of the Safety Analysis Report (SAR) is to show that these requirements have been fulfilled.

The Regulatory Body is responsible for establishing basic safety criteria. The competent authorities in the Member States approach this task in different ways and to varying degrees of detail. The criteria reflect the judgement of the Regulatory Body regarding what is required to protect the public and the operating personnel from radiological and other hazards. The IAEA's International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources [6] gives guidance on this topic and should be consulted.

Safe operation of a facility is the responsibility of the operating organization. Demonstration of safety, both during the operating lifetime of a facility and prior to operation, is also the responsibility of the operating organization. Therefore the organization must provide an SAR that demonstrates the adequacy of the design in meeting specified safety criteria.

2.2. GENERAL GUIDANCE

The allocation of specific safety analyses to either *operational states* (as discussed in Section 3) or *accidents* (as discussed in Section 4) is somewhat arbitrary. The fundamental distinction rests upon the recognition that *anticipated operational occurrences* have a sufficiently high probability of occurrence that they may be considered operational in nature, whereas *accident conditions* have a lower probability of occurrence.

Similarly, the distinction between accident conditions and severe accidents is an arbitrary one based upon consideration of the probabilities of occurrence and the consequences. It is very site dependent. The distinctions are illustrated by the figure in the Definitions Section.

Design basis accidents, as the name implies, must be addressed in the design. Severe accidents fall into two general groups: those which have a high enough probability of occurrence and severe enough consequences that some prior consideration of possible corrective or remedial actions is advisable; and those which have a low enough probability of occurrence for such consideration to be ignored.

There is a reciprocity between safety assessment and engineering design inasmuch as safety assessment both influences, and is influenced by, the engineering design. Safety assessment should therefore begin with a description and explanation of certain choices made by the designer which guide, limit or bound the resulting design.

Safety assessments make use of deterministic and probabilistic methods. Frequently, the design is based on the assessment of a given list of initiating fault conditions using certain deterministic criteria (e.g. application of the single failure criterion) to show that certain limits (e.g. fuel or material temperatures, structural stress levels) are satisfied. This may be complemented by a probabilistic safety assessment to confirm that an adequate overall level of safety has been achieved and that the balance of the design in terms of protection against different faults is reasonable.

A safety analysis should take the form of a deterministic demonstration whenever possible. This demonstration results in a safety margin being expressed in terms of the difference between the calculated value and the declared safety limit for a specific parameter. It follows that the data selected for a deterministic analysis should be conservative.

Probabilistic work is best applied to support deterministic analyses by demonstrating the frequency of breaching a known safety limit. In general, this work will require estimates to be made of the consequence as well as the probability of failure. The estimates result in a safety margin being expressed as a percentage of the risk or frequency target that is declared to be acceptable. To avoid compounding pessimism, it is normal practice to use best estimate parameters for probabilistic work.

It is also well known that probabilistic analyses need to make adequate allowance for the effects of human error and common cause failure if the results are to have credence.

In all aspects of the safety analysis, calculations should make use of verified or validated calculational methods and data, as appropriate. The source of all data used should be identified. All codes and standards used should be referenced.

The advice which follows is meant to address both wet and dry storage of spent fuel and all points raised should therefore be considered *where applicable.*

2.3. DETERMINISTIC SAFETY ANALYSIS

Certain parameters may be chosen at the discretion of the designer, or be dictated by material properties and physical or chemical constraints, or mandated directly or indirectly by the Regulatory Body. Some of these parameters will have a limiting, bounding or guiding influence on the design. The SAR should identify and explain all such parameters. Each discussion should include a justification of all choices with appropriate data, analyses and reasoned argument.

The objective is to store spent fuel safely. Therefore, a detailed description of the spent fuel to be stored should be provided. This description should characterize the fuel with respect to its nature, amount and the anticipated storage time. The characterization requires calculation of isotopic inventories which, in turn, are used to determine compliance with specific limits that have been established for storage at the facility. Different parameters might be selected, i.e. maximum irradiation and minimum cooling for shielding design, radiological protection and heat generation rate calculations, but zero irradiation and maximum initial enrichment for subcriticality calculations, unless credit for burnup is taken.

The analysis needs to provide justification (i.e. from reactor records, physical checks and measurements, management systems) for the choice of limiting fuel parameters. Justification should also be provided for assuming that the fuel sent to the facility will be within acceptable limits. The method for identifying any fuel which is not within acceptable limits and the procedures to be followed in that eventuality should also be explained and justified.

2.4. PROBABILISTIC SAFETY ASSESSMENT

To carry out a probabilistic safety assessment:

— Each initiating event or sequence of events which could lead to development of a fault condition should be identified;
— The fault scenarios or sequences leading to the postulated fault condition should be defined in detail;
— The probabilities that the various postulated fault conditions will occur should be determined;
— If necessary, the consequences of the various postulated fault conditions with particular reference to the three safety related issues of maintaining subcriticality, heat removal and radiological protection should be assessed;
— The resulting risk or probability of occurrence should be compared with a criterion of acceptability.

When the probability of occurrence is less than unity and/or the consequence is expressed in probabilistic terms, the SAR becomes one based upon risk (using risk in its technical sense as the probability of occurrence, multiplied by the consequence) and is sometimes referred to as a probabilistic safety assessment (PSA) or probabilistic risk assessment (PRA).

Techniques for estimating the probability of occurrence are well known and there is much guidance available. The main technique is fault tree analysis (FTA) supported, if necessary, by other techniques, of which perhaps failure mode and effects analysis (FMEA) is the most useful. Event trees may also be used.

FTA has several important benefits and, in particular, it can handle three specific aspects of fault analysis successfully. These are:

— Complex logic;
— The effect of human error;
— Common cause effects.

2.5. IDENTIFICATION OF INITIATING EVENTS AND FAULT SEQUENCES

Before considering each of the safety related technical issues in turn, it is necessary to establish a listing of initiating faults via such methods as creation of fault schedules, information generated by structured design and safety review exercises such as hazard and operability studies (HAZOPS), and the experience of the assessor.

It is necessary to recall that much of the input required here will derive from site and facility specific considerations. Tables I and II in Section 3.2 list examples of natural phenomena and external man-induced phenomena which should be considered in this context.

Faults may be due to environmental extremes, equipment failure, human activities (including operator error) or some combination of all of these. Examples of faults which can be analysed (as they pertain to particular systems) are:

— Receipt of defective fuel;
— Receipt of out-of-specification fuel;
— Incorrect loading of fuel;
— Fuel handling faults (dropped loads, impacts);
— System faults (e.g. heating and ventilation);
— Loss of external electrical supplies;
— Faults in heat removal system;
— Flow blockages;
— Faults in coolant or pool water circulation systems;
— Faults in coolant or pool water composition;
— Excessive coolant or pool water leakage;
— Faults in containment (e.g. container leakage);
— Structural failures (e.g. failure of baskets, fuel racks);
— Flood/high winds/seismic events/aircraft crash;
— Fire;
— Explosion;
— Failure to maintain intended fuel environment;
— Leakage from radioactive waste systems.

A schedule of faults should be prepared, and for each fault (or group of faults having common characteristics) the procedures and/or engineered safety systems (if any) which will be used should be listed. The fault studies will assess the transient development of the faults in the fuel, coolant and structures, and any other critical parameters (e.g. pressure within closed containments) to show whether these remain acceptable, taking account of possible actions such as corrective action or repairs if the time-scale is sufficiently long.

3. SAFETY ASSESSMENT OF OPERATIONAL STATES

3.1. GENERAL

The safety assessment starts with general matters as explained in Section 2 and amplified below.

3.1.1. Fundamental requirements

The SAR should explain what fundamental design requirements have been applied and how the resulting design reflects these requirements.

Typically, the fundamental design requirements will address such considerations as the need to ensure an adequate degree of redundancy, diversity and reliability, and the need to ensure that any failures which might occur are limited in scope and to the extent possible.

It will also be expected that the design will respect the principle of defence in depth (as described in The Safety of Nuclear Installations [7] and in Basic Safety Principles for Nuclear Power Plants [8]). For spent fuel storage facilities, which are characterized by relatively simple, often passive systems and relatively straightforward handling and storage operations, the implementation of defence in depth will generally mean the use of multiple barriers to shield against radiation and to prevent the escape of radioactive material from the fuel to the environment.

These barriers may include the fuel matrix and cladding, with appropriate note taken of potential cladding failures and the fact that the retention of volatile materials and particulates by the fuel matrix is a function of the temperature and environment. Further containment barriers may include the pool boundary with its auxiliary systems, a container or storage tube in a vault storage facility, or the liners and other components of casks and silos.

Defence in depth also requires that at all times when the fuel is being handled, adequate containment barriers are maintained.

3.1.2. Fuel related considerations

Typical fuel related considerations to be addressed in the SAR include:

(a) Design basis fuel assemblies
- Physical description (form, composition, materials, mass, etc.);
- Initial enrichment;
- Burnup/burnup history;
- Minimum cooling period;
- Isotopic composition at time of storage;
- Radiation fields at time of storage;
- Reactivity at time of storage;
- Decay heat production.

(b) Arrangements for damaged fuel or fuel outside specifications

(c) Fuel inventory
- Number of assemblies per storage unit;
- Total number of assemblies.

(d) Anticipated maximum storage duration.

Isotopic characterization of individual assemblies is necessary to determine accurately radiological and decay heat conditions. Several validated and verified computer codes are available for such characterization.

3.1.3. Various limiting parameters

The following are typical examples of parameters which may have a limiting, bounding or guiding influence on safety and, therefore, should be addressed in the SAR:

- Design life of the storage facility;
- Selection of component materials;
- Fuel cladding temperature;
- Material temperatures;
- Radiation fields;
- Pool water chemistry and radioactivity;
- Gaseous and liquid releases inside the facility;
- Gaseous and liquid releases outside the facility.

All choices of this kind should be justified with appropriate data, analyses and reasoned argument.

TABLE I. SITE CONDITIONS, PROCESSES, EVENTS, NATURAL PHENOMENA

1. Meteorology and climatology of the site and region
   (a) Precipitation (average and extremes)
      — rain
      — hail
      — snow, snow cover
      — ice, ice cover
   (b) Wind (average and extremes)
      — tornadoes, hurricanes, cyclones (frequency/intensity)
   (c) Insolation (average and extremes)
   (d) Temperature (average and extremes)
   (e) Barometric pressure (average and extremes)
   (f) Humidity (average and extremes)
      — fog
      — frost
   (g) Lightning (frequency/intensity)
2. Hydrology and hydrogeology of the site and region
   (a) Surface runoff (average and extremes)
      — flooding (frequency/intensity)
      — erosion (rate)
   (b) Groundwater conditions (average and extremes)
   (c) Wave action (average and extremes)
      — flooding (frequency/intensity)
      — high tides
      — storm surges
      — shore erosion (rate)
3. Geology of the site and region
   (a) Lithology and stratigraphy
      — geotechnical characteristics of site materials
   (b) Seismicity
      — faults, zones of weakness
      — earthquakes (frequency/intensity)
4. Geomorphology and topography of the site
   (a) Stability of natural materials
      — slope failures, landslides
      — avalanches
   (b) Surface erosion
5. Flora and fauna of the site
   (a) Terrestrial and aquatic (as regards effect on facility)
6. Potential for natural fires, explosions at the site

3.2. SITE CONDITIONS, PROCESSES AND EVENTS

Site conditions, processes and events will impose certain loads and other requirements on the spent fuel storage system. These will be both natural and human in origin.

All site conditions, processes and events having relevance in this regard should be identified and considered. The objective is to establish the normal or average situation and to identify the credible extreme events to be considered.

TABLE II. SITE CONDITIONS, PROCESSES, EVENTS, EXTERNAL MAN-INDUCED PHENOMENA

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1. Explosion
   - (a) Solid substance
   - (b) Gas, dust or aerosol cloud
2. Fire
   - (a) Solid substance
   - (b) Liquid substance
   - (c) Gas, dust or aerosol cloud
3. Aircraft crash
4. Missiles due to structural/mechanical failure
5. Flooding
   - (a) Structural failure of a dam
   - (b) Blockage of a river
6. Ground subsidence or collapse
7. Ground vibration
8. Release of any corrosive, toxic and/or radioactive substance
   - (a) Liquid
   - (b) Gas, dust, aerosol cloud
9. Geographic and demographic data
   - (a) Population density, and expected changes during the lifetime of the facility
   - (b) Industrial and military installations, and the effect on the facility of accidents at those installations
   - (c) Traffic
   - (d) Transport infrastructure (highways, airports, railway lines, pipelines, etc.)

The exercise is very site specific. Tables I and II, the IAEA Safety Guide on External Man-Induced Events in Relation to Nuclear Power Plant Design [9] and the Annex of this Safety Practice all contain lists which the designer may wish to consult when identifying the site conditions, processes and events that are relevant to the proposed facility.

There are widely used, well established practices for assessing natural site conditions, processes and events. Similarly, for those practices having their origin in human undertakings, there exists a wide body of experience.

With the knowledge gained from the foregoing analyses, the design of the facility can proceed in conjunction with the safety assessment, as described in Section 2.2.

All methodologies used to define such design basis conditions should be noted, explained and justified. Similarly, any decisions to ignore particular factors should also be noted and justified.

The SAR should present convincing arguments in support of all the factors ultimately chosen as the design basis, noting factors of safety and indicators of conservatism.

3.3. STRUCTURAL INTEGRITY

For the safety systems and safety related systems and components to perform properly, the components of the facility should maintain their structural integrity in operational states and accident conditions. Therefore, the integrity of the components and systems for these conditions should be demonstrated by structural analysis. This should take account of relevant loading conditions (stress, temperature, corrosive environment, etc.), and should consider creep, fatigue, thermal stresses, corrosion and material property changes with time (e.g. concrete shrinkage).

The integrity of fuel cladding and other containment barriers during the storage facility lifetime should be justified with appropriate analyses or arguments. Similarly, the pool integrity, water retention capabilities, etc., should also be justified.

The calculational codes used should be validated codes. The stresses for given conditions should comply with the limits in standards applicable in the country; if no such standards apply, justification of the resulting stress levels should be given.

Care should be taken to consider all situations where mechanisms might jam, leaving a fuel element or a basket less than adequately shielded. Consideration should also be given to the possibility of a basket jamming within the storage facility. In addition to the shielding issue, it should be considered whether the handling equipment and methods are such that recovery from such situations could be endangered by excessive stresses having been applied.

3.3.1. Structural and mechanical loads

The SAR should give a full exposition of the structural and mechanical aspects of the design of the storage system in sufficient detail to provide justification of the basic design. Typical analyses include:

- Determination of loads due to the fuel, fuel storage units and various components of the storage facility;
- Foundation analysis;
- Full structural analysis of the various components of both the storage units themselves and the storage facility;
- Analyses of auxiliary components and equipment such as cranes, transfer vehicles and protective buildings.

3.3.2. Thermal loads and processes

Because the fuel produces heat, all thermal loads and processes should be given appropriate consideration in the design. The SAR should note and explain all such considerations, typical examples being:

- Thermally induced stresses;
- Internally generated pressures;
- Heat transfer requirements;
- Evaporation/water make-up requirements;
- Effect of temperature on subcriticality (k_{eff}).

3.3.3. Time dependent material processes

The intended lifetime of the facility and the anticipated storage time for the fuel will determine the importance of topics such as:

- Corrosion;
- Creep;
- Fatigue;
- Shrinkage;
- Radiation induced changes.

The SAR should note the applicable processes in the planned facility and provide suitable arguments for the consideration given to each in the design.

3.4. PERFORMANCE OF SAFETY RELATED SYSTEMS AND COMPONENTS

The sections which follow describe the safety related systems and components which should be addressed in an SAR for a spent fuel storage facility. For each safety related system or component, the applicant should describe the safety requirements of the system, the design of the proposed system or component and how it fulfils the safety requirements.

The term *system* is used in a wide sense so as to include recognition of administrative procedures, engineered controls and the need to demonstrate that the constraints assumed for the design are respected. Where such procedures or controls are specified, an analysis should be carried out to demonstrate their reliability.

3.5. ASSURANCE OF A SUBCRITICAL STATE

The SAR should show by an appropriate analysis that for the geometry defined by the design and for the construction materials, subcriticality will be maintained. The methodology used for performing the analysis should be described and evidence provided to show that the methodology has been validated for the specific application against criticality experiments. Account should be taken of possible variations in the parameters used in the analysis.

3.5.1. Assessing subcriticality: general questions of wet and dry storage

The SAR should show that for operational states and accident conditions the fuel array is subcritical by an adequate margin. For operational states the calculation should reflect the design of the fuel loading configuration and, where appropriate, the presence of neutron absorbers. For accident conditions the effect on subcriticality of any significant variation from the design geometry should be described.

The SAR should demonstrate an adequate margin of subcriticality in all phases of fuel handling, manipulation, transportation and storage. No credit should be taken for operator action to avoid particular configurations.

If no analysis is available for a particular fuel, then that fuel is not acceptable for storage in the installation.

For analysis of criticality, the analysis should provide deterministic calculations to produce a specific estimate of the multiplication factor (k_{eff}) for each type of fuel assembly proposed for the facility. Several computer codes have been validated for accuracy and applicability to various fuel types and storage situations. For each assembly, the maximum reactivity should be chosen.

Where permitted, burnup credit may be taken, thus allowing the residual rather than the original reactivity of the fuel to be the controlling factor in criticality calculations. For a storage configuration an acceptable level of reactivity is determined on the basis of an enrichment limit for storage of fresh, unburned assemblies. Qualifying levels of burnup for initial fuel enrichments above this upper limit are then established using an appropriate technique for modelling the variable effects of fissile material production and utilization, fission product poisoning, and other reactivity effects associated with fuel depletion.

Accurate reactivity characterization and subsequent selection of qualified assemblies becomes an important component in maintaining subcriticality when the burnup credit concept is utilized. Consequently, at the discretion of the operating organization, the characterization techniques and assembly selection procedures may be supplemented with an appropriate measurement which directly or indirectly confirms the calculated fissile content or level of depletion for candidate assemblies. The general burnup credit approach and associated analyses should also be acceptable to the Regulatory Body.

Credit can be taken in the calculation for the presence of fixed neutron absorbers in the fuel assembly and/or fuel rack. This would include those absorbers incorporated into the structure of the storage racks or fuel assemblies and others that are sufficiently attached to preclude inadvertent removal. Fuel assembly control components (control rod assemblies, etc.) would not qualify as a fixed absorber.

No allowance for the presence of burnable absorbers shall be made unless on the basis of justification acceptable to the Regulatory Body. This shall include consideration of the reduction of neutron absorption capability with burnup. The analysis should demonstrate that such an absorber will not be dangerously degraded during the life of the storage facility. In the event that credit for fixed absorbers is claimed and approved, the continued effectiveness of these absorbers should be demonstrated.

To support the above, the SAR should describe whatever administrative or engineered control systems are required to ensure no constraint violation at an adequate level of reliability. The systems might be administratively based, e.g. by making use of reactor records, or could make use of operating procedures such as surveillance of actual identification marks.

The SAR for subcriticality should not be limited to *safe-by-shape* arguments (see Section 4.2).

To verify that the design basis seismic event will not cause criticality, a structural analysis will be required which considers the response of the design to the design basis earthquake. The objective is to demonstrate that any geometrical changes will not compromise the subcriticality argument.

The choice of design basis earthquake should be justified. It should be characterized according to the requirement of the Regulatory Body.

Consideration should be given in the analysis as to whether other external or internal incidents can compromise criticality safety. Examples include rack/assembly toppling, collision, crushing from dropped loads, etc. Some of these might be required by the Regulatory Body to be deterministically justified. In each case chosen for further consideration, a consequence calculation in support of the subcriticality argument should be provided.

Similarly, if any other mechanisms for loss of structural integrity can adversely affect the subcriticality, then an analysis should be provided to demonstrate a sufficiently low probability of gross failure of the systems (mainly administrative) intended to prevent the fault.

3.5.2. Assessing subcriticality: specifics for wet storage

Fuel may be stored in pools either as bare fuel assemblies or in some form of engineered container. The criticality analysis would normally consider an infinite array of assemblies or containers, assuming no axial or radial leakage or a conservatively chosen reflector. The calculated k_{eff} value should also include all appropriate mechanical and methodological tolerances and biases. Stacking of containers is often employed and the analysis should allow for this feature in its modelling, where necessary.

The SAR should clearly state whether or not the presence of a soluble neutron absorber in the pool water is assumed. If credit for such absorber has been taken, a verification requirement should be included with an appropriately justified frequency. Such justification should be directly related to absorber recovery capability during normal operation and anticipated operational occurrences. Appropriate assessment of this capability during or following postulated accidents as per the guidance in Section 4 should be considered. The credit taken must also be acceptable to the Regulatory Body.

The SAR should describe the moderator densities assumed, particularly under accident conditions.

3.5.3. Assessing subcriticality: specifics for dry storage

Subcriticality is normally achieved through a judicious geometrical arrangement of the fuel and baskets and, sometimes, the exclusion of a moderator.

While dry storage is a normal condition, the SAR should demonstrate that subcriticality of a dry storage system is maintained even if water moderation of the stored fuel occurs as the result of a fault condition. If the assumption is made that this ingress of water cannot occur, the basis for this assumption should be provided.

If subcriticality under these conditions cannot be assured, then arguments should concentrate on why they are unlikely. This will require substantial consideration of site conditions with supporting analysis and/or demonstration that the stored fuel can remain effectively isolated from the exterior environment.

If solid neutron absorbers are incorporated into the design, any administrative procedures specified to ensure they are not damaged or displaced should be described.

3.6. REMOVAL OF DECAY HEAT

The rate of degradation of the fuel cladding is dependent on the storage temperature. This is more of a concern for dry fuel storage.

The SAR should therefore demonstrate that the fuel element temperatures will not adversely affect the safety of the facility by showing that the heat balance between the heat generation rate of the fuel and the ability of the storage device to dissipate the heat through conduction, convection and radiation will result in an equilibrium temperature below that specified in the design criteria. The methodology may involve physical experiment, analysis or both. The relevance of any experiments to the real case must be shown and any thermal analyses used must be described, with justification for the values assumed for the thermal parameters, such as conductivity, specific heat, emission, etc.

3.6.1. Heat removal: general ouestions of wet and dry storage

Cooling systems will vary with the design of the fuel storage facility. The cooling system for the stored fuel should be described with respect to how it fulfils the requirement for safety. The calculations should include the full range of operational states, including buildup to a fully loaded condition.

The analysis should demonstrate an adequate thermal performance of the storage facility for temperature conditions in all parts of the fuel route, taking account of the range of ambient conditions.

The objective is to show that the temperature of the fuel elements will not result in breach of the cladding over the lifetime of the installation. The assessment should take account of possible release mechanisms from the fuel matrix at the assessed temperatures, with details of, and justification for, any assumed size and number of cladding failures, and of the possible release mechanisms from the container, storage tube or other barrier.

3.6.2. Heat removal: specifics for wet storage

Because of the heat capacity of the large volume of water, heat removal is not usually a major consideration for pool storage, but calculations should be performed to ensure that the relevant temperature limits are not exceeded. Temperature limits need to be established (or will be imposed) for fuel cladding, pool structures, etc.

Generally, a system of recirculating pool water is employed. It is not unusual for a pool to be capable of withstanding boiling water under fault conditions.

If a temperature limit is placed on the structure of the pool, then an analysis to confirm adequate reliability against cooling failure should be provided. The analysis should describe whether or not credit is taken for both make-up capacity and the time taken for a hazardous fault to develop.

3.6.3. Heat removal: specifics for dry storage

For dry storage installations, heat removal requires the transfer of the heat generated by the fuel through the structure to some surface (or surfaces) where it can be dissipated by natural or forced convection. All thermal design features should be identified and the relationship to the safety provided by the particular cooling method should be discussed. These thermal design features include such items as cooling fins, thermal barriers and thermal properties of materials that affect heat transmission by conduction, radiation and convection.

The SAR, when considering heat transfer within the storage tube, container or cask, shall demonstrate that the heat generated by the fuel located within the storage tube or container can be transferred without exceeding the specified temperature limits. If an inert cover gas is used to enhance the rate of heat transfer, consideration should be given to the effects of loss of this internal atmosphere.

Faults involving the incorrect drying of fuel, incorrect filling with inert gas or incorrect filling pressure should be analysed. The effects on the fuel temperature, fuel integrity and integrity of the container or storage tube should be assessed and the potential consequences analysed taking account of means of detection of any containment failure and subsequent remedial action. The assessment should include an analysis of the adequacy of the inert gas filling procedure.

The heat rejection systems from the storage tubes, container or cask may be passive (natural convection) or active (forced convection). They should be shown to be sufficiently effective that fuel temperature limits are not exceeded and temperatures within the storage tube and container do not adversely affect the structural integrity (e.g. in the case of concrete). If temperatures are anticipated that could allow condensation to take place, it should be shown that this will not lead to a condition favouring unacceptable corrosion rates.

Where a natural convection system is used, it should be shown that there will be adequate margins to accommodate varying atmospheric conditions, e.g. temperature, wind, snow, ice, rain. Where a forced convection system is used during operational states, it should be shown that this system and its supporting services have adequate levels of reliability, taking into account the response time of the storage system to a fault condition and the possibility of operator action for correction, rectification or repair.

Consideration should also be given to the temperature excursion experienced by the fuel elements when pool water is discharged from the cask or basket after loading.

The temperature history of the fuel and structure should be assessed for use in confirming that fuel temperature limits (which may be time dependent) and container and structural temperature limits (as used in structural integrity analyses) are not exceeded. Heat transfer calculations should be used for estimating temperatures (usually equilibrium) of specific items, e.g. fuel cladding containers (if used).

In some systems, a maximum humidity is specified for the cooling air, to be achieved by recirculating hot outlet air to maintain a given vault temperature. The means of detecting any failure to maintain the correct conditions should be specified, and the means of correcting the situation before unacceptable corrosion occurs should be defined.

3.7. RADIOLOGICAL PROTECTION

The SAR should demonstrate that the radiation doses to operating personnel and to the general public are acceptable. The operating organization should describe the safety requirements of the storage facility that limit exposures to radiological hazards. This also applies to systems associated with handling, storing and monitoring activities in addition to the components of the particular storage mode.

As regards radiation doses to operating personnel during operational states an analysis should be prepared which estimates the dose involved in all tasks which are identified as necessary to operate or to maintain the facility. This requires analysis of occupancy times as well as estimates of the radiation fields. It is usual to divide up the process areas into zones, in terms of both the radiation fields and contamination levels that could be present. The dose analysis data should be consistent with the zoning information. It is usual to list the estimates in terms of specific groups, e.g. process operators, mechanical maintenance fitters, instrument and control personnel. However, the basic requirement is to demonstrate that the dose limits can always be respected.

As to the question of initial target setting, doses well below the limits set in Ref. [6] are appropriate.

Doses to members of the public during operational states will usually be very low. Some designs have no potential for public dose from either direct radiation or as a consequence of effluents. If radioactive effluents are or could be produced, dose analysis for the public should be undertaken; this will require the use of mathematical models of pathways of radionuclides through the environment to humans. A target dose can be set, but this is usually defined in terms of all the releases from a site. A facility such as a spent fuel storage facility would only be allowed a small fraction of the target for the site.

3.7.1. Radiological protection: general questions of wet and dry storage

The analysis of doses to members of the public should use appropriate assumptions based upon facility location, e.g. weather, wind direction, proportion of time spent at site boundary, food chain. Shielding calculations should, where possible, make use of standard methods.

The analysis should consider possible routes for the escape of radioactive material from the fuel by assessing the integrity and leaktightness of the barriers to the movement of radioactive materials.

Calculations might be needed to estimate the worst case potential dose to a member of the public as a result of routine discharges (aerial, liquid). Both the calculations and the modelling will need to be verified.

In zones where fuel is handled before containerization or before sealing within storage tubes or baskets, it should be shown that ventilation systems are provided to control levels of airborne contamination within the complex and in the air outflow to the environment.

The SAR should show that contamination control systems have been provided all along the fuel handling route. If fuel arrives at the site in water filled containers, the systems required to ensure control of liquid and gaseous contamination resulting from the fuel drying process should be described.

It should be evident that adequate consideration has been given to cases where accident or fault conditions could lead to a reduction in the design shielding, either during fuel transfer or during storage. For example, where the fuel movement requires that shield doors be opened, it should be shown that adequate protection has been provided to prevent the doors being opened in an unsafe condition.

When it is anticipated that the stored spent fuel will be removed at a specific time and it is not otherwise contained, then the structural integrity must be assured. For example, the United States Code of Federal Regulations, Title 10, Chapter 1, Part 72, Section 72.72(h) [10], requires that the fuel cladding be protected against degradation and loss of containment throughout the period of storage.

Not only should the fuel cladding continue to serve as an effective barrier to releases of radionuclides during storage, but it should not degrade to the extent that it could fail during normal handling operations. This requirement may be relaxed if the fuel is placed in impermeable, sealed containers which will not require opening prior to the ultimate disposal of the spent fuel.

Where claims are made regarding the reliability of administrative controls and non-passive engineered components of the various safety systems, such statements should be substantiated with appropriate analyses.

3.7.2. Radiological protection: specifics for wet storage

In wet storage, shielding is provided mainly by the depth of water above the fuel. The SAR should describe the means of maintaining the design level. This might include a description of the engineered system to supply make-up water, an analysis of the ability of the pool to withstand external events (specified for the site of the facility) and a description of any engineered means to prevent raising the fuel too high. An adequate level of reliability for adherence to these requirements should be demonstrated. The SAR should also discuss what measures exist to prevent incorrect operations resulting in the unacceptable alteration of the pool water level. Such measures might include siphon breaks, non-return valves, locked valves, etc.

Where features of pool operation such as fuel handling require shielding provided either by the installed plant or the civil structure, analyses should be included that demonstrate the adequacy of these items. Included in this analysis should be any operational features that are necessary for safety.

If, in addition to the system for maintaining the water level, systems are proposed to control contamination by impurities and suspended matter, water chemistry and corrosion, then these systems (e.g. filters and ion exchange resins) should be described and justified. Methods should be described for decontaminating any part of the system in contact with the pool water.

The SAR should describe the systems proposed to monitor radiation fields and contamination levels. It should also describe the engineering controls which are intended to limit or clean up contamination should it occur. Both radiation and contamination zones should be identified on the basis of the potential radiation fields and contamination levels. Nevertheless, having completed the zoning exercise, operational controls should be put in place to minimize the actual levels observed in the absence of accident states.

All systems proposed for monitoring radioactive discharges (gaseous or liquid) should be described. These should include provisions for both operational states and accident conditions.

The safety analysis should contain a deterministic justification of the integrity of the pool structure, typically including the integrity of the bulk shield, means for cooling the pool water and means for detecting water leaks from the main pool structure.

3.7.3. Radiological protection: specifics for dry storage

The primary safety related systems for radiological protection during dry storage are shielding, containment and contamination control.

Shielding is provided by the storage structures which are designed to attenuate radiation levels to values acceptable to the Regulatory Body. The SAR should describe the shielding system with regard to its ability to limit both gamma and neutron radiation to these acceptable levels.

The description should show that there will be sufficient shielding when moving the fuel from the storage pool to the dry storage facility and that there will be no unreasonable limitations on access time by operating personnel.

The SAR should describe how the storage system will contain the radionuclides present in the fuel so that the dose limits are not exceeded. The fuel will normally be stored within high integrity storage tubes or sealed containers which provide the principal barriers to the escape of radionuclides. The containment boundaries such as fuel cladding, primary containment vessel, seals, welds and other closure devices should be identified. Their effectiveness in limiting radioactive releases should be described, taking into account the buildup of pressure generated as a result of heating of the fuel and recognizing some degree of fuel cladding failure.

The description should show how the effectiveness of the seals is assured both at installation of the system and during its design lifetime. The system for monitoring the effectiveness of the closures should be described, both with regard to design (e.g. using dual seals and providing the ability to monitor interspace) and operation, where administrative procedures ensure that testing and monitoring are done at appropriate intervals. For example, in the case of casks, after loading, drying, sealing and charging with inert gas, the cask should be checked for leakage prior to installation on the storage pad.

Administrative procedures to detect and limit the spread of contamination should also be described for handling, transport, storage and retrieval of fuel. Proposed methods for control of contamination in the event of a leaking container or storage tube should be described. If removal of the failed container or fuel from it is contemplated, it should be shown that a significant radiological consequence would not occur in the time required for this operation.

For natural circulation systems associated with vault storage, it is not generally practicable to filter the air outflow. With forced circulation, filters become a possibility and, if used, their effectiveness and reliability should be assessed, as well as that of any supporting administrative procedures.

3.8. MONITORING

The SAR should discuss fully the monitoring regime which is proposed for the facility. This discussion should identify and explain those factors of the design and operation which are directed to monitoring and how these allow the operating organization periodically to verify compliance with fundamental performance and safety criteria.

It should be evident from the foregoing discussion how the monitoring regime addresses the need:

- Routinely to verify the proper functioning of the storage system with respect to its equipment and components, particularly those which are safety related;
- Periodically to assess the effect of the facility on the operating personnel, the general public and the environment.

The SAR should also clearly explain what the monitoring will address and how it will be accomplished. Of particular note are:

- The aspects of the design that specifically facilitate monitoring;
- The additional components and equipment that will be used;
- The observations and measurements that will be made;

— The administrative procedures (including sampling and analysis) that will be followed.

As necessary, the discussion should include arguments in support of the effectiveness and reliability of the equipment, components and procedures chosen for the monitoring regime, and the appropriateness of the proposed observations and measurements.

4. SAFETY ASSESSMENT OF ACCIDENTS

4.1. GENERAL

In this section, recommendations are given on accident conditions that should be analysed in the SAR, both for the design basis and for severe accidents which are beyond the design basis. Many of the topics are identical to those considered under operational states, but more pessimistic assumptions are generally made in the analysis. In some countries, much of the work in this area will be probabilistic, leading to an estimate of the probability of occurrence of the initiating event.

4.2. MAINTENANCE OF A SUBCRITICAL STATE

The SAR for subcriticality should not be limited to showing that the system is *safe-by-shape*. An example of an accident having implications in this regard is crushing of the fuel elements by a load dropped as a consequence of gross mishandling during manipulation of the fuel. Any safety system that is provided for such accidents should be described, with an analysis of the reliability of the handling equipment.

4.2.1. Assessing subcriticality: wet storage

It is anticipated that all routes to criticality realistically considered possible in the facility lifetime will have been ruled out by deterministic calculation. If more unlikely routes are considered, such as those including procedural (human) error, then these are better handled probabilistically. Typical initiators include wrong (more reactive) fuel sent from the reactor, dilution of the necessary soluble neutron absorber, defective fuel, extreme damage leading to loss of shape, overturning of a fuel basket.

For a probabilistic safety assessment, three specific studies will be required: a fault tree analysis (FTA) of faults leading to criticality; validation of the data used in the FTA (and possibly also justification of the method used); and consequence calculations, including a supporting argument for, and validation of, the modelling employed.

The SAR should describe the moderator densities assumed, particularly under accident conditions.

4.2.2. Assessing subcriticality: dry storage

In most cases, it can be shown by deterministic arguments that dry storage facilities remain subcritical. The effects of water ingress to areas where fuel may be present must be analysed. This can be done either deterministically or using a probabilistic analysis based upon considering extreme environmental events or man-induced accidents combined with a breach in the containment barriers.

4.3. REMOVAL OF DECAY HEAT

4.3.1. Heat removal: wet storage

An FTA can be used to address the probability of loss of water that uncovers fuel. If the pool is not designed to withstand boiling conditions, then this fault sequence will also require consideration. In both areas, the reliability of the cooling water system and its make-up capacity will need to be studied using a fault tree (reliability) analysis of water cooling plant and water capacity. Consequence analysis may be required and is usually based on pessimistic assumptions and the time-scale of the transient. The transient analysis for temperature at various points in the structure should include supporting arguments for, and validation of, modelling used.

Most extreme external events are better handled in terms of probability of occurrence alone.

4.3.2. Heat removal: dry storage

Fault analyses are mainly used to address flow blockages and perturbations. It will be necessary to define the blockage corresponding to the worst identified accident situation in the coolant flow system caused by structural failures, dropped debris, incorrect operation of flow dampers, etc. The resulting steady state temperatures in the fuel and structures (including containers), and the corresponding pressures, stresses, etc., will be assessed. If these are shown to be acceptable, the analysis need be taken no further. If they are not, the means of rectifying the situation should be specified, demonstrating that the deterioration of the containment boundaries in the relevant time-scale will not occur with an unacceptable frequency and/or produce an unacceptable consequence.

Other faults causing flow perturbations, such as coolant bypass caused by structural failure, should be treated in a similar way.

In general, the normal ultimate heat sink is ambient air. Forced circulation might be required locally if it is necessary to filter the exhaust while a faulty container or fuel element is dealt with. In this case, failure modes of the system should be considered.

In all of the above cases, the frequency of the fault condition should be assessed by a reliability analysis and the transient conditions analysed by an appropriate thermal analysis.

The possibility of repair or rectification should be assessed, taking account of the time-scale of the transient. The consequences (in terms of damage to the facility or radiological release) should be assessed in relation to the assessed frequency.

If the fuel storage facility is within a building, the effect of building collapse should be considered. The temperature excursion which will result from the building debris around the containers should be determined together with its effect on the integrity of the fuel. The assessment should be based on conservative assumptions regarding the time needed to remove the building debris.

4.4. RADIOLOGICAL PROTECTION

The purpose of the SAR is to evaluate the radiological consequences of accidents and to compare these with established criteria.

4.4.1. Radiological protection: wet storage

Accidents leading to unacceptable pool water loss should be considered. Protection against loss of shielding due, for example, to pipe breaks or to large scale damage to the facility can normally be demonstrated deterministically. Small leaks can be addressed via a reliability analysis of the containment system, together with discussion of the capacity available for make-up water supply and the time for its deployment.

Supporting documentation should include an analysis of the failure rate and the consequence of a loss of adequate depth of water over the fuel. This could include transient effects, which might lead to a need for validating the calculational method.

4.4.2. Radiological protection: dry storage

Containment is in the form of a sealed container or storage tube closed by a sealed lid. The effects of leakage may include:

- Loss of intended containment atmosphere and reduction of heat transfer performance, increasing the potential for corrosion of components of the fuel element;
- Leakage of radioactive noble gases, volatiles or particulates.

The assessment normally includes demonstration, first, of the adequacy of containment sealing systems and, secondly, that a fault can be detected and the faulty container removed or the fuel removed from the faulty storage tube before giving rise to an unacceptable dose to the public.

It should be recognized that the facility might inadvertently receive fuel outside the specified parameters for the storage facility. The supporting analyses should include an assessment of this possibility.

The reliability of interlocks and alarms to ensure that shield doors cannot be left open in potentially hazardous circumstances should be analysed to demonstrate that the risk to the workers and to the public is acceptably low.

4.5. MISCELLANEOUS ASSESSMENTS

There are several additional accident sequences which have not yet been considered. They result from a number of postulated initiating events which may be natural or man-induced. In each case, the performance of the fuel storage facility should be assessed.

4.5.1. Seismic event

The response of the fuel containment to a seismic event should be evaluated. The site specific nature of seismic events is recognized and the applicant needs to define the nature of the earthquake for which the installation is designed and some extreme value whose probability of being exceeded is acceptably small.

The applicant should specify, explain and justify the parameters of the design basis seismic event. A seismic analysis of the integrity of the overall containment should be carried out at a level of detail commensurate with the hazard to the storage facility.

In the case of wet storage, consideration needs to be given to the potential of seismically generated waves on the water surface.

The natural frequency of oscillation of the structure of storage containers is generally so high that its frequency response to seismic excitation can be neglected and it can be treated like a rigid body.

4.5.2. High winds

For dry storage facilities, high winds might be a significant consideration. It should be demonstrated that the facility is adequately protected against the effects of high winds. The SAR should also discuss the wind conditions under which fuel loading or transfer activities should not be performed because of possible hazardous circumstances.

Consequences of high winds are the possible displacement of structures and components, or the impact of wind generated missiles on the containment. In the case of tipover, the container and its contents will be subjected to a dynamic load of a magnitude depending upon the stiffness of the container and the stiffness of the foundation. The dynamic loads generated by the tipover accident should be absorbed by the storage facility components in such a way that the geometry of the fuel arrangement is not significantly changed, that the leakage rate of the sealing system is not increased beyond that permissible for accident conditions and that there are no structural failures that could compromise the integrity of the primary containment vessel. Another effect to consider is that if a cask or silo overturns, it may affect one or more neighbouring units, causing them to overturn and thus initiating a succession of similar events.

Where there is a requirement for maintaining the geometry of fuel, the structure supporting the fuel must not undergo any gross plastic deformation that would significantly alter its geometry. This does not include local plastic deformations, provided that the support material has sufficient ductility to absorb this plastic deformation without cracking.

With regard to the closure system, it is expected that the dynamic loads will alter the conditions that were optimized for operational states and that some increase in leakage will occur. However, the damage to the closure system should not be so great that the radiological hazard to which the public and operating personnel will be exposed exceeds the limits set by the Regulatory Body for this infrequent event.

Finally, although the containment system might under impact suffer a degree of plastic deformation intolerable under normal handling conditions, the deformation should not be so great that loss of the containment is a credible event. This requires some consideration of the toughness of the containment and may entail an analysis of its ability to withstand brittle fracture.

4.5.3. Fire and explosion

There are some circumstances which could give rise to fire or explosion. The radiological consequences of these should be assessed. This can be done probabilistically, but other solutions are possible, e.g. by showing that the containment can withstand an explosion.

4.5.4. Aircraft crash, missiles, flying debris

The effect of crashing aircraft and missiles originating from adjacent installations (e.g. turbine missiles) should be assessed. If it can be shown that the probability of impact is sufficiently low to be discounted, this is all that need be done. If this cannot be demonstrated, appropriate protection (bunkering, missile barriers, etc.) should be provided and its effectiveness analysed. Appropriate supporting documentation will be required.

The analysis for safety should consider small objects of high velocity and investigate the possibility of puncture of vulnerable surfaces on the containment. Larger objects of lower velocity may also produce local damage or, in the case of casks or silos, may contribute to a tipover event.

There will be a wide range of probability for aircraft crashes, depending on the size of the storage installation. If the Regulatory Body insists that the likelihood of such an event needs to be considered, then the applicant should specify in the design criteria the maximum expected magnitude of explosion in terms of external overpressure, the temperature and duration of any fire accompanying an aircraft crash and the variety and speed of missiles that might be involved. The design basis aircraft crash should be specified, explained and justified.

4.5.5. Dropping of a fuel container or other heavy loads

Dropping a fuel container is of particular significance when fuel is transferred from a pool to dry storage. A complete analysis of a dropped fuel container should be done for each of the several possible scenarios. Examples include:

- Drop of a basket or an empty transfer cask within the pool;
- Drop of a basket into a silo or pool;
- Drop of a basket from a transfer cask onto the ground;
- Drop of a loaded transfer cask (with a basket inside) into the pool or onto the ground;
- Drop of a storage cask (loaded or unloaded) within the pool;
- Drop of a loaded storage cask onto the ground;
- Vehicle accident during transfer.

The design should anticipate the possibility of an accidental drop anywhere between the loading facility and the storage site. The severity of this accident depends to a large extent upon the height from which the container falls and upon its orientation when it strikes the ground. The magnitude of dynamic load depends upon both the stiffness of the container and that of the impact surface. Since the dynamic load is a function of the height from which the container falls, the applicant should stipulate this value in the SAR under design criteria and show how it will not be exceeded.

Where there is a possibility of dropping other heavy loads, the consequences of these events should be assessed.

4.5.6. Flood

Floods are of concern principally in the case of dry storage facilities that are located on a flood plain. Given these circumstances, the ability to withstand submergence and the effect of high velocity stream flow should be demonstrated. As in the case of seismic forces, the severity of floods is site specific and assumptions will have to be made for the magnitude that the design should consider. The loading of the structure due to flood conditions derives from the imposition of external pressure forces which should be analysed to determine the margin against tipover or other displacement.

In the case of dry storage structures such as vaults, the building should be placed above the level of the postulated flood to prevent water ingress.

The design basis flood should be specified, explained and justified.

4.5.7. Loss of electric power

If the safe functioning of the facility requires electric power (e.g. forced convection, ventilation, pool water circulation), then the assessment should demonstrate adequate reliability of the electric power supply or, failing that, demonstrate that an adequate level of safety is maintained in the event of loss of electric power.

5. SAFETY ANALYSIS REPORT

5.1. PURPOSE OF A SAFETY ANALYSIS REPORT

The purpose of an SAR is to demonstrate that a spent fuel storage facility can be implemented safely, i.e. in compliance with the safety criteria defined by law or regulations valid in the Member State.

The first step in this demonstration is to show that the proposal has been described and rendered into its constituent parts. The second step is to show that appropriate technical consideration has been given to each of the parts and to the whole.

Consequently, it is vital that the report clearly and completely describes the fundamental assumptions upon which the design is based, especially with regard to the quantity and characteristics of the fuel to be stored, the assumptions regarding the range of conditions under which the facility may operate and the hazards to which the facility will be exposed. Furthermore, the report should clearly and completely describe the performance criteria such as maximum k_{eff}, maximum temperature of the fuel elements, and radiation levels inside and outside the facility boundaries.

5.2. CONTENTS OF A SAFETY ANALYSIS REPORT

An SAR should include a full description of the spent fuel storage facility structures, systems and components; the applicable performance criteria; details of the process by which the design has been defined; details of the engineered and administrative aspects of the facility; a general description of the operation of the proposed facility and a prediction of performance together with the method by which this was determined.

The Annex provides an example of the contents of an SAR. The following general points are presented to illustrate the type of information that should be included.

Proposal:

(a) The purpose of the proposal should be explained and a full description given of the proposed facility, including dedicated equipment and systems.
(b) Where design choices affect safety, these should be explained and supported by an appropriate justification.

Performance criteria:

(a) The major safety related technical issues should be identified.
(b) The performance criteria adopted by the Regulatory Body should be presented and explained.

Design process:

(a) The design process should be described in sufficient detail to show how it was approached and what factors were considered.
(b) The SAR should demonstrate that the design process was complete, that the task was rendered into its constituent parts and adequately defined and delineated, and that all important factors were appropriately considered.
(c) It should be clear that appropriate technical consideration was given to each part of the system and to the system as a whole, and that all analyses and computations were satisfactorily performed.

Components:

(a) The fuel should be fully characterized with respect to its physical, chemical, radiological and engineering properties. Its enrichment, burnup history and post-irradiation cooling should be noted. Anticipated changes with time should be described. The minimum required cooling time for the fuel before it can be safely placed in a particular type of storage facility should be determined.

(b) The SAR should show how the various engineered components of the system exhibit an adequate degree of redundancy and how the design of the engineered components has incorporated considerations such as diversity, reliability and the need to ensure that any failures which might occur are limited in scope and, to the extent possible, benign.

(c) The administrative components (procedures, controls, monitoring, etc.) should be described.

(d) It should be apparent to the reviewer that all components will interact favourably and complement one another, contributing to the successful functioning of the system as a whole.

(e) The way in which the system design has been guided by the principle of defence in depth should be explained.

(f) It should be demonstrated that the design is technically sound and can be implemented with available technology or with reasonably achievable developments.

Performance prediction:

(a) The effects of external conditions (site conditions, processes, events; natural and external man-induced phenomena) on the spent fuel storage facility should be identified, the extent of effects estimated and any anticipated changes with time described. The impacts which the facility is designed to withstand should be identified.

(b) The integrity of the components during operational states and accident conditions should be demonstrated by structural analysis. This analysis should take account of relevant loading conditions and should consider changes with time in the loading conditions, material properties, etc.

(c) The nature and extent of all effects of the spent fuel storage facility (radiological and perhaps non-radiological; exposures, releases, doses) on the environment and humans should be assessed and compared with the established performance criteria. Any anticipated changes in the effects with time should be described, including those due to changes in surrounding populations.

(d) The analyses and supporting arguments should be explicit, i.e. it should be readily apparent what models were used, what parameters were chosen, what boundary conditions were applied and what assumptions were made. The reasons for each choice should be given.

(e) It should be evident that the models used are appropriate, that they relate to the problem at hand, that they effectively represent the processes in question and that they have been assembled into a coherent system model.
(f) The circumstances and methods used for validation, verification and sensitivity analysis should be described.
(g) The reviewer should be able to conclude that all analyses and calculations were properly done.

Quality assurance:

(a) It should be evident that all aspects of the design process, including data collection, analysis and report preparation, were subject to quality assurance (QA) procedures, and that an adequate QA programme will be in place for the implementation and operation.
(b) The SAR should also clearly describe the QA programme in place with respect to the assessments undertaken and the preparation of the SAR itself.

If the SAR has adequately addressed the above subjects, then an experienced reviewer should be able to conclude that probably no unanticipated issues or events will arise after the proposal is implemented.

5.3. STAGED LICENSING

If licensing of a facility proceeds in stages, it may be necessary to prepare an appropriate SAR to support an application for each stage. The content will reflect the particular stage of licensing, gradually increasing in scope to support an application to operate a constructed facility.

5.4. TIME LIMITATIONS

It is important to realize that safety assessments often have a limited period of validity. There are time dependent processes and events both within and outside the system which will eventually modify certain assumptions, parameters and boundary conditions. An operating organization should therefore expect to review and possibly modify an SAR from time to time.

Annex

CONTENTS OF A SAFETY ANALYSIS REPORT

This example is general in nature, addressing both wet and dry storage, and all points should therefore be considered *where applicable*. It is based upon guidance developed by the Canadian Regulatory Body with respect to dry storage of spent fuel.

1. Introduction
    - 1.1. Purpose of facility
        - 1.1.1. Rationale for fuel storage
        - 1.1.2. Anticipated lifetime of facility
        - 1.1.3. Long term objectives
    - 1.2. Overview of facility
        - 1.2.1. Principal facility components
        - 1.2.2. Facility location and layout
        - 1.2.3. Summary of fuel handling operations
    - 1.3. Performance objectives
        - 1.3.1. Radiological protection
            - 1.3.1.1. Workers
            - 1.3.1.2. Public
        - 1.3.2. Environmental protection
        - 1.3.3. Maintaining subcriticality
        - 1.3.4. Removal of decay heat
        - 1.3.5. Other

2. Design description of facility components
    - 2.1. Fuel assembly, fuel bundle
    - 2.2. Fuel handling devices
    - 2.3. Cask internals
    - 2.4. Container handling system
    - 2.5. Transfer casks
    - 2.6. Transporters
    - 2.7. Fuel storage structure
    - 2.8. Auxiliary structures
        - 2.8.1. Buildings
            - 2.8.1.1. Building services
        - 2.8.2. Berms, ramparts
        - 2.8.3. Cranes, lifting devices

3. Natural site characteristics
   - 3.1. Geology of site and region
     - 3.1.1. Lithology and stratigraphy
       - 3.1.1.1. Natural materials
       - 3.1.1.2. Imported materials
     - 3.1.2. Geotechnical characteristics of site materials
     - 3.1.3. Seismicity
       - 3.1.3.1. Faults, zones of weakness
       - 3.1.3.2. Earthquake history
   - 3.2. Geomorphology and topography of the site
     - 3.2.1. Stability of site
       - 3.2.1.1. History of slope stability
       - 3.2.1.2. Surface erosion
     - 3.2.2. Impact of surrounding area
       - 3.2.2.1. Landslides
       - 3.2.2.2. Avalanches
   - 3.3. Meteorology and climatology of the site and region
     - 3.3.1. Precipitation
       - 3.3.1.1. Normal ranges (rain, hail, snow, snow cover, ice, ice cover)
       - 3.3.1.2. Extremes recorded
     - 3.3.2. Wind
       - 3.3.2.1. Average directions, intensities
       - 3.3.2.2. Extreme events (tornadoes, hurricanes/cyclones)
     - 3.3.3. Insolation
     - 3.3.4. Normal temperature range
       - 3.3.4.1. Extremes recorded
     - 3.3.5. Normal range of barometric pressure
     - 3.3.6. Normal range of humidity
     - 3.3.7. Relevant chemical characteristics of atmosphere
     - 3.3.8. Lightning
       - 3.3.8.1. Frequency of electrical storms
       - 3.3.8.2. Ground strikes (per year, per square kilometre)
   - 3.4. Hydrology and hydrogeology of the site and region
     - 3.4.1. Normal surface runoff conditions
       - 3.4.1.1. Flooding: frequency, intensity
     - 3.4.2. Groundwater regime
       - 3.4.2.1. Range of normal conditions
       - 3.4.2.2. Highest recorded groundwater table

3.4.3. Coastal processes
3.4.3.1. Wave action
3.4.3.2. Tides
3.4.3.3. Storm surges
3.4.3.4. Shore erosion
3.5. Potential for natural fires or explosions
3.5.1. Volcanoes, forest fires, oil seeps, gas venting, etc.
3.6. Terrestrial fauna and flora of the site
3.7. Aquatic fauna and flora adjacent to the site

4. Human environment surrounding the site
4.1. Population distribution
4.2. Agriculture
4.3. Residential and commercial neighbourhoods
4.3.1. Mix and nature of commercial pursuits
4.4. Industrial parks
4.4.1. Mix and nature of industry
4.5. Transportation routes adjacent to the site
4.5.1. Waterways
4.5.2. Roads
4.5.3. Railway lines
4.5.4. Air corridors
4.6. Mining and excavation
4.7. Nuclear installations
4.8. Electrical power stations (including nuclear)
4.9. Potentially hazardous engineering works such as upstream dams

5. Design basis
5.1. Fuel characteristics
5.1.1. Physical description of fuel assembly, fuel bundle
5.1.1.1. Surface deposits on fuel assembly, fuel bundle
5.1.2. Initial enrichment
5.1.3. Burnup, power history
5.1.4. Minimum cooling period
5.1.5. Isotopic composition at time of storage
5.1.6. Radiation fields at time of storage
5.1.7. Reactivity at time of storage
5.1.8. Decay heat production at time of storage
5.2. Fuel load
5.2.1. Fuel load per storage unit
5.2.2. Total fuel load in facility
5.3. Intended fuel storage time

5.4. Fuel handling operations
  5.4.1. Pool operations: equipment and procedures
  5.4.2. Transfer operations: equipment and procedures
  5.4.3. Loading or emplacement operations: equipment and procedures
5.5. Selection and justification of component materials
  5.5.1. Physical and chemical characteristics
  5.5.2. Thermal properties
  5.5.3. Strength properties
  5.5.4. Limiting parameters
    5.5.4.1. Maximum material temperatures
    5.5.4.2. Maximum material stresses
  5.5.5. Time dependent material processes
    5.5.5.1. Corrosion
    5.5.5.2. Creep
    5.5.5.3. Fatigue
    5.5.5.4. Shrinkage
    5.5.5.5. Radiation-induced changes
  5.5.6. Intended design life of facility
5.6. Governing site conditions: selection and justification
  5.6.1. Parameter values required for design basis
  5.6.2. External parameter values required for severe accident analysis
5.7. Fault analysis
  5.7.1. Initiating events: selection and justification
    5.7.1.1. External natural
    5.7.1.2. External man-induced
    5.7.1.3. Internal man-induced
    5.7.1.4. Equipment or component failure
  5.7.2. Coupled and synergistic effects
  5.7.3. Normal operation: definition and justification
  5.7.4. Anticipated operational occurrences: selection and justification
  5.7.5. Design basis accidents: selection and justification
  5.7.6. Severe accidents: selection and justification
5.8. Design basis loads
  5.8.1. Static
  5.8.2. Dynamic
    5.8.2.1. Cyclic
    5.8.2.2. Impact
  5.8.3. Thermally induced stresses
  5.8.4. Internal pressure
5.9. Performance criteria
  5.9.1. Summary of performance objectives

- 5.9.2. Criteria values
  - 5.9.2.1. Radiation fields
  - 5.9.2.2. Contamination levels
  - 5.9.2.3. Zones for contamination and radiation control
  - 5.9.2.4. Releases (radiological, non-radiological)
  - 5.9.2.5. Maximum fuel cladding temperature
  - 5.9.2.6. Other
- 5.9.3. Justification of surrogate estimates
- 5.9.4. Justification of criteria values

6. Design justification
   - 6.1. States of the facility considered
     - 6.1.1. Normal operation (Reference: Sections 5.7.3 and 5.8)
     - 6.1.2. Anticipated operational occurrences (Reference: Sections 5.7.4 and 5.8)
     - 6.1.3. Design basis accidents (Reference: Sections 5.7.5 and 5.8)
     - 6.1.4. Severe accidents (Reference: Sections 5.7.6 and 5.8)
   - 6.2. Summary of analyses
     - 6.2.1. Foundation analysis
     - 6.2.2. Structural integrity of facility components (Reference: Section 2)
       - 6.2.2.1. Pool wall
       - 6.2.2.2. Pool floor
     - 6.2.3. Heat transfer
     - 6.2.4. Dose estimates and ALARA demonstration
       - 6.2.4.1. Worker dose estimates for maximum individual, group average and collective dose
       - 6.2.4.2. Public dose estimates for critical group and collective
     - 6.2.5. Factors of safety
   - 6.3. Analytical conclusions
     - 6.3.1. Shielding
     - 6.3.2. Containment
     - 6.3.3. Fuel geometry
     - 6.3.4. Change of moderation
     - 6.3.5. Dissipation of decay heat
   - 6.4. Accident response
     - 6.4.1. Available resources
       - 6.4.1.1. Equipment, material
       - 6.4.1.2. Personnel
     - 6.4.2. Contingency plans
     - 6.4.3. Administrative structure for management of response
     - 6.4.4. Mitigating effects as a result of response

6.5. Impacts
  6.5.1. Radiological
  6.5.2. Environmental
  6.5.3. Other

7. Fuel management system
  7.1. Safeguards
  7.2. Physical protection
  7.3. Control of fuel receipts
    7.3.1. Determining acceptability: equipment and procedures
  7.4. Defective fuel
    7.4.1. Detection
    7.4.2. Handling: equipment, components, procedures
  7.5. Fuel retrieval in the event of malfunction
  7.6. Minimization of impact of container loading on routine pool operations

8. Monitoring regime
  8.1. What to monitor
    8.1.1. Personnel
    8.1.2. Radiation fields
      8.1.2.1. On contact
      8.1.2.2. Within facility
      8.1.2.3. At perimeter of facility
    8.1.3. Contamination control
    8.1.4. Routine releases
      8.1.4.1. Airborne
      8.1.4.2. Waterborne
    8.1.5. Receiving environment
    8.1.6. Specific system parameters
      8.1.6.1. Selection and justification
  8.2. How to monitor
    8.2.1. Adequacy and reliability

9. Inspection and maintenance programme

10. Conceptual plan for decommissioning of facility
  10.1. Decommissioning options
    10.1.1. Cost estimates
    10.1.2. Impacts
    10.1.3. Benefits
  10.2. Decommissioning considerations
    10.2.1. Retrievability of fuel after long term storage
    10.2.2. Dismantlement/decontamination/disposal of equipment

10.2.3. Dismantlement/decontamination/disposal of storage containers and structures

10.2.4. Restoration of site

10.3. Programme to review and update decommissioning plan periodically

11. Quality assurance programme

11.1. Design and analysis

11.2. Construction of facility

11.2.1. Fabrication of components

11.3. Operation

11.3.1. Fuel handling

11.3.2. Fuel management system

11.3.3. Monitoring

11.3.4. Inspection and maintenance

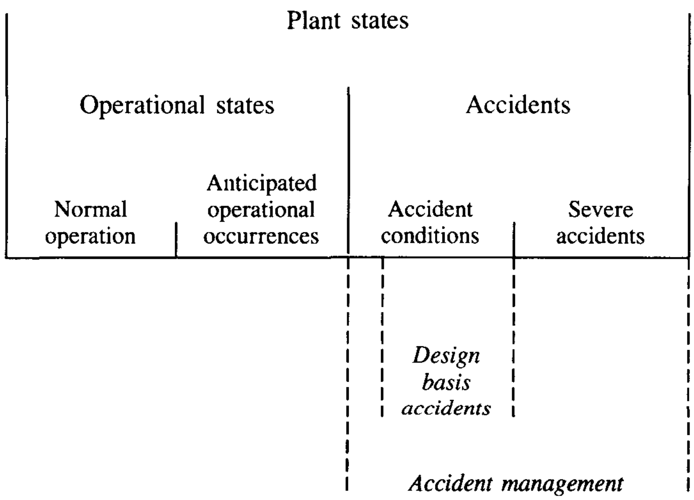
11.4. Decommissioning

DEFINITIONS

The definitions below are those specific to this document. Other terms in this document have the meaning as defined in other publications of the IAEA.

The specific definitions of plant states given below are taken from NUSS documents.

The relationships among the following fundamental definitions of plant states are illustrated by the accompanying diagram.



Operational States

States defined under normal operation or anticipated operational occurrences.

Normal Operation

Operation of a spent fuel storage facility within specified operational limits and conditions including fuel handling, storage, retrieval and fuel monitoring, maintenance and testing.

Anticipated Operational Occurrences[1]

All operational processes deviating from normal operation which are expected to occur once or several times during the operating life of the fuel storage facility and which, in view of appropriate design provisions, do not cause any significant damage to items important to safety nor lead to accident conditions.

Accident (or **Accident State)**

A state defined under accident conditions or severe accidents.

Accident Conditions

Deviations[2] from operational states in which the releases of radioactive materials are kept to acceptable limits by appropriate design features. These deviations do not include severe accidents.

Design Basis Accidents

Accident conditions against which the spent fuel storage facility is designed according to established design criteria.

Severe Accidents

Spent fuel storage facility states beyond accident conditions, including those causing significant fuel degradation.

Accident Management

Accident management is the taking of a set of actions

— during the evolution of an event sequence, before the design basis of the plant is exceeded, or
— during severe accidents without allowing unacceptable radionuclide releases to the environment

to return the facility to a controlled safe state and to mitigate any consequences of the accident.

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[1] Examples of anticipated operational occurrences are loss of normal electric power, malfunction of individual items of a normally running plant and failure to function of individual items of control equipment.

[2] A deviation may be, for example, a major fuel failure caused by equipment malfunction, operator error, etc.

Other definitions used throughout this document are as follows:

Acceptable Limits

Limits acceptable to the Regulatory Body.

Applicant

The organization that applies for formal granting of a licence to perform specific activities related to siting, design, construction, commissioning, operation and decommissioning of a spent fuel storage facility.

Barrier

A natural or engineered feature which delays or prevents material migration to or from storage components. Facilities may include multiple barriers.

Burnup Credit

The assumption in criticality safety analysis that considers the reduction in reactivity due to changes of fissile material, and/or increase in fission product neutron absorbers in spent fuel that has occurred as a result of use in a nuclear reactor.

Concrete Canister (or **Silo)**

A concrete canister is a massive container comprising one or more individual storage cavities. It is usually circular in cross-section, with its long axis vertical. Containment and shielding are provided by an inner, sealed liner and the massive concrete of the canister body. Heat removal is accomplished by radiant transfer, conduction and convection within the body of the canister and natural convection at its exterior surface. Canisters may be located in enclosed or non-enclosed areas.

Containment System for Spent Fuel Storage

Systems, including ventilation, that act as barriers between areas containing radioactive substances and the environment.

Dry Storage

In dry storage, spent fuel is surrounded by a gas environment such as air or an inert gas. Dry storage facilities include the storage of spent fuel in casks, silos or vaults.

Fault

A failure of a single device or component to perform its safety function when required to do so by a demand on the safety system.

Fuel Assembly

A grouping of fuel elements which is not taken apart during the handling, storage, retrieval and monitoring activities of the spent fuel storage facility. It may include non-fuel components such as control rod spiders, burnable absorber rod assemblies, control rod elements, thimble plugs, fission chambers, neutron sources and fuel channels that are contained in, or are an integral part of, the fuel assembly but do not require special handling.

Fuel Element

The smallest structurally discrete part of a fuel assembly that has fuel as its principal constituent.

HAZOP method

HAZOP is a hazard and operability study. It is a systematic, structured, critical examination of a proposed design or operation, seeking to identify safety or operational questions requiring further study. It is carried out by an appropriate multidisciplinary team, studying possible deviations from the design or process intent as the means of identification of such questions or issues.

Licence

Authorization issued to the applicant by the Regulatory Body to perform specified activities related to siting, design, construction, commissioning, operation and decommissioning of the spent fuel storage facility.

Licensee

The holder of a licence.

Operating Organization

The organization authorized pursuant to a licence issued by the Regulatory Body to operate the spent fuel storage facility.

Operation

All activities performed to achieve the purpose for which the spent fuel storage facility was constructed, including maintenance, inspection and other associated activities related to spent fuel handling, storage, retrieval and monitoring.

Operational Limits and Conditions

A set of rules which set forth parameter limits, the functional capability and the performance levels of equipment and personnel approved by the Regulatory Body for safe operation of the spent fuel storage facility.

Postulated Initiating Events

Identified events that lead to anticipated operational occurrences or accident conditions and their consequential failure effects.[3]

Regulatory Body

A national authority or a system of authorities designated by a Member State, assisted by technical and other advisory bodies, and having the legal authority for conducting the licensing process, for issuing licences and thereby for regulating the spent fuel storage facility. The Regulatory Body will consider the siting, design, construction, commissioning, operation and decommissioning or specified aspects thereof.[4]

Residual Heat

The heat originating from radioactive decay in the spent nuclear fuel.

Silo (see **Concrete Canister)**

Site

The area containing the spent fuel storage facility, defined by a boundary and under effective control of the plant management.

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[3] The primary causes of postulated initiating events may be credible equipment failures and operator errors (both within and external to the spent fuel storage facility), or man induced or natural events. The specification of the postulated initiating events is to be acceptable to the Regulatory Body for the spent fuel storage facility.

[4] This national authority could be either the government itself, or one or more departments of the government, or a body or bodies specially vested with appropriate legal authority.

Site Personnel

All persons working on the site, either permanently or temporarily.

Spent Fuel Storage Facility

An installation used for the interim storage of fuel assemblies and related components after their removal from the reactor pool and before reprocessing or disposal as radioactive waste.

Storage Cask, Cask

A storage cask is a massive container which may or may not be transportable. It provides shielding and containment of spent fuel by physical barriers which may include the metal or concrete body of the cask and welded or sealed liners, canisters or lids. Heat is removed from the stored fuel by radiant transfer to the surrounding environment and natural or forced convection. Casks may be located in enclosed or non-enclosed areas.

Vaults

Vaults consist of above- or below-ground reinforced concrete buildings containing arrays of storage cavities suitable for containment of one or more fuel units. Shielding is provided by the exterior structure. Heat removal is normally accomplished by circulating air or gas over the exterior of the fuel containing units or storage cavities, and subsequently exhausting this air directly to the outside atmosphere or dissipating the heat via a secondary heat removal system.

Wet Storage

Wet storage facilities for spent fuel are those facilities which store spent fuel in water. The universal mode of wet storage consists of storing spent fuel assemblies or elements in water pools, usually supported on racks or in baskets, and/or in canisters which also contain water. The pool water surrounding the fuel provides for heat dissipation and radiation shielding, and the racks or other devices ensure a geometrical configuration which maintains subcriticality.

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HEAT TRANSFER

A widely used technique for analysing the heat transfer characteristics of a dry storage container (e.g. a cask or canister) is to represent the contents as a porous medium. A proper representation requires empirical information derived from geometries which are similar to that of the fuel and its container. This information may be available in the open scientific and engineering literature or, if unavailable, must be obtained by the operating organization through appropriate experimentation.

When a representative porous medium has been defined, the analysis proceeds using conventional thermohydraulics techniques based upon finite element or finite difference methods.

Example analyses may be found in:

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