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IAEA SAFETY STANDARDS
for protecting people and the environment

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Storage of Spent Fuel

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DS371

Draft Safety Guide

IAEA
International Atomic Energy Agency

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IAEA SAFETY STANDARDS

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STORAGE OF SPENT FUEL

The following States are Members of the International Atomic Energy Agency:

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STORAGE OF SPENT FUEL

SAFETY GUIDE

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FOREWORD

by Mohamed ElBaradei
Director General

The IAEA’s Statute authorizes the Agency to establish safety standards to protect health and minimize danger to life and property — standards which the IAEA must use in its own operations, and which a State can apply by means of its regulatory provisions for nuclear and radiation safety. A comprehensive body of safety standards under regular review, together with the IAEA’s assistance in their application, has become a key element in a global safety regime.

In the mid-1990s, a major overhaul of the IAEA’s safety standards programme was initiated, with a revised oversight committee structure and a systematic approach to updating the entire corpus of standards. The new standards that have resulted are of a high calibre and reflect best practices in Member States. With the assistance of the Commission on Safety Standards, the IAEA is working to promote the global acceptance and use of its safety standards.

Safety standards are only effective, however, if they are properly applied in practice. The IAEA’s safety services — which range in scope from engineering safety, operational safety, and radiation, transport and waste safety to regulatory matters and safety culture in organizations — assist Member States in applying the standards and appraise their effectiveness. These safety services enable valuable insights to be shared and I continue to urge all Member States to make use of them.

Regulating nuclear and radiation safety is a national responsibility, and many Member States have decided to adopt the IAEA’s safety standards for use in their national regulations. For the Contracting Parties to the various international safety conventions, IAEA standards provide a consistent, reliable means of ensuring the effective fulfilment of obligations under the conventions. The standards are also applied by designers, manufacturers and operators around the world to enhance nuclear and radiation safety in power generation, medicine, industry, agriculture, research and education.

The IAEA takes seriously the enduring challenge for users and regulators everywhere: that of ensuring a high level of safety in the use of nuclear materials and radiation sources around the world. Their continuing utilization for the benefit of humankind must be managed in a safe manner, and the IAEA safety standards are designed to facilitate the achievement of that goal.

CONTENTS

1. INTRODUCTION 1
BACKGROUND 1
OBJECTIVE 2
SCOPE 2
STRUCTURE 3
2. PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT 3
3. ROLES AND RESPONSIBILITIES 4
GENERAL 4
RESPONSIBILITIES OF THE GOVERNMENT 5
RESPONSIBILITIES OF THE OPERATOR 7
ACCOUNTING AND CONTROL OF NUCLEAR MATERIAL AND PHYSICAL PROTECTION SYSTEMS 11
4. MANAGEMENT SYSTEM 11
SPENT FUEL MANAGEMENT 12
RESOURCE MANAGEMENT 12
PROCESS IMPLEMENTATION 14
5. SAFETY CASE AND SAFETY ASSESSMENT 14
DOCUMENTATION OF THE SAFETY CASE 21
6. GENERAL SAFETY CONSIDERATIONS FOR STORAGE OF SPENT FUEL 22

GENERAL 22
DESIGN PROCESS 24
CONSIDERATIONS FOR DESIGN OF SPENT FUEL STORAGE FACILITIES 26
Siting 26
Defence in depth....26
Structural integrity....27
Structural and mechanical loads....29
Thermal loads and processes....29
Time dependent material processes....30
Subcriticality 30
Heat removal 32
Containment of radioactive materials....33
Radiation protection 34
Layout....35
Handling....36
Ventilation systems 39
Communications....39
Control and instrumentation....39
Fire protection 40
Radioactive waste management....40
Lighting 40
Area monitoring....41
Emergency preparedness....41
Support systems....41
COMMISSIONING OF SPENT FUEL STORAGE FACILITIES....42
General 42
Commissioning stages....43
OPERATION OF SPENT FUEL STORAGE FACILITIES 44
General 45
Operational aspects....46
Maintenance, inspection and testing....50
Operational radiation protection....52
Characterization and acceptance of spent fuel 52
DECOMMISSIONING OF SPENT FUEL STORAGE FACILITIES 58
APPENDIX I. 60
SPECIFIC SAFETY CONSIDERATIONS FOR WET OR DRY STORAGE OF SPENT FUEL....60
SPECIFIC DESIGN CONSIDERATIONS FOR WET STORAGE FACILITIES....60
SPECIFIC OPERATIONAL CONSIDERATIONS FOR WET STORAGE FACILITIES 64
SPECIFIC DESIGN CONSIDERATIONS FOR DRY STORAGE FACILITIES....66
SPECIFIC OPERATIONAL CONSIDERATIONS FOR DRY STORAGE FACILITIES....70
APPENDIX II 73
SPECIFIC FUEL AND ADDITIONAL CONSIDERATIONS 73

GENERAL 73
MOX FUEL..73
FUEL WITH HIGH BURNUP 73
BURNUP CREDIT 74
FUEL FROM RESEARCH REACTORS 74
REFERENCES 76
ANNEX 1 80
Short term storage...80
Long term storage..80
ANNEX 2 81
ANNEX 3 84
ANNEX 4 86
ANNEX 5 87
CONTRIBUTORS TO DRAFTING AND REVIEW 90
BODIES FOR THE ENDORSEMENT OF SAFETY STANDARDS.................................91

1. INTRODUCTION

BACKGROUND

~~6.81.~~1.1. Spent nuclear fuel is generated from the operation of nuclear reactors of all types and needs to be safely managed following its removal from the reactor core. Spent fuel is considered as a waste in some circumstances or as a potential future energy resource in others and as such, management options may involve direct disposal (generally known as the ‘once through fuel cycle’) or reprocessing (generally known as the ‘closed fuel cycle’).“~~Spent fuel is considered as a waste in some circumstances or as a potential future energy resource in others and as such, management options may involve reprocessing or disposal.~~ Either management process will involve a number of steps, which will necessarily include storage for some period of time. This time period can vary depending on the management strategy adopted and can vary from a few months to several decades. The time period for storage will be a significant factor in determining the storage arrangements adopted. The final management option may not have been determined at the time of designing the storage facility, leading to some uncertainty in the storage period that will be necessary, a factor that needs to be considered in the adoption of a storage option and the design of the facility. Storage options include wet storage in some form of storage pool or dry storage in a facility or storage casks built for this purpose. Storage casks can be located in a designated area on a site or in a designated storage building. A number of different designs for both wet and dry storage have been developed and used in different countries.

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~~6.81.~~1.2. Whatever the circumstances of storage are (either as a waste or an energy resource), the safety aspects for storage remain the same, as indicated in the Joint Convention [1]. As such this document does not differentiate between the spent fuel stored as waste or as a resource material.

~~6.81.~~1.3. The safety of a spent fuel storage facility, and the spent fuel stored within it, is ensured by: appropriate containment of the radionuclides involved, criticality safety, heat removal, radiation shielding, and retrievability. These functions are ensured by the proper siting, design, construction and commissioning of the storage facility, its proper management and safe operation. Due consideration is also needed for decommissioning of the facility during the design stage.

~~6.81.~~1.4. Spent fuel is generated continually by operating nuclear reactors. It is stored in the reactor fuel storage pool for a period of time for cooling and then may be transferred to a designated wet or dry spent fuel storage facility, waiting for reprocessing or disposal (if it is considered to be radioactive waste). Some reactor spent fuel storage pools have sufficient capacity for all the spent fuel that will be produced during the lifetime of the reactor.

~~6.81.~~1.5. The basic safety aspects for storage of spent fuel are applicable for storage of spent fuel from research reactors as well as power reactors. An approach should be adopted that accounts for the differences between the fuel types when considering containment, heat removal, criticality control, radiation shielding and retrievability (e.g. lower heat generation, higher enrichment and less corrosion-resistant cladding materials

~~6.81.~~1.6. Many spent fuel storage facilities at reactors were intended to serve for a limited period of time (a few years) as a place to keep spent fuel between unloading from the reactor and its subsequent reprocessing or disposal. In view of the time being taken to develop disposal facilities and the limited reprocessing programmes that have been developed, storage periods are being extended from years to decades. This conceptual change in the management of spent fuel has been accompanied by other developments, e.g. increase in enrichment, increase of burnup, use of advanced fuel design and mixed oxide (MOX) fuel, re-racking, use of burnup credit and in some cases extension of storage periods beyond the original design life. Nevertheless, storage can not be considered as the ultimate solution for the management of spent fuel, which requires a defined endpoint such as reprocessing or disposal in order to ensure safety. The design lifetime of nuclear installations is generally of the order up to decades and experience with storage of spent fuel up to around fifty years has accrued. Whilst design lifetimes of up to one hundred years have been considered and adopted for spent fuel storage, in view of the rate of industrial and institutional change, periods beyond around fifty years are deemed to be "longer term" in the context of this document (See also Annex 1)

~~6.81.~~1.7. This Safety Guide supersedes the publications Safety Series No. 116, 117 and 118, which were published in 1994 and covered the design, operation and safety assessment of spent fuel storage facilities respectively. It combines the contents of the three earlier Safety Series publications and also incorporates recommendations addressing the impact of the new developments identified above. It complements the Safety Guide on storage of radioactive waste [2].

OBJECTIVE

~~6.6.~~1.8. The objective of this Safety Guide is to provide up-to-date guidance and recommendations on the design, safe operation and assessment of safety for the different types of spent fuel storage facilities (wet and dry), considering different types of spent fuel from nuclear reactors, including research reactors, and different storage periods, including storage going beyond the original design lifetime of the storage facility. The Safety Guide presents guidance and recommendations on how to fulfil the requirements established in the following IAEA Safety Requirements publications: Safety of Nuclear Fuel Cycle Facilities [3], Radioactive Waste Management [4], Safety Assessment and Verification of Nuclear Facilities and Activities [5], and The Management System for Facilities and Activities [6].

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SCOPE

~~6.7.~~1.9. This Safety Guide covers spent fuel storage facilities that may be either co-located with other nuclear facilities (such as a nuclear power plant, research reactor or reprocessing plant) or on their own sites. However, it is not specifically intended to cover the storage of spent fuel as long as it is part of the

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~~6.8.~~1.10. The scope of this Safety Guide includes the storage of spent fuel from water moderated reactors and can, with due consideration, also be applied to other fuel types, such as those from gas cooled reactors and research reactors and also to spent fuel assembly components and degraded or failed fuel[1] that may be placed in canisters.

~~6.9.~~1.11. The Safety Guide does not provide comprehensive and detailed recommendations on physical protection of nuclear material and nuclear facilities. Recommendations and guidelines on physical protection arrangements at nuclear facilities, including risk assessment, threat definition, designing, maintaining and operation of physical protection systems, evaluation of effectiveness and inspection of physical protection system can be found in Refs [7, 8] and in publications in the IAEA Nuclear Security Series. The Safety Guide considers physical protection and safeguards arrangements only to highlight their potential implications on safety.

STRUCTURE

Chapter two of this publication addresses the safety objectives and criteria applicable to the storage of spent fuel. The roles and responsibilities of the organizations involved are set out in chapter three and chapter four provides guidance on the management systems necessary to provide assurance of safety. Chapter five provides guidance on safety assessment and chapter six the considerations in respect of design, construction, operation and decommissioning of spent fuel storage facilities, including considerations for long terms storage. Chapter seven addresses considerations specific to wet and dry storage of spent fuel and chapter eight considerations in respect of spent fuel with particular characteristics.

2. PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT

~~3.1.~~2.1. National radiation protection requirements are to be established keeping in view the safety objective and fundamental safety principles set out in Ref. [9] and in compliance with the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources [10]. In particular, the radiation protection of any person who is exposed as a consequence of the storage of spent fuel is required to be within specified dose limits and is to be optimized within dose constraints.

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~~3.2.~~2.2. If several nuclear installations (e. g. NPPs, spent fuel storage facilities, reprocessing facilities etc.) are located at the same site, the dose constraints for public exposure should take into account potential sources of exposures that could arise from activities at the site, leaving an appropriate margin

[1] The terms degraded or failed fuel can cover a broad range of conditions ranging from minor pinholes to cracked cladding to broken fuel pins. The nature and extent of failure is an important consideration.

for foreseeable future activities at the site that may also give rise to exposure. Particularly in this case the regulatory body should require the operating organization(s) of the nuclear installation on the site to develop constraints, subject to regulatory approval, or ~~in some cases~~ the regulatory body may establish the dose constraint(s). Requirements on dose constraints are provided in Ref. [10] and guidance in Ref [11].

~~2.1.~~2.3. The design and storage of spent fuel must be carried out in such a way that workers, the public and the environment, present and future, will be protected against the harmful effects of radiation from all sources of exposures that could arise from current activities with spent fuel at the site, leaving if appropriate, sufficient margins [9, 10].

~~2.2.~~2.4. Discharges to the environment from spent fuel storage facilities should be controlled in accordance with the conditions imposed by the national regulatory body and be included when estimating dose to workers and the public.

~~2.3.~~2.5. The adequacy of control measures taken to limit the radiation exposure of the workers and the public should be verified by the monitoring and surveillance both inside and outside of the facility.

~~2.4.~~2.6. In the generation and storage of spent fuel, as well as in subsequent management steps, a safety culture should be fostered and maintained to encourage a questioning and learning attitude to 'protection' and 'safety' and to discourage complacency [3, 10, 12, 13].

3. ROLES AND RESPONSIBILITIES

GENERAL

Requirement 1 (GSR Part 5): Legal and regulatory framework **The government shall provide for an appropriate national legal and regulatory framework within which radioactive waste management activities can be planned and safely carried out. This shall include the clear and unequivocal allocation of responsibilities, the securing of financial and other resources, and the provision of independent regulatory functions. Protection shall also be provided beyond national borders as appropriate and necessary for neighbouring States that may be affected.**

Requirement 6 (GSR Part 5): Interdependences **Interdependences among all steps in the predisposal management of radioactive waste, as well as the impact of the anticipated disposal option, shall be appropriately taken into account.**

~~4.1.~~3.1. Storage of spent fuel should be undertaken within an appropriate national legal and regulatory framework that provides for a clear allocation of responsibilities [14], including responsibilities for international obligations and for verifying compliance, and ensures the effective regulatory control of the facilities and activities concerned [3, 4]. The national legal framework should also ensure compliance with other relevant national and international legal instruments, such as the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [1].

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~~3.3.~~3.2. The management of spent fuel may entail the transfer of spent fuel from one operating organization to another and various interdependencies exist among the various steps in the management of spent fuel. The legal framework should include provisions to ensure a clear allocation of responsibility for safety throughout the entire process, in particular, with respect to storage, including the transfer between operating organizations. The continuity of responsibility for safety should be ensured by means of authorizations by the regulatory body. For transfers between Member States, authorizations from the respective national regulatory bodies should be obtained [1, 15].

~~3.4.~~3.3. The responsibilities of the regulatory body[2], the operating organization and when appropriate the spent fuel owner in respect of spent fuel management should be clearly specified and functionally separated.

~~3.5.~~3.4. A mechanism for providing adequate financial resources should be established to cover any future costs, in particular, the costs of the spent fuel after storage decommissioning and also the costs of managing radioactive waste. The financial mechanism should be established before licensing and eventual operation and should be updated, as necessary. Considerations should also be given to providing the necessary financial resources in the event of premature shutdown of the spent fuel storage facility.

RESPONSIBILITIES OF THE GOVERNMENT

Requirement 2 (GSR Part 5): National policy and strategy on radioactive waste management **To assure the effective management and control of radioactive waste, the government shall ensure that a national policy and a strategy for radioactive waste management are established. The policy and strategy shall be appropriate for the nature and the amount of the radioactive waste in the State, shall indicate the regulatory control required, and shall consider relevant societal factors. The policy and strategy shall be compatible with the Fundamental Safety Principles [2] and with international instruments, conventions and codes that have been ratified by the State. The national policy and strategy shall form the basis for decision making with respect to the management of radioactive waste.**

~~4.2.~~3.5. The government is responsible for establishing a national policy and corresponding strategies for the management of spent fuel and for providing the legal and regulatory framework necessary to implement the policies and strategies. These policies and strategies should address all types of spent fuel and spent fuel storage facilities in the Member State, taking into account the interdependencies between the various stages of spent fuel management, the time periods involved and the options available.

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[2] The regulatory body may be one or a number of regulatory authorities with responsibility for the facility or activity.

~~4.3.~~3.6. The government is responsible for establishing a regulatory body independent from the spent fuel owners and spent fuel management operating organizations, with adequate authority, power, staffing and financial resources to discharge its assigned responsibilities [14].

~~4.4.~~3.7. The government should consult interested parties (i.e. those who are involved in or are affected by spent fuel management activities) on matters relating to the development of policies and strategies that affect the management of spent fuel.

~~4.5.~~3.8. In the event that circumstances change and require storage beyond the storage period envisaged in the national strategy a re-evaluation of the storage strategy should be initiated.

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RESPONSIBILITIES OF THE REGULATORY BODY

Requirement 3 (GSR Part 5): Responsibilities of the regulatory body
The regulatory body shall establish the requirements for the development of radioactive waste management facilities and activities and shall set out procedures for meeting the requirements for the various stages of the licensing process. The regulatory body shall review and assess the safety case and the environmental impact assessment for radioactive waste management facilities and activities, as prepared by the operator both prior to authorization and periodically during operation. The regulatory body shall provide for the issuing, amending, suspension or revoking of licences, subject to any necessary conditions. The regulatory body shall carry out activities to verify that the operator meets these conditions. Enforcement actions shall be taken as necessary by the regulatory body in the event of deviations from, or non-compliance with, requirements and conditions.

~~3.6.~~3.9. Regulatory responsibilities may include contributing to the technical input for defining policies, safety principles and associated criteria, and for establishing regulations or conditions to serve as the basis for regulatory activities. The regulatory body should also provide guidance to operating organizations on requirements relating to the safe storage of spent fuel.

~~3.7.~~3.10. Since spent fuel may be stored for long periods of time prior to its retrieval for reprocessing or disposal, the regulatory body should verify that the operating organization is providing the necessary personnel, technical and financial resources for the lifetime of the spent fuel storage facility, to the extent that such confirmation is within its statutory obligations.

~~3.8.~~3.11. The regulatory review of the decommissioning plans for spent fuel storage facilities should follow a graded approach, particularly considering the phases in the storage facility lifetime. The initial decommissioning plan should be conceptual and should be reviewed by the regulator for overall completeness rather than specific decommissioning arrangements, but should include specifically how financial and human resources and the availability of the necessary information from the design, construction and operational phases will be assured for when the decommissioning takes place. The decommissioning plan should be regularly updated by the licensee and reviewed by the regulatory body. If a facility is shut down and no longer used for its intended purpose, a final decommissioning plan should be submitted to the regulatory body for both review and approval.

~~3.9.~~3.12. General recommendations for regulatory inspection and enforcement actions related to spent fuel storage facilities are provided in Ref. [16]. The regulatory body should periodically verify that the key aspects of the operation of the storage facility meet the requirements of the national legal system and facility license conditions, such as the keeping of records on inventories and material transfers, compliance with acceptance criteria for storage, maintenance, inspection, testing and surveillance, operational limits and conditions, physical protection of nuclear material and emergency arrangements. This may be carried out, for example, by routine inspections of the spent fuel storage facility and audits of the operating organization. The regulatory body should confirm that the necessary records are prepared and that they are maintained for an appropriate period of time. A suggested list of records is included in Ref. [17].

~~3.10.~~3.13. The regulatory body should set up appropriate means of informing interested parties, such as persons living in the vicinity, the general public, information media and others about the safety aspects (including health and environmental aspects) of the spent fuel storage facilities and about regulatory processes and consult these parties, as appropriate, in an open and inclusive manner. Demands for confidentiality, e.g. for security reasons, should be respected.

~~3.11.~~3.14. The regulatory body should consider the licensing strategy to be adopted, for example:

(a) Licence issued for the entire lifetime of the storage system/facility that encompasses the whole anticipated operating period with periodical reviews of safety assessments as elaborated in section 5, or

(b) Licence issued for a specified time period with the possibility of its renewal after expiration

~~3.12.~~3.15. If the regulatory body consists of more than one authority, effective arrangements should be made to ensure that regulatory responsibilities and functions are clearly defined and co-ordinated in order to avoid any omissions or unnecessary duplication and to prevent conflicting requirements being placed on the operating organization. The main regulatory functions of review and assessment and inspection and enforcement should be organized in such a way as to achieve consistency and to enable the necessary feedback and exchange of information.

RESPONSIBILITIES OF THE OPERATOR[3]

Requirement 4 (GSR Part 5): Responsibilities of the operator

[3] The operator is assumed to be a licensee. If the facility is operated under contract the interface between responsibilities of the licensee and contracted operational management should be clearly defined, agreed and documented.

Operators shall be responsible for the safety of predisposal radioactive waste[4] management facilities or activities. The operator shall carry out safety assessments and shall develop a safety case, and shall ensure that the necessary activities for siting, design, construction, commissioning, operation, shutdown and decommissioning are carried out in compliance with legal and regulatory requirements.

~~3.13.~~3.16. The operator is responsible for the safety of all activities associated with the storage of spent fuel (including activities undertaken by contractors), and for the identification and implementation of the programmes and procedures necessary to ensure safety. The operator should maintain a high level of safety culture and demonstrate safety. In some instances the operator may own the fuel and in other cases the owner may be a separate organisation. In the latter instance the interdependencies, including any activity prior to receipt of the spent fuel, such as characterization or packaging or subsequent transport from the facility should be considered to ensure that conditions for safety will be met

~~3.14.~~3.17. The responsibilities of the operating organization of a spent fuel storage facility would typically include:

(a) Applying to the regulatory body for permission to site, design, construct, commission, operate, modify or decommission a spent fuel storage facility;

(b) Conducting appropriate safety and environmental assessments to support the application for a licence;

(c) Operating the spent fuel storage facility in accordance with the requirements of the safety case, the licence conditions and the applicable regulations;

(d) Developing and applying acceptance criteria for the storage of spent fuel as approved by the regulatory body; and

(e) Providing periodic reports as required by the regulatory body (e.g. information on the actual inventory, any transfers of spent fuel into and out of the facility and any reportable events that occur at the facility) and communicating with relevant stakeholders and the general public.

~~3.15.~~3.18. Prior to the authorization of a spent fuel storage facility, the operating organization should provide the regulatory body with a safety case[5] that demonstrates the safety of the proposed activities and demonstrates that the activities are in compliance with the safety requirements and criteria set out in national laws and regulations. The operating organization should use the safety assessment to establish specific operational limits and conditions. The operating organization may wish to set an

[4] As indicated in the introduction (para 1.1) no difference is made between spent fuel considered as waste or as resource material in respect of safety.

[5] A collection of arguments and evidence in support of the safety of a facility or activity. This collection of argument and evidence may be known by different names such as a safety report, a safety dossier, a safety file etc in different countries and may be presented in a single or a series of documents. (See Section 5).

operational target level below these specified limits to assist in avoiding any breach of approved limits and conditions (see para. 6.106).

3.19. At an early stage in the lifetime of a spent fuel storage facility, the operating organization should prepare preliminary plans for its eventual decommissioning. For new facilities, features facilitating decommissioning should be taken into consideration at the design stage and should be compiled into a decommissioning plan together with arrangements for how availability of the necessary human and financial resources and information will be assured for presentation in the safety case. Requirements on decommissioning are provided in Ref. [19] and guidance in Ref. [19].

3.20. For existing facilities without a decommissioning plan, plans should be prepared as soon as possible. Requirements on decommissioning are provided in Ref. [19] and guidance in Ref. [19].

3.21. The operating organization should establish the training and qualification requirements for its staff and contractors, including initial and periodic refresher training. The operating organization should ensure that all concerned staff members understand the nature of the spent fuel, its potential hazards and the relevant operating and safety procedures. Supervisory staff should be competent to perform their activities and should therefore be selected, trained, qualified and authorized for that purpose. A radiation protection officer should be appointed to oversee the application of radiation protection requirements.

3.22. The operating organization should carry out pre-operational tests and commissioning tests to demonstrate compliance with the requirements of the safety assessment and with the safety requirements established by the regulatory body.

3.23. The operating organization should ensure that discharges of radioactive and other potentially hazardous materials to the environment are in accordance with the conditions of licence. Discharges should be documented.

3.24. The operating organization should prepare plans and implement programmes for personnel monitoring, area monitoring, environmental monitoring, and for emergency preparedness and response (see para. 6.44).

3.25. The operating organization should establish a process on how to authorize and make modifications to the spent fuel storage facility, storage conditions, or the spent fuel to be stored, that is appropriate given the significance of the modifications. The process should evaluate the potential consequences of the modifications, including consequences on the safety of other facilities and also on the retrieval, reprocessing or disposal of spent fuel.

3.26. The operating organization should put in place appropriate mechanisms to ensure that sufficient financial resources are available to undertake all necessary tasks throughout the lifetime of the facility, including its decommissioning [14].

3.27. The operating organization should develop and maintain a records system on spent fuel data and on the storage system, which includes the radioactive inventory, location and characteristics of the spent fuel, information on ownership, origin and information about its characterization. There should be an unequivocal identification with a marking system that will last for the storage period. These records should be preserved and updated, to enable the implementation of the spent fuel management strategy whether disposal or reprocessing

3.28. The operator should draw up emergency plans based on the potential radiological impacts of accidents [20, 21] and be prepared to respond to accidents at all times as indicated in the emergency plans (See para 6.77).

RESPONSIBILITIES OF THE SPENT FUEL OWNER

Requirement 6 (GSR Part 5): Interdependences
Interdependences among all steps in the predisposal management of radioactive waste, as well as the impact of the anticipated disposal option, shall be appropriately taken into account.

3.29. There should be clear and unequivocal ownership of the spent fuel stored in the facility. The interface between the responsibilities of the operator and the spent fuel owner, if they differ, should be clearly defined, agreed upon and documented. The spent fuel owner, i.e. a body having legal title to spent fuel, including financial liabilities (usually the spent fuel producer), should be responsible for the overall strategy for the management of its spent fuel, taking into account interdependencies between all stages of spent fuel management, options available and the overall national spent fuel management strategy. The owner should analyse the available options, justify the reasons for the approach chosen and provide the regulatory body with plans for the management of the spent fuel beyond the anticipated storage period (which should be in line with approved national policy) together with justification for the plans. These plans should be periodically updated as needed and specifically before the end of the storage period.

3.30. Information about changes of spent fuel ownership or about changes in the relationship between the owner and the operator of a spent fuel storage facility should be provided to the regulatory body.

ACCOUNTING AND CONTROL OF NUCLEAR MATERIAL AND PHYSICAL PROTECTION SYSTEMS

Requirement 21 (GSR Part 5): System of accounting for and control of nuclear material
For facilities subject to agreements on nuclear material accounting[5], in the design and operation of predisposal radioactive waste management facilities the system of accounting for and control of nuclear material shall be implemented in such a way so as not to compromise the safety of the facility.

Requirement 5 (GSR Part 5): Requirements in respect of security measures
Measures shall be implemented to ensure an integrated approach to safety and security in the predisposal management of radioactive waste.

3.31. The operating organization will be required to establish, maintain and implement a system for nuclear material accounting and control as an integrated part of the State System of Accounting for and Control (SSAC)[6] of nuclear material. In addition physical protection systems to detect and deter the intrusion of unauthorized persons and prevent sabotage from inside and outside will be designed and installed during the construction and operation of the spent fuel storage facility. The implications of these systems and arrangements on the safety of the facility should be assessed and it should be ensured that no safety functions will be compromised nor that the overall level of safety will be significantly reduced on account of these systems and arrangements.

4. MANAGEMENT SYSTEM

Requirement 7 (GSR Part 5): Management systems
Management systems shall be applied for all steps and elements of the predisposal management of radioactive waste.

~~5.1.~~4.1. The requirements on management systems for each stage in the lifetime of a spent fuel storage facility are established in Ref. [6]. The safety guide for the management system for the spent fuel storage is published in [22].

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~~5.2.~~4.2. A management system is required to be established, implemented, assessed and continually improved by the operating organization [6], and should be applied to all stages of the storage of spent fuel that have a bearing on safety. It should be aligned with the goals of the operating organization and should contribute to its achievement. The scope of the management system should include siting, design, commissioning, operation, maintenance and ~~,~~ decommissioning ~~and long term management~~ of the spent fuel storage facility. The management system should be designed to ensure that the safety of the spent fuel and of the spent fuel storage facility is maintained, and that the quality of the records and of

[6] NPT safeguards agreements contain the obligation of the State to establish and maintain a "State's system of accountancy for and control of nuclear material". The Agency document describing the structure and content of NPT safeguards agreements, INFCIRC/153, also known as the "Blue Book", lays down the basic requirements for a State's system of accounting for and control of nuclear material — SSAC for short.

subsidiary information of spent fuel inventories is preserved, with account taken of the length of the storage period and the consecutive management steps, for example reprocessing or disposal. A management system should also contain provisions to ensure that the achievement of its goals can be demonstrated.

4.3 The long term nature of spent fuel management operations means that particular attention should be paid to establishing and maintaining confidence that the performance of the spent fuel storage facilities and activities will meet the requirements for the lifetime of the facility through to the end of decommissioning (e.g. creating the funding arrangements that will be necessary to manage the spent fuel in the long term).

SPENT FUEL MANAGEMENT

4.4 National and international policies and principles for spent fuel management that currently constitute an accepted management arrangement can evolve over the lifetime of the facility. Policy decisions (e.g. regarding fuel reprocessing) and technological innovations and advances (e.g. in partitioning and transmutation) can lead to fundamental changes in the overall spent fuel management strategy. However, management will retain its responsibility for all activities at all times, and continuous commitment by management will remain a prerequisite to ensuring safety and the protection of human health and the environment.

4.5 For the plans, goals and objectives that define the strategy for achieving an integrated approach to safety, interactions with all interested parties should be considered, as well as long term aspects such as: (a) Providing adequate resources (the adequacy of resources for maintenance may need to be periodically reviewed over operational periods that may extend over decades); (b) Preserving technology and knowledge and transferring it to people joining the programme or the organization in the future; (c) Retaining or transferring ownership of spent fuel and spent fuel management facilities; (d) Succession planning for the programme's or organization's technical and managerial human resources; (e) Continuing arrangements for interacting with interested parties.

RESOURCE MANAGEMENT

4.6 Spent fuel management activities will require financial and human resources, and the necessary infrastructure within the site where the ~~working environment~~ spent fuel storage facility is located. Senior management should be responsible for making arrangements to provide adequate resources for spent fuel management activities, to satisfy the demands imposed by the safety, health, environmental, security, quality and economic aspects associated with the full range of activities involved and the potentially long duration of the activities.

4.7 Funding arrangements for future spent fuel management activities should be specified, and responsibilities, mechanisms and schedules for providing the funds should be established in due time. The ~~generator~~owner of the spent fuel should establish an appropriate funding mechanism.

4.8 Management systems for spent fuel management activities should include provisions to deal with several funding challenges: (a) For various reasons (e.g. bankruptcy, cessation of business), it may not be feasible to obtain the necessary funds from the spent fuel generator, especially if funds were not set aside at the time the benefits were received from the activity, or if ownership has been transferred to other parties. (b) If funds are to come from public sources, this will compete with other demands for public funding, and it may be difficult to gain access to adequate funds on a timely basis. (c) It may be difficult to make realistic estimates of costs for spent fuel management activities that are still in the planning stage and for which no experience has been accumulated. (d) It may be difficult to estimate anticipated costs for activities that will only begin in the long term, because they will depend strongly on assumptions made about future inflation rates, bank interest rates and technological developments. (e) It may be difficult to set appropriate risk and contingency factors to be built into estimates of future costs, owing to the uncertainty associated with unforeseeable future changes in societal demands, political imperatives, public opinion and the nature of unplanned events that may require resources for dealing with them. (f) If several organizations are involved in the spent fuel management activities, the necessary financial arrangements may be complex and variable. The establishment of an adequate degree of confidence in all the arrangements so that the necessary continuity of funding throughout the entire series of activities is ensured may be problematic.

4.9 Accumulated experience, including lessons learned from incidents and events should be reviewed periodically and used in revising training programmes and in future decision making.

4.10 In designing facilities for long term spent fuel management activities, consideration should be given to incorporating measures for ease of operation, maintenance of equipment and eventual decommissioning of the facility. For long term spent fuel management activities, future infrastructural requirements should be specified and plans should be made to ensure that these will be met. In such planning, consideration should be given to the continuing need for support services, for spare parts for equipment that may eventually no longer be manufactured, for equipment upgrades to meet new regulations and operational improvements, and for the evolution and inevitable obsolescence of software. Consideration should also be given to the need to develop monitoring programmes and inspection techniques for use during extended periods of storage.

4.11 Consideration should be given to the possible need to relocate spent fuel casks if problems arise after they have been placed in storage (e.g. threats to the integrity of caskspackages or problems associated with criticality or decay heat). The availability of any specialized equipment that may be required over a long time period while spent fuel is in storage or that may be required in the future should be assessed.

4.12 Records about the spent fuel and its storage that need to be retained for an extended period should be stored in a manner that minimizes the likelihood and consequences of loss, damage or deterioration due to unpredictable events such as fire, flood or other natural or human initiated occurrences. Storage arrangements for records should meet the requirements prescribed by the national authorities or the regulatory body. This retention status should be periodically reassessed. When unpredictable events lead to the inadvertent destruction of records, the status of surviving records should be examined and the importance of their retention and their necessary retention periods should be re-evaluated.

4.13 Management systems should be reassessed whenever the owner/operator structure changes (e.g. public organizations are privatized, new organizations are created, existing organizations are combined or restructured, responsibilities are transferred between organizations, or operating organizations undergo internal reorganization of the management structure or the reallocation of resources).

5. SAFETY CASE AND SAFETY ASSESSMENT

Requirement 13 (GSR Part 5): Preparation of the safety case and supporting safety assessment
The operator shall prepare a safety case and a supporting safety assessment. In the case of a step by step development, or in the event of the modification of the facility or activity, the safety case and its supporting safety assessment shall be reviewed and updated as necessary.

Requirement 14 (GSR Part 5): Scope of the safety case and supporting safety assessment
The safety case for a predisposal radioactive waste management facility shall include a description of how all the safety aspects of the site, the design, operation, shutdown and decommissioning of the facility, and the managerial controls satisfy the regulatory requirements. The safety case and its supporting safety assessment shall demonstrate the level of protection provided and shall provide assurance to the regulatory body that safety requirements will be met.

Requirement 22 (GSR Part 5): Existing facilities
The safety at existing facilities shall be reviewed to verify compliance with requirements. Safety related upgrades shall be made by the operator in line with national policies and as required by the regulatory body *(some recommendations to be developed)*

5.3.5.1. In demonstrating the safety of the spent fuel storage facility and related activities a safety case should be developed together with the development of the facility and supporting safety assessment should be carried out in a structured and systematic manner. Proposed facilities, process, operations, activities, etc., should be examined to determine if they can be implemented safely and meet all requirements regarding safety [21]. If ~~n the end of~~ storage casks ~~being~~ are used, there may be one or separate safety cases and or safety assessment(s) for the storage casks, the storage building or facility and subsequent transport arrangement if the cask will be used eventually for transport as well as storage. This will depend on the national regulatory approach, however whatever approach is taken, the interdependencies should be taken into consideration such that an integrated approach to safety is adopted and safety is optimized. The safety case and supporting safety assessment should provide the primary input to the licensing documentation required to demonstrate compliance with regulatory requirements [5].

~~5.4.~~5.2. The different stages in the life time of the spent fuel storage facility (i.e. siting, design, construction, commissioning, operation and decommissioning) should be taken into account in the safety assessment. The safety assessment should be periodically reviewed in accordance with regulatory requirements and revised as necessary.

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~~5.5.~~5.3. The Fundamental Safety Principles [9] place the prime responsibility for safety throughout the lifetime of a facility on the operating organization. This includes the responsibility for ensuring and demonstrating safety of a facility. The safety assessment is an important aspect to ensure and demonstrate the safety of nuclear facilities.

~~5.6.~~5.4. Comprehensive guidance on development of a safety case and supporting safety assessment, together with review by the regulatory body is provided in reference [21]. Guidance is provided on the objectives of the safety case and development of the safety case and the approach to structuring and carrying out safety assessment. Specific issues are addressed in particular the evolution of the safety case with the development of the facility, assessment of measures to provide defence in depth and aspects related to longer term storage.

~~5.7.~~5.5. Longer term storage, may involve a period of time which exceeds the normal design life of civil structures including short term storage facilities and this will have implications for the choice of materials, operating methods, quality assurance and quality control requirements, etc. Specific issues that should be given special consideration in the safety case for longer term storage include the assumed facility lifetime, the importance of passive safety features, retrievability and management systems. Consideration should also be given to the provision of supporting services when the lifetime of the spent fuel storage facility is longer than other facilities on the site, in particular for storage facilities at reactor sites.

~~5.8.~~5.6. The rationale for selecting the assessment time frame should be explained and justified. Depending on the purposes of the assessment for longer term storage, it might be convenient to divide the overall time frame of the safety assessment into shorter time windows with different endpoints for modelling or presentational reasons.

~~5.9.~~5.7. The assessment time frame should be defined by taking account of the characteristics of the particular storage facility or activity, site, and the spent fuel to be stored. Other factors that should be considered when deciding on assessment time frames include:

- For most longer term storage systems (including storage casks, engineered constructions and surrounding environment) potential health and environmental impacts may rise for a period of time after commissioning of the facility. In the longer term, depending on the nature of the facility, impacts may decrease, in particular through decay of the radioactive inventory of the spent fuel. The safety assessment calculations should consider the maximum, or peak, dose or risk associated with the facility or activity.

- Another consideration which may influence decisions on time frames is the return period of natural external hazards such as extreme meteorological events or earthquakes.

- Several factors that can significantly affect safety assessment results may change with time such as the nature of; external hazards from anthropogenic activities such as the construction of nearby facilities, natural events such as the change in water levels or changes to the availability of supporting facilities and infrastructure due to shutdown and decommissioning of co located facilities. The assessment should consider these changes. As a means to assess the possible evolution of the longer term storage, assessments may consider one or more scenarios to reflect different evolution paths. Assessment time windows may be defined, as appropriate, to reflect the potential changes at the storage facility.

- The habits and characteristics of the radiation dose receptor group, as well as the conditions in which they are located, may change over time. Consequently, such receptors should be considered as hypothetical, but receptors and populations in the future should be afforded at least the same level of protection as is required at the present day. The habits and characteristics assumed for the group should be chosen on the basis of reasonably conservative and plausible assumptions, considering current lifestyles as well as the available site or regional environmental conditions.

~~5.10.~~5.8. The operator should demonstrate as soon as possible that, to the extent possible, passive safety features are applied. The assessment of longer term safety should account for the degradation of passive barriers over time.

~~5.11.~~5.9. The complementary performance of the different safety functions should be evaluated. Each safety function should be as independent as possible from the others to ensure that they are complementary and cannot fail through a single failure mode. The safety case should explain and justify the functions provided by each barrier and identify the time periods over which they are expected to perform their various safety functions and also the alternative or additional safety functions that operate if a barrier does not fully perform.

~~5.12.~~5.10. Similar to disposal situations, the environment may also offer additional protective barriers (e.g. underlying clay layers which would provide a sorption capacity for contaminants in cases of any leakages from the facility). Such aspects should be taken into account during the siting of the facility and considered in the safety case.

~~5.13.~~5.11. Storage is by definition an interim measure, but it can last for several decades. The intention in storing spent fuel is that it can be retrieved for reprocessing or processing and/or disposal at a later time. The safety case should consider a plan for safe handling of the spent fuel following the period of storage and assess the potential effects of degradation of the spent fuel and or any elements of containment on the ability to retrieve and handle the spent fuel (see also section 6).

~~5.14.~~5.12. The possibility of inadvertent human intrusion normally would not be considered relevant when assessing the safety of a storage facility because the facility will require continued surveillance and maintenance not only during but also after the spent fuel emplacement phase. The prevention of intentional human intrusion requires adequate security arrangements and these should be addressed in the safety case and confidence needs to be built in their long term effectiveness.

~~5.15.~~5.13. Because storage is an interim measure, the safety case should describe the provisions for the regular monitoring, inspection and maintenance of the storage facility to ensure its continued integrity over the anticipated lifetime of the facility.

~~5.16.~~5.14. Because of the long time frames potentially involved, the safety case should also consider a plan for adequate record keeping over the expected time frame for storage.

~~5.17.~~5.15. Periodically, the safety case should be reviewed to consider the continuing adequacy of the storage capacity, with account taken of the predicted waste arising, both for normal operation and for possible incidents, the expected lifetime of the storage facility and the availability of reprocessing or disposal options.

~~5.18.~~5.16. It may be required to reassess the anticipated impacts of decommissioning after operational experience has been gained.

~~5.19.~~5.17. The requirement to perform a safety assessment comes from national programme requirements and the realization that the safety assessment can contribute directly to safety by identifying appropriate measures that can be put in place to protect the workers, the public and the environment. Safety assessment is undertaken in conjunction with the planning and design of a proposed facility or activity rather than being a separate activity. The results of the safety assessment can be used to determine any necessary changes in the plans or designs so that compliance with all requirements is assured. They are also used to establish controls and limitations on the design, construction and operation of the facility.

~~5.20.~~5.18. Safety assessment is typically an iterative process used to ensure that a spent fuel storage facility can be operated safely and should be used early in the design process. Generally, reliance should be placed principally on design features rather than on operational procedures in the control of radiation hazards.

~~5.21.~~5.19. The postulated initiating events that may influence the design of the spent fuel storage facility and the integrity and safety of the spent fuel should be identified. The primary causes of postulated initiating events may be credible equipment failures and operator errors or human induced or natural events (both within and external to the facility). In identifying the postulated initiating events, generic lists should be consulted (See Annexes 3,4 and 5). They should not be solely relied on, since site specific environmental conditions and phenomena and the design and operation of the facility will also influence the decision as to which postulated initiating event should be evaluated in the safety assessment.~~ There may be significant non-radiological hazards associated with the storage of spent fuel. If non-radiological properties such as corrosiveness, flammability, explosiveness and toxicity may affect the safe management of the radiological hazard, then these should be taken into consideration during the safety assessment~~.

~~5.22.~~5.20. The safety assessment should cover the storage facility and the type of spent fuel to be stored and storage arrangements. In this regard the types, quantities, initial enrichment, burnup, fuel integrity, heat production, storage mode (wet or dry storage) and physical and chemical characteristics of the spent fuel represent basic elements that need to be available in the safety assessment of spent fuel storage facilities.

~~5.23.~~5.21. The safety assessment of a spent fuel storage facility should encompass the expected operational period of the facility. The storage of spent fuel for long periods of time would require events of lower likelihood to be evaluated in the safety assessment than for a shorter duration of storage. Processes that may not be relevant for a shorter duration of storage may become significant for a longer duration of storage (e.g. generation of gas, general corrosion, stress corrosion, radiation or hydride induced embrittlement of cladding material, natural processes such as vermin infestation and possible ~~slow increase~~change of nuclear reactivity over a long time).

~~5.24.~~5.22. A facility specific safety case and supporting assessment would include aspects such as:

(a) Description of the site and facility (including the maximum expected inventory of spent fuel and its acceptance criteria, the storage facility and its characteristics, structures, systems and components, including the characteristics of the items important to the safety of the spent fuel storage facility, in accordance with the requirements of the licence) and a specification of the applicable regulations and guidance.

(b) Description of spent fuel handling and storage activities and any other type of operation

(c) Systematic identification of hazards and scenarios associated with operational states and accident conditions and external events (e.g. fires, handling accidents and ~~analysis of the~~ seismic events~~situation~~).

(d) An evaluation of hazards and scenarios ~~to include screening of their combinations~~ that may result in the release of radioactive material, including a screening mechanism ~~,~~ to eliminate those hazards or combinations of hazards that are of insufficient likelihood or consequence.

(e) Assessment of the probabilities and consequences of the release(s) of radioactive material identified in the hazard evaluation by quantitative analysis and comparison of the results of that assessment with regulatory limits.

(f) Establishment of operational limits, conditions and administrative controls based on the safety assessment. If necessary, the design of the spent fuel storage facility has to be modified and the safety assessment has to be updated~~If necessary, the design of the spent fuel storage facility is modified and the safety assessment is updated~~. This should include acceptance criteria for spent fuel casks, including canisters containing failed fuel.

(g) Documenting safety analyses and the safety assessment in the documentation supporting the licensing of the facility.

(h) Commissioning programme.

(i) The organizational control of the operations.

(j) Procedures and operational manuals for activities with significant safety implications.

(k) A programme for periodic maintenance, inspections and testing.

(l) The expected values for sub criticality, heat removal capacity and calculated radiation doses inside and at the boundary of the spent fuel storage facility.

(m) Monitoring programmes, including shielding verification, a programme for surveillance of the condition of stored spent fuel and a programme of surveillance of the stored spent fuel assemblies if appropriate. .

(n) An operational feedback programme.

(o) The training programme for staff.

(p) Safety implications of safeguards aspects.

(q) Physical protection arrangements for radioactive materials.

(r) Emergency preparedness and response plan.

(s) The management system.

(t) Provisions for radiation protection and

(u) Provisions for the management of radioactive waste and decommissioning.

~~5.25.~~5.23. The safety assessment should identify the key hazards so that the required safety functions and safety systems are identified and so that a level of confidence in the parameters supporting the safety assessment can be established that is commensurate with their significance (e.g. by sensitivity analysis).

~~5.26.~~5.24. The safety assessment should include an assessment of hazards during operational states and under accident conditions. It should provide an assessment of doses at the site boundary and potential exposures in areas where there is to be unrestricted access. Under normal operation, spent fuel storage facilities have no sources for a fast increase of nuclear reactivity and as such there are relatively few credible mechanisms for a sudden excursion followed by release of radioactive material.

~~5.27.~~5.25. As appropriate, limitations on authorized discharges should be established for the spent fuel storage facility, following the guidance provided in Ref. [23].

~~5.28.~~5.26. An initial safety assessment that yields results that are close to or exceed the limiting performance objectives would suggest the need for a more rigorous evaluation of the suitability of generic data sources that may have been used, and/or an inventory reduction or additional safety systems and controls.

Requirement 16 (GSR Part 5): Periodic safety reviews
The operator shall carry out periodic safety reviews and shall implement any safety upgrades required by the regulatory body following this review. The results of the periodic safety review shall be reflected in the updated version of the safety case for the facility.

~~5.29.~~5.27. The safety case and supporting safety assessments including their implementing management systems should be periodically reviewed in accordance with regulatory requirements. The review of management systems should include aspects of safety culture. In addition, they should be reviewed and updated:

(a) When there is any significant change to the installation or permitted radionuclide inventory that affects safety;

(b) When changes occur in the site characteristics that may impact on the storage facility, e.g. industrial development, nearby population;

(c) When significant changes in knowledge and understanding occur (such as from research data or operational experience feedback);

(d) When there is an emerging safety issue due to a regulatory concern or an incident; and

(e) Periodically at predefined periods as specified by the regulatory body. Some Member States specify not less than once in ten years.

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Safety should be reassessed in the case of significant, unexpected deviations in the storage conditions, e.g. if safety relevant spent fuel properties change and begin to deviate from those taken as a basis in the safety assessment.

For storage beyond the original design lifetime a re-evaluation of the initial design (and the existing design if significantly changed), the operations, maintenance, aging management, the safety assessment and any other aspect of the spent fuel storage facility relating to safety should be performed. If during the design lifetime it is foreseen that an extension to the storage period may be required, then a precautionary approach should be applied in particular validating the adequacy of design assumption for the extended periods envisaged.

DOCUMENTATION OF THE SAFETY CASE

Requirement 15 (GSR Part 5): Documentation of the safety case and supporting safety assessment
The safety case and its supporting safety assessment shall be documented at a level of detail and to a quality sufficient to demonstrate safety, to support the decision at each stage and to allow for the independent review and approval of the safety case and safety assessment. The documentation shall be clearly written and shall include arguments justifying the approaches taken in the safety case on the basis of information that is traceable.

5.30.5.28. In documenting the safety case particular attention should be given to ensuring that the level of detail and supporting assessment is commensurate with the importance to safety of a particular system or component and their complexity, and that an independent reviewer will be able to come to a conclusion on the adequacy of the assessment and safety arguments, both in extent and depth. Assumptions must be justified as must the use of generic information.

6. GENERAL SAFETY CONSIDERATIONS FOR STORAGE OF SPENT FUEL

GENERAL

Requirement 11 (GSR Part 5): Storage of radioactive waste
Waste shall be stored in such a manner that it can be inspected, monitored, retrieved and preserved in a condition suitable for its subsequent management. Due account shall be taken of the expected period of storage, and to the extent possible passive safety features shall be applied. For long term storage[7] in particular, measures shall be taken to prevent the degradation of the waste containment.

Requirement 5 (GSR Part 5): Requirements in respect of security measures
Measures shall be implemented to ensure an integrated approach to safety and security in the predisposal management of radioactive waste.

Requirement 21 (GSR Part 5): System of accounting for and control of nuclear material
For facilities subject to agreements on nuclear material accounting5, in the design and operation of predisposal radioactive waste management facilities the system of accounting for and control of nuclear material shall be implemented in such a way so as not to compromise the safety of the facility.

6.1. Spent fuel storage facilities, should provide for the safe, stable and secure storage of spent fuel before it is reprocessed or disposed. The design features and facility operations should be such as to provide containment of radionuclides, to ensure that radiation protection of workers, members of the public and the environment is optimized within the dose constraints according to the requirements in the Ref. [10], to maintain subcriticality, to ensure removal of decay heat and to ensure retrievability of the spent fuel or spent fuel casks. These safety functions should be maintained during all operational states and accident conditions, taking into account external hazards.

6.2. Various types of wet and dry spent fuel storage facilities are in operation or under consideration. Spent fuel is stored in essentially three different modes:

(a) Wet storage in pools at, or remote from a reactor site. The spent fuel is stored in standard or compact storage racks with closer spacing of the fuel assemblies or fuel elements allowed, to increase the capacity of storage;

[7] See para 1.6

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(b) Dry storage in either dual purpose, (i.e. storage and transport) casks at or remote from a reactor site. Casks are modular in nature. These systems are sealed systems designed to prevent the release of radioactive material during storage. They provide shielding and containment of the spent fuel by physical barriers which may include the metal or concrete body and metal liner or metal canister and lids. They are usually circular in cross-section, with the long axis being either vertical or horizontal. The fuel position is maintained by a storage basket which may or may not be an integral part of the cask. Heat is removed from the stored fuel by conduction, radiation and forced or natural convection to the surrounding environment. Casks may be enclosed in buildings or stored in an open area; and

(c) Dry storage in vault type storage facilities: a vault is a massive, radiation shielded facility where spent fuel is stored. A vault can be either above or below ground level; it may be a reinforced concrete structure containing an array of storage cavities. The spent fuel is appropriately contained in order to prevent unacceptable releases of radioactive material. Shielding is provided by the structure surrounding the stored material. Primary heat removal is by forced or natural air convection over the exterior of the cavities. This heat is released to the atmosphere either directly or via appropriate filtration, depending upon the system design. Some systems also use a secondary cooling circuit. However, if natural convection is used, active components, e.g. pumps and ventilators, should be minimized with higher operational reliability of the system and corresponding cost reduction and higher operational reliability of the system.

6.3. Although designs of spent fuel storage facilities may differ, they should consist of relatively simple, preferably passive inherently safe systems, which are intended to provide adequate safety over the design life of the facility, this may span several decades. The lifetime of the spent fuel storage facility should be appropriate for the envisaged storage period. The design should also contain features to ensure that associated handling and storage operations are relatively straightforward. In general:

(a) The storage facility should be designed to fulfill the fundamental safety functions, i.e. control of subcriticality, removal of heat, containment of the radioactive material, retrievability and shielding of radiation. The design features should at least, if possible, include the following: If possible, systems for heat removal from the spent fuel should be driven by the energy generated by the spent fuel itself (e.g. natural convection);

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(b) A multi-barrier approach should be adopted in ensuring containment taking account all elements including the fuel matrix, the fuel cladding, the storage cask, the storage vaults, building structures etc as may be demonstrated to be reliable and competent;

(c) Safety systems should be designed to achieve their safety functions with a minimum reliance on monitoring;

(d) Safety systems should be designed to function with minimum human intervention;

(e) The storage building, or the cask in case of dry storage, should be resistant to the hazards taken into consideration in the Safety Assessment;

(f) Access should be provided for response to incidents;

(g) The spent fuel storage facility should enable retrieval of the spent fuel or spent fuel package for inspection or reworking;

(h) The spent fuel and the storage system should be sufficiently resistant to degradation;

(i) The storage environment should not adversely affect the properties of the spent fuel, any spent fuel package and the storage system;

(j) The spent fuel storage system should allow for inspections;

(k) The system should be designed to avoid or minimise the generation of secondary waste stream.

6.4. Security and access controls are required at spent fuel storage facilities to prevent the unauthorized access of individuals and the unauthorized removal of radioactive materials and should be compatible with the safety of the facility.

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DESIGN PROCESS

~~6.6.~~6.5 In the design process, appropriate analytical methods, procedures and tools should be used in conjunction with suitably selected input data and assumptions covering all operational states and credible accident conditions, taking also natural phenomena into account. Only verified and validated ~~numerical~~ methods should be used for predicting the consequences of operational states and accidents. The input data should be selected so as to be conservative, albeit realistic. Where possible conservatism should be quantified. Where uncertainties in input data, analyses or predictions are unavoidable, appropriate allowances should be made to compensate for such uncertainties. The sensitivity of the results to uncertainties should be evaluated.

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~~6.7.~~6.6. As part of the overall process leading to an acceptable design, its evolution and the supporting rationale should be clearly and adequately documented and kept readily available for future reference. The supporting documentation should be presented as a safety case. [5].

~~6.8.~~6.7. It should be demonstrated in the safety case that in the design, all ~~potential~~credible hazards and scenarios have been adequately analysed and appropriately addressed. The safety case should describe the performance assessment models and methodologies used and the resulting conclusions. Thus, for any design proposed, it should be demonstrated in the safety case that the spent fuel storage facility can, within the bounds of existing technology, be safely constructed, commissioned, operated and decommissioned in accordance with the design specifications and the requirements of the regulatory body.

~~6.9.~~6.8. The procedures related to the control of design modifications during subsequent stages should also be defined. Such modifications might be required to take into account the results of the safety case. The items important to safety, including their structures, systems and components, should be identified and classified according to their relative importance.

~~6.10.~~6.9. For storage beyond the original design lifetime, testing, examination and/or an evaluation may be necessary to assess the integrity of the spent fuel_or the storage cask. Careful consideration is needed of the approach to be adopted to prevent unnecessary worker exposure and the potential for accidental release of radioactivity. Potential problems with the integrity of the spent fuel or the storage cask should be considered in advance of the need arising for physical actions, such as placing the spent fuel into new casks. In some cases it may be necessary to move the storage casks to another storage facility where the building or structures within the building provide the necessary containment and isolation, rather than replacing the storage cask. In the case of considering extending storage periods in dry storage casks, assessment of the cask and spent fuel integrity, including survey of the casks for leak tightness may be sufficient to demonstrate that the spent fuel the storage period may be extended. In such cases it may be possible that the need for an immediate inspection of the content of the casks may be excluded. In considering extending the storage period beyond the design lifetime, all factors should be taken into consideration, in particular the radiation dose and potential accidents that could occur in opening the cask and removing the contents or inspecting them in situ. In the event that it is concluded that the storage period cannot be extended without undertaking an inspection of the fuel, all the necessary precautions should be taken in planning and undertaking the work. ~~The necessity for inspection of the spent fuel should be evaluated by an (extension of existing) accompanying investigation programme.~~

~~6.11.~~6.10. For storage beyond the original design lifetime, consideration should be given to mitigation of the consequences of potential changes in the storage facility and the stored spent fuel. Changes of the storage facility may be caused by radiation, heat generation, chemical or galvanic reactions. Changes in the stored spent fuel and storage cask may include:

(a) The generation of gases which may cause hazard, by chemical and radiolytic effects (e.g. the generation of hydrogen gas by radiolysis) and the build-up of overpressure;

(b) The generation of combustible or corrosive substances;

(c) The corrosion of metals; and

(d) Degradation of the spent fuel containment system.

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These considerations are especially important for storage beyond the original design lifetime for which small effects may accumulate over long periods of time.

CONSIDERATIONS FOR DESIGN OF SPENT FUEL STORAGE FACILITIES

Requirement 10 (GSR Part 5): Processing of radioactive waste
… The processing of radioactive waste shall be based on appropriate consideration of the characteristics of the waste and of the demands imposed by the different steps in its management (pretreatment, treatment, conditioning, transport, storage and disposal). Waste packages shall be designed and produced so that the radioactive material is appropriately contained during both normal operation and in accident conditions that could occur in the handling, storage, transport and disposal of waste.

Requirement 17 (GSR Part 5): Location and design of facilities
Predisposal radioactive waste management facilities shall be located and designed so as to ensure safety for the expected operating lifetime under both normal and possible accident conditions, and for their decommissioning.

DEFENCE IN DEPTH (NS-R-5)
2.4. The concept of defence in depth shall be applied at the facility for the prevention and mitigation of accidents (Principle 8 of Ref. [1]).

Siting

~~6.12.~~6.11. The Safety Requirements publication on Site Evaluation for Nuclear Installations [24] and the associated Safety Guides on the siting of nuclear power plants [25-31] contain criteria and methods that could be used in a graded approach in the siting of spent fuel storage facilities.

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Defence in depth

~~6.13.~~6.12. The concept of defence in depth should be applied to all safety activities, organizational, behavioural or design related, ensuring that if a failure were to occur, it would be detected and compensated for or corrected by appropriate measures [34]. Defence in depth should be applied during the siting of a spent fuel storage facility and in its design, as well when considering subcriticality, heat removal and containment and radiation protection issues. The concept of defence in depth should be applied to all safety activities, organizational, behavioural or design related, ensuring that if an accident were to occur, it would be detected and compensated for or corrected by appropriate measures [34]

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~~6.14.~~6.13. Application of the concept of defence in depth in the design of spent fuel storage should entail providing a series of levels of defence (inherent features, equipment and procedures) aimed at preventing accidents and ensuring appropriate protection in the event that prevention fails [34].

~~6.15.To prevent deviations from normal operation, and to prevent system failures, careful attention should be paid to the selection of appropriate design codes and materials, and to the control of fabrication of components and of spent fuel storage construction. In order to detect and intercept deviations from normal operational states, specific systems should be provided as determined in the safety case. The engineered safety features should be provided, that are capable of leading the spent fuel storage and its components subsequently to a safe conditions, maintaining at least one barrier for the containment of radioactive material. Finally, provision of adequately on-site and off-site emergency response should be ensured.~~

~~6.16.~~6.14. It is recommended that the facility should have a reserve storage capacity: this should be included in the design or is otherwise available, e.g. to allow reshuffling spent fuel casks or unpackaged spent fuel elements for inspection, retrieval or maintenance work. The reserve capacity should provide for the largest type of storage cask to be unloaded or in the case of a modular storage facility for at least one module to be unloaded.

Structural integrity

~~6.17.~~6.15. For the safety systems and safety related items to perform properly, the components of the spent fuel storage facility should maintain their structural integrity under all operational states and accident conditions. Therefore, the integrity of the components and their related systems should be demonstrated by a structural evaluation. This should take account of relevant loading conditions (stress, temperature, corrosive environment, radiation levels etc.), and should consider creep, fatigue, thermal stresses, corrosion and material property changes with time (e.g. concrete shrinkage).

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6.16. To prevent deviations from normal operation, and to prevent system failures, careful attention should be paid to the selection of appropriate design codes and materials, and to the control of fabrication of components and of spent fuel storage construction. In order to detect and intercept deviations from normal operational states, specific systems should be provided as determined in the safety case.

~~6.18.~~6.17. The integrity of the spent fuel and its required subcritical and heat removal geometries and its related containment barriers, should be maintained during the lifetime of the facility and should be verified using appropriate methods including both prospective analysis and through ongoing surveillance~~.~~

~~6.19.~~6.18. The allowable stresses for given conditions should comply with the applicable codes and standards. If no such standards apply, justification of the resulting stress levels should be given.

6.20.Safety related systems, structures, and components of a spent fuel storage facility should be designed to preserve their function during their design life. Provisions should be made for routine inspection, refurbishment, and replacement of parts during its design life.

6.21.6.19. The selection of structural materials and welding methods should be based upon accepted codes and standards. Consideration should be given to the potential cumulative effects of radiation on materials likely to be subjected to significant radiation fields. In addition, the potential thermal effects on material degradation should also be considered.

6.22.6.20. The materials of items important to safety, including those structures and components in direct contact with the spent fuel, should be compatible with the spent fuel and should minimize chemical and galvanic reactions which might degrade the integrity of the spent fuel during its storage not contaminate the spent fuel with substances which might significantly degrade the integrity of the spent fuel during its storage.

6.21. Detailed consideration should be given to the effects of the storage environment on the spent fuel and the items important to safety, i.e. structures, systems and components. In particular, the potential for the oxidation of exposed UO_2 to U_3O_8, with the consequent volume increase and particulate formation, should be considered. In addition, any effects of changes in storage environments (e.g. wet-dry-wet) should be assessed.

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6.23.Detailed consideration should be given to the effects of the storage environment on the spent fuel and the items important to safety, i.e. structures, systems and components. In particular, the potential for the oxidation of exposed UO_2 to U_3O_8, with the consequent volume increase and particulate formation, should be considered. In addition, any effects of changes in storage environments (e.g. wet-dry-wet) should be assessed.

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6.49.All items important to safety should have an adequate reliability over their design life commensurate with the radiological consequence of their failure.

6.50.6.22. As determined during the design, attaining an adequate reliability might require the use of durable construction materials, redundancy of key components, specifying the reliability of supporting services (e.g. electrical power supply), incorporating effective monitoring plans and efficient maintenance programmes (i.e. programmes compatible with normal facility operations).

6.24.6.23. The materials of construction should allow easy decontamination of surfaces. Compatibility of decontamination materials and the operating environments should be considered for all operational states and accident conditions.

6.24. The integrity of systems connected to spent fuel storage system such as heat removal system is also important. Tube failures and leaks in the spent fuel storage system should not be able to provide a path for chemical species detrimental to either fuel or containment integrity, such as chloride ions, to enter a spent fuel storage pond

~~6.24.~~6.25. Structural and mechanical loads

~~6.25.~~6.26. A full description of the structural and mechanical aspects of the design of the storage facility should be provided in sufficient detail to justify the basic design. Typical items include:

(a) Determination of loads due to the fuel, fuel storage casks and various components of the spent fuel storage facility under operational states and accident conditions;

(b) Foundation evaluation;

(c) Full structural evaluation of the safety systems of the spent fuel storage facility; and

(d) Evaluations of supporting features such as cranes, transfer vehicles and protective buildings.

In evaluating the structural integrity of the facility building and structures inside, justification should be provided for the structural and mechanical loads evaluated from off-normal and accident conditions such as storms, wind-driven missiles, earthquakes etc. and the acceptability criteria adopted for the responses to these loads. Consideration should be given to the storage conditions that may prevail following postulated initiating events, including external events, i.e. earthquakes, tornadoes, floods, etc., and their acceptability should be ensured by the design.

~~6.26.~~6.27. Care should be taken to consider all situations where handling mechanisms might malfunction,~~lead to jams,~~ leaving fuel elements or casks inadequately shielded or irrecoverable. Consideration should also be given to the possibility of the casks jamming within the spent fuel storage facility. In addition to the shielding issue, consideration should be given to whether the handling equipment and systems can enable recovery from such situations that could be endangered by the application of excessive stresses.

Thermal loads and processes

~~6.27.~~6.28. Considering the decay heat of the spent fuel, all thermal loads and processes should be given appropriate consideration in the design. Typical items include:

(a) Thermally induced stresses;

(b) Internally and externally generated pressures;

(c) Heat transfer requirements;

(d) Evaporation/water make-up requirements;

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(e) Effect of temperature on subcriticality.

Time dependent material processes

~~6.28.~~6.29. The anticipated lifetime of the storage facility will be a determining factor for topics such as corrosion, creep, fatigue, shrinkage, radiation induced changes and associated radiations fields. Consideration of the impact of these processes in the design of the storage facility should be provided.

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Subcriticality

~~6.29.~~6.30. A fundamental safety objective of all designs for spent fuel storage facilities is to ensure subcriticality of the entire system under all credible circumstances [3].

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~~6.30.~~6.31. The subcriticality of spent fuel may be ensured or influenced by a number of design factors and precautions. The physical layout and arrangement of the spent fuel storage facility should be designed in such a way as to ensure, through geometrically safe configurations, that subcriticality will be maintained during all operational states and credible accident conditions.

~~6.31.~~6.32. Where spent fuel cannot be maintained subcritical through geometrically safe configurations alone, additional means such as fixed neutron absorbers and/or the use of a burnup credit (see Appendix II paras.7 -11) could be used. If fixed neutron absorbers are used, it should be ensured by proper design and fabrication that the absorbers will not be separated or displaced during operational states and accident conditions. The effects of aging, corrosion and handling on the fixed neutron absorbers should also be taken into consideration.

~~6.32.~~6.33. Subcriticality can be influenced by internal and external hazards which have the potential to reconfigure the pre-existing spent fuel assembly array in such a way as to increase the potential for criticality. There is also a need to consider routine fuel movements, which could bring the fuel being moved into close proximity to stored fuel or where during movement, the fuel if it was dropped could fall onto stored fuel. For operational states and accident conditions, the sequences of events leading to such abnormal fuel configurations should be evaluated. The possible consequences of such occurrences should be evaluated using reliable data and verified and validated methodologies. If warranted, appropriate mitigating measures should be provided to ensure that subcriticality will be maintained under all such conditions.

~~6.33.~~6.34. An adequate subcriticality margin on the effective neutron multiplication factor which is acceptable to the regulatory body should be maintained for operational states and credible accident conditions. A 5% margin, after inclusion of the uncertainties in the calculations and data, is being applied ~~has been used~~ in many Member States. For a dry spent fuel storage facility, the minimum margin should be ensured even under the situation of water flooding of the spent fuel storage locations unless flooding is precluded by location or design. The potential for re arrangement or compaction of fuel pins should also be considered in demonstrating the required subcriticality margin.

6.34.6.35. The most appropriate approach to estimate multiplication factors will depend on a number of factors including the type of reactor and spent fuel properties as well as the circumstances being addressed e.g. normal or accident conditions. A reasonably conservative estimate should be made of subcriticality (K_{eff} - effective neutron multiplication factor) taking into account:

(a) If the initial enrichment (of fissile materials U-235) within a fuel assembly and/or between fuel assemblies is variable, appropriate modeling should be used. Alternatively the highest enrichment may be used to conservatively appropriately characterise the fuel assembly.

(b) Where uncertainties exist in any data relating to the fuel (design, geometries, nuclear data, etc.) conservative values should be determined and used in all subcriticality calculations. If necessary, sensitivity analysis should be performed to quantify the effects of such uncertainties.

(c) Those geometric deformations to the fuel and storage equipment which might be caused by any postulated initiating events should be taken into account.

(d) Optimum moderation and reflection should be assumed for operational states and accident conditions to provide a pessimistic assessment of criticality. bearing in mind that the maximum keff should be evaluated based on a credible moderator density, which may not be optimum, if achieving optimum moderation is not credible. It is important to ensure that the system is subcritical for all credible water densities. The highest nuclear reactivity may be reached at some intermediate density, for example, if water in the pool begins to boil due to failure of the heat removal system or during drying of a cask. Flooding should be assumed in dry storage situations, unless precluded by location or design features.

(e)For certain accident conditions such as boron dilution, limited credit for soluble boron could be allowed considering the double contingency principle. By virtue of this principle, two unlikely independent and concurrent incidents are beyond the scope of required analysis.

(f)(e) Neutron moderation and reflection should be considered. Flooding should be assumed in dry storage situations.

(g)(f) The inventory of the spent fuel storage facility should be assumed to be at the maximum design capacity.

(h)Credit should not be claimed for neutron absorbing parts or components of the spent fuel storage facility unless they are fixed, their neutron absorbing capabilities can be determined, and they are demonstrated not to be degraded by any postulated initiating events.

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(i)(g) Consideration of the neutron absorbing characteristics of the fuel assembly may be included.

(j)(h) Consideration of the reactivity changes of the fuel assembly may be included although Nno allowance for the presence of burnable absorbers should be made unless on the basis of justification acceptable to the regulatory body, which should include consideration of the reduction of neutron absorption capability with burnup. If burnable absorbers are taken into account, the representative fuel should be assumed to correspond to the highest nuclear reactivity.

(k)(i) All fuel should be assumed to be at a burnup and enrichment value resulting in maximum nuclear reactivity unless credit for burnup is assumed on the basis of an adequate justification. Such justification should include an appropriate measurement or evaluation which directly or indirectly confirms the calculated values for fissile content or depletion level. For burnup credit application in long term storage, the possible change of the nuclide composition of the spent fuel with storage time has to be taken into account.“

(l)(j) Assumptions of neutronic decoupling of different storage areas should be substantiated by appropriate calculations.

6.35.6.36. The infinite multiplication factor[8] may be used as a conservative estimation of k_{eff}.

6.36.6.37. The estimation of subcriticality for other kinds of fuel may require special considerations. The composition of spent fuel may vary over a large range and it may not be easy to define appropriate conservative conditions. For example, spent fuel from , BWR fuel with burnable poison may have higher reactivity by burning of poison.fast reactors may have higher multiplication properties than fresh fuel with an initial enrichment. In such instances the assumption of fuel with the highest enrichment may not be conservative. Also, uranium thorium mixed oxide fuel or fuel from research reactors may have very complicated properties that need to be considered.

Heat removal

6.37.6.38. Spent fuel storage facilities should be designed with heat removal systems capable of reliably cooling the stored spent fuel when that fuel is initially loaded into the facility. The heat removal capability should be such that the temperature of all spent fuel, including the spent fuel cladding does not exceed the maximum allowable temperature. In addition, the temperature of the other safety related components in the facility should also not exceed their maximum allowable temperatures. Active heat removal systems when performing a safety function should be designed to withstand all operational states and accident conditions and should satisfy the deterministic single failure criterion.

[8] The *infinite multiplication factor* is the ratio of the neutrons produced by fission in one generation to the number of neutrons lost through absorption in the preceding generation.

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~~6.38.~~6.39. In the design of heat removal systems for a spent fuel storage facility appropriate provision should be included to maintain fuel temperatures within acceptable limits during handling and transfer of spent fuel.

~~6.39.~~6.40. The heat removal system should be designed for adequate removal of heat likely to be generated by the maximum inventory of spent fuel anticipated during operation. In determining the necessary heat removal capability, the post-irradiation cooling interval and the burnup of the fuel to be stored should be taken into consideration. Heat removal systems should be designed to include an additional margin of heat removal capability to account for any processes foreseen to degrade or impair the system over time. In the design of the heat removal system consideration should also be given to the maximum heat capacity of the installation.

~~6.40.~~6.41. In the case of modular facilities such as vaults, the fact that the heat produced from the decay of spent fuel fission products decreases with time can be taken into account. For example, if forced cooling is initially provided, later in the facilities lifetime, natural cooling may be adequate. An analysis should be performed to determine how long forced cooling is required with due consideration given to maintaining its operability and the potential effect(s) of its failure.

~~6.41.~~6.42. Redundant and/or diverse heat removal systems might be appropriate, depending on the type of storage system used and the potential for fuel overheating over an extended time.

Containment of radioactive materials

~~6.42.~~6.43. In the design of spent fuel storage and handling systems adequate and appropriate measures should be provided for containing radioactive materials so as to prevent uncontrolled release of radionuclides to the environment. The spent fuel cladding should be protected during storage against degradation during normal operational states, accident conditions, and later retrieval~~. If fuel cladding degradation is foreseeable during storage, in particular in case of long term storage, the fuel cladding should not be considered as a containment barrier. The radioactive material~~, containment should be ensured by at least ~~by~~ two independent static barriers. As needed and as far as possible, spent fuel storage containment systems should be provided with monitoring to determine when corrective action is needed to maintain safe storage conditions.

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~~6.43.~~6.44. Ventilation and off-gas systems should be provided where necessary to ensure collection of airborne radioactive particulate materials during operational states and accident conditions. In the design of the air supply system for the facility consideration should be given to the potential for the presence of corrosive gases such as chlorine, sulphur dioxide etc., in the outside environment which could be detrimental to the integrity of the spent fuel cladding or any other safety related component.

Radiation protection

~~6.44.~~6.45. The design of a spent fuel storage facility should be such as to provide for radiation protection of the workers, the public and the environment in accordance with the requirements of national legislation and recommendations presented in Refs [10, 31].

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~~6.45.~~6.46. Adherence to the above requirements and recommendations during the design of spent fuel handling systems in a storage facility requires that:

(a) Appropriate ventilation, including efficient, appropriately qualified and designed air filtration systems and their periodic checks, should, as necessary, be included in the design to limit the concentrations of airborne radioactive materials and related exposures of workers and the public to acceptable levels;

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(b) Provisions should be made for monitoring of radioactive effluents;

(c) Spent fuel handling be designed to avoid the build-up of contamination to unacceptable levels and to provide for remedial measures should such contamination occur;

(d) Handling of spent fuel and casks be carried out in an environment in which important parameters (e.g. temperature, concentration of impurities, intensity of radiation) are controlled;

(e) Areas where spent fuel and casks are handled or stored are provided with suitable radiation monitoring for the protection of workers;~~.~~

(f) The storage facility should not contain any operation room with access solely through the storage area; and

(g) Water monitoring and filtration for wet storage facilities.

~~6.46.~~6.47. Shielding should be provided to meet the recommendations in Ref. [31]. To meet these recommendations, the following provisions should be included:

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(a) The source term for shielding design analysis should consider the bounding conditions of enrichment, burnup and cooling times for gamma and neutron radiation, an inventory at the maximum design capacity of the spent fuel storage facility, the axial burnup effects on gamma and neutron source and the activation of non fuel hardware;

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(b) Suitable shielding should be provided for normal and accident conditions;

(c) Penetrations through shielding barriers (e.g. penetrations associated with cooling systems or penetrations provided for loading and unloading) should be designed to avoid localized high gamma and neutron radiation fields from both the penetration and radiation streaming;

(d) Equipment for handling spent fuel should be assumed to contain the maximum amount of spent fuel;

(e) Handling equipment should be designed to prevent inadvertent placing or lifting of spent fuel into insufficiently shielded positions; and

(f) The radiological impact of deposits of activation products should be considered.

Layout

~~6.47.~~6.48. Design aspects associated with the layout of a spent fuel storage facility are as follows:

(a) Handling and storage areas for spent fuel should be secure against unauthorized access or unauthorized removal of fuel;

(b) The area used for storage should not be part of an access route to other operating areas;

(c) The transport routes for handling should be as direct and short as practical so as to avoid the need for complex or unnecessary moving and handling operations;

(d) The need for moving heavy objects above stored spent fuel and items important to safety should be minimized by layout;

(e) The layout should be carried out in such a way as to reflect application of optimization regarding all spent fuel handling operations, storage of spent fuel and the required personnel access;

(f) The layout should be carried out in such a way as to provide for decontamination of deposits of activation products on surfaces of spent fuel elements and appropriate maintenance and repair of spent fuel handling equipment and storage casks;

(g) Space should be provided to permit the inspection of spent fuel or spent fuel casks and inspection and maintenance of components, including spent fuel handling equipment;

(h) The layout should be ~~carried out in such a way as to provide a spare storage capacity in order to allow an potential reorganization of the storage;~~designed to facilitate access to any stored fuel without moving or handling other stored fuel;

(i) A division into sectors should be privileged in order to make easier the access to any stored fuel and to avoid the concept FILO (first in last out);

(j) Retrieval of spent fuel or spent fuel packages as well as possible needs for spent fuel encapsulation or conditioning should be addressed in the layout of the facility;

(k) Space should be provided to allow movement of the spent fuel and storage casks and the transfer of these between different handling equipment;

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(l) Space should be provided for the safe handling of a shipping and/or storage cask. This may be achieved by using a separate cask loading/unloading area or by including dedicated space within the spent fuel storage facility;

(m) Space should be provided for the storage and use of the tools and equipment necessary for the repair and testing of storage components. Space for the receipt of other radioactive parts may also be required;

(n) Appropriate arrangements for containment measures and the safe storage of degraded or failed fuel should be provided;

(o) The facility should be laid out in such a way as to provide easy exit for personnel in an emergency;

(p) The facility should be designed in such a way as to permit access to all parts of the spent fuel storage facility requiring periodic inspection and maintenance;

(q) Penetrations should be designed in such a way as to prevent the ingress of foreign material (e.g., rain, inorganic solutions, organic materials, etc.) which could reduce subcriticality margins, impair heat transfer or increase corrosion and degradation of the storage facilities in ways that might reduce the effectiveness of the primary safety functions or prevent inspection or repair; and

(r) The floor area where any transport vehicle with a heavy spent fuel cask could move or be parked should be designed with adequate floor loading margins. Such areas should be clearly marked to avoid the overloading a floor area designed to a lower floor loading

Handling

~~6.51.~~6.49. Spent fuel handling and transfer equipment and systems might include:

(a) Fuel handling machines;

(b) Fuel transfer equipment;

(c) Fuel lifting devices;

(d) Fuel dismantling devices;

(e) Handling devices for all operations associated with transport casks or inspection of spent fuel or cask; and

(f) Provision for the safe handling of degraded or failed fuel or casks.

~~6.52.~~6.50. Handling equipment should be designed to minimize the probability and consequence of incidents and accidents, and to minimize the potential for damaging spent fuel, spent fuel assemblies, and storage or transport casks. The following should be considered:

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(a) Equipment should not contain sharp edges or corners which could damage the surfaces of spent fuel assemblies;

(b) Equipment should be provided with positive latching mechanisms to prevent accidental release;

(c) Equipment should be designed to take account of radiation protection aspects and easy maintenance;

(d) Moving equipment should have defined speed limitations;

(e) Systems should be designed so that spent fuel cannot be dropped as a result of loss of power. Consideration should be given to the consequences of a single failure and, where appropriate, redundant load paths should be provided;

(f) Where it is necessary to ensure that spent fuel assemblies can be readily placed in a safe location, fuel handling equipment should be designed for emergency manual operation;

(g) Equipment should be designed to ensure that the magnitude and direction of any forces that are applied to spent fuel assemblies are within acceptable limits; and

(h) Equipment should be provided with suitable interlocks or physical limitations to prevent dangerous or incompatible operations. Such interlocks or limitations should prevent travel in some circumstances (e.g. to avoid incorrect placement of spent fuel or, in the case of wet storage, where the machine is too close to the pool walls), and also prevent ~~over~~ lifting of spent fuel assemblies or other components over spent fuel, accidental release of loads or the application of incorrect forces.

(i) Controls and tools should be ergonomically designed and user-friendly.

(j) The possibility for tools to be mistaken should be avoided by design.

(k) The environmental conditions (noise, brightness) should provide for optimal conditions of work.

~~6.53.~~6.51. Where the operating personnel require information on the non-visible state of the equipment or components to ensure safety of an operation, as stated in the safety case, the design should be such as to include provisions to effectively transmit such information to the operating personnel through appropriately located indicator systems or by any other alternative means.

~~6.54.~~6.52. In the design of spent fuel handling equipment provisions should be included for the related use of portable manual or power operated tools, provided that the planned use of such tools is consistent with the design objectives and that such use does not compromise the safety of the spent fuel handling operations.

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~~6.55.~~6.53. To minimize the probability of an accidental drop of any load the equipment for transferring spent fuel to a spent fuel storage facility should be designed to ensure that the equipment is capable of withstanding normal, off-normal operational states and accident conditions. In the event of an accidental drop, the equipment should not damage the containment or the shielding of fuel casks in any manner that may result in unacceptable radiation exposure to workers or the public. In addition, an accidental drop should not prevent fuel retrieval or cause significant damage to the spent fuel or spent fuel storage facility.

~~6.56.~~6.54. Assumptions critical to operational safety should be documented at the design stage to facilitate the subsequent development of operational procedures. These assumptions and conclusions concerning the operational safety of the spent fuel storage facility should be justified through detailed analyses using appropriate techniques.

~~6.57.~~6.55. In order to ensure safe operation spent fuel handling and storage systems should include the following:

(a) Measures to limit radioactive releases and radioactive exposures of workers and the public during operational states and accident conditions in accordance with the philosophy of dose optimization required by Ref. [9] or those limits established by the regulatory body, with particular consideration being given to the use of remote techniques in areas of high radiation to reduce worker exposures;

(b) Measures to limit anticipated operational occurrences and design basis accidents from developing into severe accident conditions;

~~(c)~~© Provision for ease of operation and maintenance of essential equipment (in particular, items important to safety); and

(d) Provision through equipment and procedures for ready retrieval of spent fuel from storage.

~~6.58.~~6.56. The operating organization should consider categories of dropped loads such as casks or lids, spent fuel and spent fuel storage racks in the design and assessment of lifting and handling equipment.

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~~6.59.~~6.57. Dropping spent fuel during transfer from the cask to the storage rack (or vice versa in the case of cask loading for dry storage) might result in impacts that should be avoided such as:

(a) Partial defects in the spent fuel cladding, leading to leaks and resulting fission product contamination of the pool;

(b) Spent fuel deformation (e.g. bending) or damage which may lead to difficulties in subsequent spent fuel handling;

(c) An increased potential of a criticality accident if new or low burnup spent fuel fall alongside a basket or other spent fuel in storage racks; and

(d) Personnel radiation exposure due to the release of fission products.

Ventilation systems

~~6.60.~~6.58. Ventilation systems should maintain a safe and comfortable working environment and be operated in such a way as to limit the potential release of radionuclides.

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~~6.61.~~6.59. Ventilation systems should be operated in such a way as to control the accumulation of flammable and/or explosive gases (e.g. H2 formed by radiolysis). The potential for drawing in hazardous gases from external sources should also be considered.

~~6.62.~~6.60. Ventilation systems should satisfy the recommendations of Ref. [3~~4~~]. Their operation should be compatible with fire protection requirements.

Communications

~~6.63.~~6.61. Adequate communications means should be provided by design to satisfy the operational and emergency requirements of the spent fuel storage facility.

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Control and instrumentation

~~6.64.~~6.62. Whenever practicable, control and protection functions should be mutually independent. If this is not feasible, a detailed justification for shared and interrelated systems should be provided. Ergonomic factors should be implemented in the design of ~~when operating provisions for~~ alarms and indications to the operating personnel. Control and monitoring equipment should be calibrated for the type of use.

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Fire protection

~~6.65.~~6.63. The operation of the fuel handling and storage areas should be carried out in accordance with the fire protection recommendations of Ref. [3~~3~~4]. Fire protection measures should be operated in such a way as to limit the risk of damage due to fires to personnel, items important to safety, spent fuel storage areas, spent fuel handling systems and supporting systems.

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~~6.66.~~6.64. Fire protection systems of appropriate capacity and capability should be provided.

~~6.67.~~6.65. Fire protection precautions should include the limitation and control of combustible materials in fuel handling and storage areas (e.g. combustible packing materials, piping systems carrying combustible materials etc). The spent fuel storage area should be operated in such a way as to ensure that the use of fire suppression cannot cause inadvertent criticality.

Radioactive waste management

~~6.68.~~6.66. The systems should be operated to:

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(a) Avoid or minimize the potential for generating radioactive waste; and

(b) Provide safe and adequate means for handling radioactive waste.[4]

~~6.69.~~6.67. Processing methods for such waste should be compatible with the requirements of the receiving waste facility.

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Lighting

~~6.70.~~6.68. Provision should be made for adequate and reliable illumination in support of operation and the inspection and/or physical protection of spent fuel storage areas.

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~~6.71.~~6.69. For wet storage in pools, the pool area should be provided with the necessary illumination equipment, including underwater lighting near work areas and provisions for replacement of underwater lamps.

~~6.72.~~6.70. Materials used in underwater lighting should be compatible with the environment and, in particular, should not undergo unacceptable corrosion or cause any unacceptable contamination of the pool water.

Area monitoring

~~6.73.~~6.71. Area monitoring should include measurements of radiation dose rates and airborne radionuclides. In controlled areas, fixed continuously operating instruments with local alarm and unambiguous readout should be installed to give information on the radiation dose rates. Any such instruments should have characteristics and ranges adequate to cover the potential ~~expected~~ radiation levels.

~~6.74.~~6.72. Instrumentation to detect external contamination of workers should be provided at exits from locations with a significant probability of such contamination. Instruments for area and personnel monitoring should be demonstrated to be fit for purpose and comply with appropriate manufacturing standards.

~~6.75.~~6.73. Provisions for the decontamination of personnel, equipment and components should be available.

Emergency preparedness

~~6.76.~~6.74. The potential radiological impacts of accidents should be assessed by the operating organization and reviewed by the regulatory body [21]. Provisions should be made to ensure that there is an effective capability to respond to them. Considerations should include the development of scenarios of anticipated sequences of events (see Section 5) and the establishment of emergency procedures and emergency plan to deal with each of the scenarios, including checklists and lists of persons and organizations to be alerted.

~~6.77.~~6.75. Emergency response procedures should be documented, made available to the personnel concerned and kept up to date. Exercises should be held periodically to test the emergency response plan and the degree of preparedness of the personnel. Inspections should be performed regularly to ascertain whether the equipment and other resources needed in the event of an emergency are available and in working order.

Support systems

~~6.78.~~6.76. In addition to the above design items a number of other support systems may be required to ensure the operation and safety of spent fuel storage facilities, e.g. emergency electrical power should be available.

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~~6.79.~~6.77. Where the safety of spent fuel storage is dependent upon the supply of utilities (e.g. compressed air or water), adequate sources should be reliably available.

COMMISSIONING OF SPENT FUEL STORAGE FACILITIES

Requirement 18 (GSR Part 5): Construction and commissioning of the facilities
Predisposal radioactive waste management facilities shall be constructed in accordance with the design as described in the safety case and approved by the regulatory body. Commissioning of the facility shall be carried out to verify that the equipment, structures, systems components, and the facility as a whole perform as planned.

General

~~6.80.~~6.78. Commissioning involves a logical progression of tasks intended to demonstrate the correct functioning of features specifically incorporated into the design to provide for safe storage of spent fuel. In addition, operational procedures are confirmed and the readiness of staff to operate the spent fuel storage facility is demonstrated. These procedures should cover both operational states and accident conditions.

~~6.81.~~6.79. The basis for commissioning should be established at an early stage of the design process as an intrinsic part of the project to facilitate its effective implementation. Commissioning plans should be reviewed and, where appropriate, made subject to the approval of the regulatory body. The responsibilities of the different groups typically involved in commissioning should be clearly established. Arrangements should be established to cover:

(a) Specification of tests to be carried out(test objectives, safety criteria to be met);
(b) Documentation provision and approval;
(c) Responsibilities;
(d) Safety of testing;
(e) Control of test work;
(f) Recording and review of test results; and
(g) Regulatory interaction.
(h) Management of equipments for temporary commissioning aids and their removal before facility operation (and after tests completion).

6.80. ~~6.83.~~ Testing arrangements should include:

(a) Regulatory requirements;
(b) Progression through stages of commissioning;
(c) Reporting of results and approval for operation;
(d) Retention of records.

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~~6.82.~~6.81. For modular storage systems, most of the commissioning is completed with the loading of the first storage module. However, some of the commissioning processes may become a regular operation as new modules are placed in service. However, a change in module design may require some of the commissioning steps to be repeated for the new design.

~~6.83.~~6.82. Some commissioning steps may continue into the spent fuel storage facility operation. For example, the heat removal capacity of a storage pool may not be tested and verified with justifiable efforts until the facility has received spent fuel. Some large storage facilities use transport casks and spent fuel of various designs. Some commissioning steps may need to be repeated when new casks or new spent fuel designs are first used.

Commissioning stages

~~6.84.~~6.83. Commissioning will usually be completed in several stages:

(a) Construction completion;
(b) Equipment testing;
(c) Performance demonstration;
(d) Inactive commissioning; and
(e) Active commissioning.

~~6.87.~~6.84. During the construction completion stage, the spent fuel storage facility should be physically inspected in detail to confirm compliance with the detailed design. Factors such as physical dimensions and initial radiation background conditions should be established. A systematic check against the design drawings and project documentation should be carried out to establish the as-built status of the facility. (In addition to providing information to facilitate operation of the plant, this check can also be important when considering possible future modifications and ultimate decommissioning of the installation.)

~~6.88.~~6.85. During the equipment testing stage the spent fuel storage facility equipment and systems should be energized and the various controls, rotation direction, flow directions, currents, interlocks, etc., tested. Activities such as load testing of casks and spent fuel assembly lifting equipment should also be carried out and safe control of equipment should be demonstrated during these tests. In some cases limited physical interaction between equipment items should also be demonstrated.

~~6.89.~~6.86. During the performance testing stage, after the individual equipment items have been tested, a range of tests should be performed to demonstrate the safe interaction of all equipment and the overall operational capability and capacity of the spent fuel storage facility. At this stage, the safety and

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effectiveness of all instructions and procedures should be demonstrated. This should include demonstration of satisfactory training of operating personnel for both normal operation and anticipated operational occurrences. The ability to conduct maintenance work safely and effectively should also be demonstrated.

~~6.90.~~6.87. The inactive commissioning stage should provide a formal demonstration that the plant personnel, equipment and procedures function in the manner intended, especially those identified as important to the safety of plant operation, usually derived from the safety case. All safety features that can be tested without spent fuel present should be checked before the spent fuel storage facility is put into operation.

~~6.91.~~6.88. Once the inactive commissioning has been satisfactorily accomplished, the active commissioning stage begins with the introduction of radioactive material into the spent fuel storage facility. It is highly recommend that all tests and any resulting amendments be completed before introducing radioactive material. This effectively marks the start of the operation of the facility and, hence, from this stage, the relevant safety requirements for plant operation should apply. Active commissioning should involve a range of tests to demonstrate that the design criteria for radiological protection have been met.

~~6.92.~~6.89. Upon completion of commissioning, a final commissioning report should be prepared. This should detail all testing and provide evidence of its successful completion. This report has to demonstrate to the regulatory body that its requirements have been satisfied and may provide the basis for the subsequent licensing of the spent fuel storage facility for full operation. Additionally, any changes to plant or procedures implemented during commissioning should be documented in an appropriate way.

OPERATION OF SPENT FUEL STORAGE FACILITIES

Requirement 9 (GSR Part 5): Characterization and classification of radioactive waste
At various steps in the predisposal management of radioactive waste, the radioactive waste shall be characterized and classified in accordance with requirements established or approved by the regulatory body.

Requirement 19 (GSR Part 5): Facility operation
Predisposal radioactive waste management facilities shall be operated in accordance with national regulations and with the conditions imposed by the regulatory body. Operations shall be based on documented procedures. Due consideration shall be given to the maintenance of the facility to ensure its safe performance. Emergency preparedness and response plans, if developed by the operator, are subject to the approval of the regulatory body.

General

~~6.93.~~6.90. All spent fuel storage facility operations should be performed in accordance with written procedures prepared by the operating organization. These documents and their updates should be prepared in co-operation with the organizations responsible for the design of the spent fuel storage facility. However, the operating organization is responsible for ensuring that the procedures are prepared, reviewed, approved and issued. These procedures should as a minimum, ensure compliance with the operational limits and conditions for the spent fuel storage facility and, more generally, with the safety assessment.

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~~6.94.~~6.91. Instructions and procedures should be developed for normal operations of the spent fuel storage facility, anticipated operational occurrences and design basis accident conditions. Instructions and procedures should be prepared so that each action can be readily performed in the proper sequence by the designated responsible person. Responsibilities for approval of any required deviations from procedures for operational reasons should be clearly defined.

~~6.95.~~6.92. Adequate arrangements should be made for the review of operating procedures, a systematic evaluation of operating experience, also of other facilities, and the taking of corrective actions in a timely and appropriate manner to prevent and counteract developments adverse to safety. Provisions should be made for implementing a controlled distribution of operational procedures, in order to guarantee that operating personnel have only the last approved edition.

~~6.96.~~6.93. The maintenance and modification of any equipment, process or document of the spent fuel storage facility should be subject to specific procedures. These procedures will require authorization before they are implemented. The procedures should involve the categorization of the modification in accordance with its safety significance. Depending upon the safety categorization, each modification will be subject to varying degrees of review and endorsement by safety departments, plant management and the regulatory body. The inactive commissioning stage should provide a formal demonstration that the plant personnel, equipment and procedures function in the manner intended, especially those identified as important to the safety of plant operation, usually derived from the safety case.

~~6.97.~~6.94. All maintenance and modification should be appropriately recorded and documented including their commissioning test results. The documents should be revised immediately after completion of the maintenance or modification

Operational aspects

~~6.98.~~6.95. The operating organization should ensure that operating procedures relating to maintaining subcriticality are subjected to rigorous review and compared with the safety requirements of the design,. This may include confirmatory analysis and review by the regulatory body. Some of the factors to be considered in this review include:

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(a) Spent fuel types;
(b) Subcritical spent fuel geometries;
(c) Spent fuel container types (if used);
(d) Spent fuel handling operations;
(e) Potential for abnormal operation;
(f) Confirmation of spent fuel parameters (e.g. initial enrichment, final enrichment, burnup); and
(g) Dependence on neutron absorbers.

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~~6.99.~~6.96. Cladding failure can result in the release of isotopes such as ^{85}Kr, ^{134}Cs and ^{137}Cs, which are characteristic fission products detected following cladding failures in spent fuel that has been cooled for long periods. Cladding failures may be more probable when spent fuel and spent fuel cladding is subjected to high temperatures, and when chemical conditions in the medium surrounding the spent fuel promote cladding corrosion. The operating organization should ensure that adequate monitoring of environmental conditions within the facility (e.g. pool water composition and/or storage area atmosphere and moisture or water on spent fuel cladding) is undertaken to prevent and provide notice of such conditions. Procedures should be provided for detecting and dealing with degraded and failed fuel.

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~~6.100.~~6.97. Additionally, the operating organization should ensure that procedures exist for the receipt, handling and storage of spent fuel with failed cladding or that such fuel is not accepted at the spent fuel storage facility. In cases where it is accepted, in addition to containment considerations there may be criticality implications which should be fully assessed and, where appropriate, subject to specific procedures.

~~6.101.~~6.98. Operational procedures should be developed for monitoring of spent fuel storage containment systems (e.g. closure seals on storage casks and canisters, and ventilation and filtration systems) ~~to provide monitoring capability~~. This monitoring should be such that the operating organization will be able to determine when corrective action is needed to maintain safe storage conditions.

~~6.102.~~6.99. There are other safety considerations which should be taken into account. It should be noted that many of these are either anticipated operational occurrences or design basis accidents. However, some of these events could ~~an~~ also lead to ~~be considered as~~ severe accidents, which are beyond the design basis.

Whilst the probability of such accidents occurring is extremely low, the operating organization should consider events such as these during the preparation of operating procedures and contingency plans. Some examples of these events are:

(a) Crane failure with a water filled and loaded cask, suspended outside the pool;

(b) Loss of safety related plant process systems such as electrical supplies, process water, compressed air and ventilation;

(c) Explosions due to the build-up of radiolytic gases;

(d) Fires leading to damage of items important to safety (to reduce the risk of fire; the accumulation of combustible material or waste should be controlled, as should be the amount of other flammable materials);

(e) Extreme weather conditions which could alter operating characteristics or impair pool or cask heat removal systems;

(f) Other natural events such as earthquake or tornado;

(g) External man-induced events (airplane crash, sabotage, etc.);

(h) Failure of physical protection system.

The possible misuse of chemicals (e.g. accidental introduction into the pool water of acidic or alkaline fluids used for ion exchange resin regeneration) should also be taken into consideration.

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6.103.6.100. In addition to providing instructions and contingency procedures as described above, the operating organization should also produce an emergency plan in accordance with Ref. [2019].

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6.104.6.101. Operating experience and events at the facility and reported by similar facilities should be collected, screened and analysed in a systematic way. Conclusions should be drawn and implemented in an appropriate feedback procedure. Any new standards, regulations or regulatory guidance should also be reviewed to check for applicability.

6.105.6.102. During the operation of a spent fuel storage facility the integrity of stored spent fuel should be monitored. unless a specific justification is given to show that the monitoring is not necessary. When spent fuel is stored in sealed casks, the means for safeguards monitoring or verifying the related sealing operations will be available. Such means should not impair the integrity of the spent fuel.

6.106.6.103. Operational limits and conditions for a spent fuel storage facility should be based on:

(a) The design specifications and operational parameters, commissioning test results;

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(b) The sensitivity of the items important to safety and the consequences of the events following the failure of items, the occurrence of specific events or variations in operational parameters;

(c) Accuracy and calibration of instrumentation equipment that measure safety related operating parameters;

(d) Consideration of the technical specification for each item important to safety and the need to ensure that these items continue to function in the event of any specified fault occurring or recurring;

(e) A requirement that items important to safety will be available to ensure safety in operational states including maintenance;

(f) A definition of the equipment which should be available to enable a full and proper response to foreseeable fault conditions or accidents; and

(g) The minimum staffing levels which must be available to operate the spent fuel storage facility safely.

Table 1 shows examples of technical operational limits and conditions which may be required for a spent fuel storage facility

TABLE 1: EXAMPLES OF OPERATIONAL LIMITS AND CONDITIONS FOR SPENT FUEL STORAGE

Subjects	Operational limits and conditions
Subcriticality	Maximum allowable fresh fuel enrichment or Pu content
	Minimum allowable concentration of neutron poisons in fixed absorbers, if required
	Restricted movement and restrictions on storage configurations of spent fuel
	Restricted use of moderator
	Specified minimum spent fuel burnup, if applicable
	Spent fuel assembly characteristics
Radiation	Maximum allowable spent fuel burnup
	Minimum allowable water level in storage pool
	Specific requirements for radiation monitors, alarms and interlocks
	Minimum cooling periods after the discharge from the reactor
	Maximum radionuclide concentrations in pool water
	Maximum radiation dose rates on cask surfaces and 1-2 meters from cask
	Minimum tightness of spent fuel cask

Heat removal	Specified availability of cooling systems with defined maximum and minimum system temperatures Minimum spent fuel cooling period after discharge of spent fuel from the reactor and maximum spent fuel burnup Maximum concrete and cask surface temperature Minimum tightness of spent fuel cask
Water Composition	Specification of water composition to prevent corrosion of spent fuel and storage components to ensure adequate water clarity and to prevent microbial growth

~~6.107.~~6.104. Operational limits and conditions form an important part of the basis on which operation is authorized and as such should be incorporated into technical and administrative arrangements which are binding on the operating organization and operating personnel. Operational limits and conditions for spent fuel storage facilities, which result from the need to satisfy legal and regulatory requirements, should be set by the operating organization and agreed with the regulatory body as part of the licence conditions. The operating organization may set an operational target level below these specified limits to assist in avoiding any breach of approved limits and conditions.

~~6.108.~~6.105. While all operations can be directly or indirectly related to some aspect of safety, the aim of operational limits and conditions should be to manage and control the basic safety hazard in the facility and they should be directed toward:

(a) Preventing situations which might lead to unplanned exposure of people (workers and the public) to radiation; and

(b) Mitigating the consequences of such events should they occur.

~~6.109.~~6.106. Personnel directly responsible for the spent fuel storage facility operation should be thoroughly familiar with the facility''s operating procedures, operational limits and conditions to ensure compliance with their provisions. Systems and procedures should be developed in accordance with the approved management system so that the operating personnel should be able to demonstrate compliance with the operational limits and conditions.

~~6.110.~~6.107. Operational limits and conditions should be kept under review and may also have to be changed according to the national regulatory framework:

(a) In the light of operating experience;

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(b) Following modifications of the spent fuel storage facility and type of fuel;

(c) As part of the process of periodically reviewing the safety case (including as part of periodic safety review) for the spent fuel storage facility; and

(d) In the case that legal or regulatory conditions change.

Operational experience, technological progress or changes may recommend correspondent changes on operational conditions. Such changes must be justified through safety assessment and approved by the regulatory body.

Maintenance, inspection and testing

~~6.111.~~6.108. A management system (see also Section 4) covering operation and maintenance using approved procedures should ensure:

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(a) Maintenance and inspection of the lifting attachments on the casks and of the lifting apparatus (e.g. slings, beams, chains and hooks);

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(b) Maintenance of spent fuel storage facility cranes and spent fuel grabs;

(c) Periodic load testing of cranes and other attachments.

(d) Maintenance, inspection and testing

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~~6.112.~~6.109. The operation of a spent fuel storage facility should include an appropriate programme of maintenance, inspection and testing of items important to safety, i.e. structures, systems and components. Safe access to all structures, systems, areas and components requiring periodic maintenance, inspection and testing should be provided. Such access should be sufficient for the safe operation of all required tools and equipment and for the installation of spares.

~~6.113.~~6.110. Before the operation of any spent fuel storage facility commences, the operating organization should prepare the maintenance, inspection and testing programme. The programme should have specific start dates for all inspections, and will need to be re-evaluated in the light of commissioning. The safety case for the spent fuel storage facility will form a basis for preparing the programme in terms of the items, i.e. structures, systems and components, which should be included and the periodicity of planned activities for each of these items.

~~6.114.~~6.111. Provision should be available for maintenance of hot cell components, if a hot cell exists. This maintenance work can be done either in the cell or externally whatever the preferred option may be.

~~6.115.~~6.112. The programme of periodic maintenance, inspection and testing should be subjected to periodic review, taking account of operational experience. All these activities should be covered consistently by the management system, taking into account manufacturer recommendations.

~~6.116.~~6.113. The standard and frequency of these activities should ensure that the level of reliability and effectiveness remains in accordance with the design assumptions and intent so that a consistently high level of safety is maintained throughout the life of the spent fuel storage facility.

~~6.117.~~6.114. It is equally important that the reliability and effectiveness of any component is not significantly affected by the frequency of testing, which may result in premature wear and failure or induced maintenance errors, or can cause an excessive unavailability if the component is inoperative during maintenance and testing.

~~6.118.~~6.115. If maintenance, inspection or testing of the spent fuel storage facility can only be carried out while equipment is shut down, the maintenance schedule should be defined accordingly.

~~6.119.~~6.116. The maintenance, inspection and testing programme should take into account the structures, systems and components which are affected by the operational limits and conditions, as well as any regulatory requirements. Examples of structures, systems and components which may be included in a maintenance, inspection and testing programme are listed in Table 2.

TABLE 2: EXAMPLES OF EQUIPMENT FOR MAINTENANCE, INSPECTION AND TESTING

Item	Nature and subject of test
Lifting equipment: cranes, lugs, eyebolts, chains, cables, transporters and yokes	Brake systems, interlocks, mechanical integrity, load testing, overload protection signalling
Storage structure or module	Structural integrity, accumulations of vegetation, snowfall or other effects which may impair heat removal capability Leak detection and monitoring Detection of corrosion of storage structures and tools
Loop components for cleaning, heat removal and monitoring of transport cask cavity	Flexible pipes for overpressure reliability Calibration, for example, of - temperature and pressure gauges - specified radiation monitoring equipment required for cask (e.g. for measurement of selected radionuclides, such as ^{85}Kr,

	^{134}Cs and ^{137}Cs)
	- flow rate measurement
Special valve equipment to be fitted on cask	Mechanical maintenance, performance and testing of seals and valves
Grabs to handle fuel	Mechanical verification of ability of tool to fasten onto fuel, and check of locking mechanism functionality Verification of mechanical integrity of tool
Radiological monitoring equipment	Calibration and function tests of fixed or portable equipment
Storage racks	Confirm presence and condition of neutron absorbers (if appropriate) Inspection of mechanical wear of casks, baskets and racks, if appropriate
Video cameras	Confirm functionality of cameras
Security	Confirm perimeter fences/gates functionality

~~6.120.~~6.117. Suitably qualified and experienced operating personnel should be involved in the approval and implementation of the maintenance, inspection and testing programme and in the approval of working procedures and acceptance criteria for these activities.

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Operational radiation protection

~~6.121.~~6.118. An operational radiation protection programme should be in place that ensures areas of the facility are classified and that access control is in place according to the level of classification. It should ensure radiation levels are monitored and that personnel working in the facility are issued with appropriate dosimetry. A programme of work planning should also be in place to ensure that radiation doses are maintained as low as reasonably achievable.

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Characterization and acceptance of spent fuel

Requirement 12 (GSR Part 5): Radioactive waste acceptance criteria
Waste packages and unpackaged waste that are accepted for processing, storage and/or disposal shall conform to criteria that are consistent with the safety case.

~~6.122.~~6.119. Acceptance criteria should be developed for the spent fuel storage facility and the spent fuel, taking into account all relevant operational limits and conditions and the future reprocessing or disposal requirements, including retrieval. Before spent fuel is transferred to the storage facility,

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acceptance must be given by the operator and the respective legal authority. Contingency plans should be available on how to deal safely with spent fuel that does not comply with acceptance criteria.

~~6.123.~~6.120. The operating organization of a spent fuel storage facility should receive detailed information concerning the characteristics of the spent fuel received for storage. This information should be supplied by the nuclear facility (i.e. power plant or research reactor) generating spent fuel. The minimum information to be provided is:

(a) Fuel design, including scale drawings;
(b) Materials of construction of fuel, the radionuclide inventory including the initial masses of the fissile content, the burnup and the cooling time;
(c) Fuel identification numbers (e.g. serial numbers on fuel assemblies);
(d) Fuel history (e.g. burnup, reactor power rating during irradiation, decay heat and dates of loading and discharge from the reactor);
(e) Details of conditions present that would affect fuel handling or storage (e.g. damage to fuel cladding or structural damage);
(f) Confirmation that fuel can be correctly handled upon receipt at the spent fuel storage facility; and
(g) Specific instructions for storage (e.g. degraded or failed fuel).
(h) Admissible surface contamination level and dose rate for the fuel assemblies

Fuel can be considered as damaged if it displays the following characteristic: pinholes, cracks, mechanical deviations, missing fuel assembly components, bowing fretting, serious physical damage, etc. The full criteria should be established to cover these issues.

~~6.124.~~6.121. Upon receipt, spent fuel casks should be checked for gamma and neutron radiation levels, leakage, surface contamination and to ensure that they are consistent with the documentation. Characterization of the spent fuel including process control and process monitoring, should be applied within a formal management system.

~~6.125.~~6.122. In addition, information concerning the fuel transport cask must also be transmitted by the shipper to the operating organization of the spent fuel storage facility. This information should include:

(a) Type of cask and appropriate information on its design, and the arrangement of fuel and internal components inside the cask cavity;

(b) Radiological survey data of the cask before shipment;

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(c) Cask identification (e.g. serial number) and certification of compliance with current transport regulations;

(d) Cask handling and sealing requirements and procedures; and

(e) Results of the most recent inspection of the cask.

~~6.126.~~6.123. During cask handling, the following operations should be considered in order to ensure safety:

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(a) Before a cask is loaded with spent fuel: decontamination, as required;

(b) During loading and unloading of a cask, both under wet and dry conditions: sampling of the internal gas before the closure lid is removed and examining the spent fuel, as appropriate; and

(c) After a cask has been emptied: decontamination, as required and routine cask maintenance and recertification operations.

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~~6.127.~~6.124. For facilities receiving spent fuel from a number of sources, the operating organization of the spent fuel storage facility should ensure that each source provides data on the spent fuel parameters in a clearly understandable form which allows the operating organization to demonstrate that subcritical conditions will exist during the handling and storage of the spent fuel. The operating organization should also ensure that the data provided is supported by an approved management system and verified as appropriate.

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~~**6.128.**~~6.125. Loss of containment has the potential for both exposing workers to radiation and releasing radionuclides into the environment. Mechanisms by which loss of containment might occur should be understood by the operating organization and personnel and addressed, as appropriate, in operating procedures.

Fuel integrity

~~6.129.~~6.126. The integrity of spent fuel may become degraded and lead to release or radioactive material into the storage environment due to a number of causes, including:

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~~(e)~~(a) Manufacturing defects, due to incomplete welds or leaking end plugs;

~~(f)~~(b) Embrittlement of the cladding material due to interaction with hydrogen or by exposure to high irradiation;

~~(g)~~(c) General corrosion of the cladding as a result of an improper chemical composition of the cooling water;

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(i)(e) Unrevealed failures which arose during reactor irradiation.

6.130.6.127. Loss of integrity of spent fuel cladding may lead to the release of radioactive material into the storage environment. Such fuel can be referred to as degraded or failed fuel.

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6.131.6.128. Usually spent fuel with decreased integrity should be canned to maintain the quality of the storage environment and/or to satisfy licensing requirements. Sealable casks or containers of approved design for leaking or damaged fuel assemblies should be readily available.

6.132.6.129. Spent fuel assemblies that have become damaged as a result of mechanical events, should be kept separate from intact fuel and provided with appropriate monitoring to detect any outer containment failure. Consideration should be given to contingency arrangements on how to deal with spent fuel that is not retrievable by normal means or that cannot be transported easily.

6.133.6.130. For storage of spent fuel that has been characterised as defective or failed (see Section: “Characterization and Acceptance of Spent Fuel” and “Fuel Integrity”) the storage approach should consider the condition of the fuel in the design. This may include additional engineered methods for the safe handling of damaged fuel during loading and unloading evolutions, e.g., instrument tube tie rods for assemblies where top nozzle stress corrosion cracking is of concern, the canning of damaged fuel assemblies to maintain spent fuel configuration and ensure criticality control, and additional measures to ensure the robustness of containment since the primary containment feature, i.e., the spent fuel cladding, cannot be relied upon for control of the spent fuel material. A specific task for storage facility operation in such cases is the monitoring of the stored degraded spent fuelobject. To manage that, it is necessary:

a to design the storage in order to make easier the monitoring task ;

b to monitor the containment efficiency as close as possible to each containment barrier ;

c to control periodically the state of the stored spent fuel (by sampling, by destructive test, by corrosion test pieces set up into the storage, by reference object use…)

Record of documents

6.134.6.131. Operational data of a spent fuel storage facility should be collected and maintained in accordance with the requirements of the management system addressed in section 4.

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6.135.6.132. Records should be kept of maintenance, inspection and testing and should be subject to periodic examination to establish whether the structures, systems and components give the required reliability and to provide a basis on which to review and justify the programme of maintenance, inspection and testing.

~~6.136.~~6.133. Since the storage time could span more than one generation, transfer of information to subsequent generations is important. Therefore, accurate records of all relevant information should be maintained. This should include updated information on the spent fuel storage facility itself, of the stored spent fuel, and also supporting data such as monitoring results and records of unplanned events.

~~6.137.~~6.134. These records should be duplicated and stored in separate locations. It should be ensured that the information is stored on media that remain accessible during and after the envisaged storage lifetime.

Retrieval of spent fuel

~~6.138.~~6.135. A storage facility should be operated in such a way as to allow retrieval of spent fuel or spent fuel package at the end of the anticipated storage lifetime and at the end of the lifetime of the storage facility.

~~6.139.~~6.136. If spent fuel or spent fuel package cannot be retrieved from storage with normal operating procedures, special operating procedures should be developed to ensure safe retrieval of spent fuel or spent fuel package.

~~**6.140.**~~6.137. A spent fuel storage facility should be considered to be an operating facility until all the spent fuel or spent fuel package has been removed.

Transport after storage

~~6.141.~~6.138. After storage, the integrity of the spent fuel and the storage/transport casks and associated paperwork has to be considered~~examined~~ before transport. The following issues should be checked:

(a) Ownership and responsibility for the safe retention of records;
(b) Inspection and surveillance regime;
(c) Control of storage environment;
(d) Conventional safety issues, such as periodic inspection of the handling equipments;
(e) Nuclear safety issues, such as any degradation of the spent fuel itself, the spent fuel support structure and the neutron shielding materials.

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~~6.142.~~6.139. The safety functions of the storage/transport casks should be assessed periodically to demonstrate compliance with current safety standards and the approval requirements and conditions of the transport licence. Possible degradation of casks should be assessed and consideration should be given to:

(a) Confinement system: spent fuel, fuel support structure;
(b) Containment system: metal seals and restraining system, such as lid bolts;
(c) Packaging components: corrosion effects, radiation effects, etc.;
(d) Impact limiters: compatibility of the attachment and performance;
(e) Shielding materials: changes of density and composition, etc.
(f) Design features incorporated to ensure sub criticality.

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Storage beyond the original design lifetime

~~6.143.~~6.140. If storage of spent fuel is envisaged beyond the original design lifetime, the nuclear reactivity of the fuel should be re-assessed and taken into account, as necessary. In this case an appropriately wide safety margin or additional safety provisions may be applied.

~~6.144.~~6.141. It is essential that the operating organization has developed expertise to manage difficulties that may arise from the effects of storage beyond the original design lifetime.

~~6.145.~~6.142. The para 3.36 of Fundamental Safety Principles [9] require that "Radioactive waste must be managed in such a way as to avoid imposing an undue burden on future generations". What constitutes an 'undue burden' to a large extent depends on national circumstances. Aspects to be taken into account, certainly if long-term storage is anticipated to span many generations, are:

(a) Adequate financial resources to ensure safe management of the waste over this storage lifetime;
(b) Maintaining regulatory control;
(c) Transfer and maintenance of knowledge and technical capability; and
(d) Education of specialists, even after electricity generation by nuclear power has ceased to exist.

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~~6.146.~~6.143. Safe operation of a spent fuel storage facility should be ensured for its life time. This is generally longer than the average life expectation of a commercial company; consequently, in the event that the commercial company ceases to exist after several decades, transfer of ownership to a government institute may be considered.

~~6.147.~~6.144. For storage of spent fuel a safety and environmental assessment should be carried out prior to licensing. For long-term storage a re-assessment of the safety case may become necessary e.g.

due to possible degradation of the containment of the fuel. The regulatory body should take such failure scenarios into account when determining the duration of the operating licence for the spent fuel storage facility.

~~6.148.~~6.145. A monitoring programme should be established in order to be able to detect any deficiencies at an early stage. This monitoring programme should specify the parameters to be monitored, the frequency of monitoring, reference levels for actions as well as the specific actions to be taken.

~~6.149.~~6.146. Prolonged irradiation of cladding material, gaskets, or other materials relevant to ensuring the containment of the spent fuel, may result in degradation of the safety functions. An aging management programme should be set up to deal with age related degradation. The programme should specify the monitoring requirements aimed at early detection of any deficiency.

~~6.150.~~6.147. A mechanism for incorporating changes based on new findings from research and development, especially with respect to ageing and degradation of materials due to storage beyond the original design lifetime, should be established.

~~6.151.~~6.148. The longer the envisaged storage lifetime, the greater are the uncertainties in the assumptions on the safety parameters. In order to provide the operational or regulatory decisions with a scientific basis research and development projects should be undertaken which are aimed to reduce the bandwidth of these uncertainties, if they are of specific importance or sensitivity. As examples, accelerated irradiation experiments on materials used in the spent fuel storage or long-time sealing tests with intentionally aggressive media could give useful information on their sensitivity for aging.

DECOMMISSIONING OF SPENT FUEL STORAGE FACILITIES

Requirement 20 (GSR Part 5): Shutdown and decommissioning of facilities
The operator shall develop, in the design stage, an initial plan for the shutdown and decommissioning of predisposal radioactive waste management facilities and shall periodically update it throughout the operational period. The decommissioning of the facility shall be carried out on the basis of the final decommissioning plan, as approved by the regulatory body. In addition, assurance shall be provided that sufficient funds will be available to carry out shutdown and decommissioning.

~~6.152.~~6.149. Decommissioning of nuclear facilities comprises:

~~(c)~~(a) preparations and approval of the decommissioning plan;
~~(d)~~(b) the actual decommissioning operations; and
~~(e)~~(c) the management of waste resulting from decommissioning activities.
~~(f)~~(d) Release of the site for unrestricted or restricted use.

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~~6.153.~~6.150. An initial version of the decommissioning plan should be prepared during the design of the spent fuel storage facility in accordance with safety standards in decommissioning [18, 19].

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~~6.154.~~6.151. During the operation of the spent fuel storage facility, the initial decommissioning plan should be periodically reviewed and updated and should be made more comprehensive with respect to:

(a) Technological developments in decommissioning;

(b) Possible man made and natural incidents and accidents;

~~(c)~~I Modifications to systems and structures affecting the decommissioning plan;

(d) Amendments to regulations and changes in government policy; and

(e) Cost estimates and financial provisions.

~~6.155.~~6.152. A comprehensive decommissioning strategy should be developed for sites having also other nuclear facilities than a spent fuel storage to ensure that interdependencies are taken into account in the planning for individual facilities [18].

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~~6.156.~~6.153. A final decommissioning plan should be submitted for approval within two years of shutdown of a spent fuel storage, unless an alternative schedule for the submission of the final decommissioning plan has been agreed with the regulatory body.

~~6.157.~~6.154. Even when the bulk of the residual process material has been removed, a significant amount of radioactive contamination may remain. The expeditious removal of this material should be considered as it would reduce the requirements for monitoring and surveillance. Other activities associated with decommissioning may be conducted concurrently with the removal of this material, but potential interactions should be identified and assessed.

~~6.158.~~6.155. Dismantling and decontamination techniques should be chosen which minimize waste arising and airborne contaminations and to ensure protection of both workers and members of the public during decommissioning~~.~~

~~6.159.~~6.156. Before a site is released, for example for unrestricted use, it should be monitored and, if necessary cleaned. A final survey should be performed to demonstrate that the end point conditions, established by the regulatory body, have been met.

APPENDIX I.

SPECIFIC SAFETY CONSIDERATIONS FOR WET OR DRY STORAGE OF SPENT FUEL

~~a.~~I.1. In addition to the general considerations for the design and operation of spent fuel storage facilities described in Section 6, there are specific considerations for the design and operation of wet and dry storage facilities. These include unique characteristics that maintain design parameters within acceptable limits specific to wet or dry storage facilities and which satisfy regulatory requirements.

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SPECIFIC DESIGN CONSIDERATIONS FOR WET STORAGE FACILITIES

Subcriticality

~~1.1.~~I.2. For facilities where the safety assessment takes into consideration and makes allowance for the boiling of pool water during abnormal operating conditions, specific allowances should be provided in the design evaluations for the change in water moderator density during such conditions. For water storage pools sub criticality should be demonstrated under all credible water densities, including events for which boiling of pool water cannot be excluded

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I.3. In the criticality safety of pool storage, the use of soluble neutron poison should be avoided. If this is not possible or if the operator chooses to use soluble neutron poison such as borated water, the design of the facility should include engineering features to preclude an increase in the reactivity of stored fuel caused by the inadvertent dilution of the pool water by the addition of non borated water, where soluble boron is used for criticality control.

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~~I.3.The design of the facility should include engineering features to preclude an increase in the reactivity of stored fuel caused by the inadvertent dilution of the pool water by the addition of non-borated water where soluble boron is used for criticality control. Nevertheless in the criticality safety study of pool storage the use of soluble neutron poison should be avoided.~~

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Heat removal

~~1.8.~~I.4. Active heat removal systems for wet spent fuel storage facilities should be designed to ensure the safe operation of the facility. The primary objective of the systems should be to ensure that no temperature limit, set to protect the structures, systems, components and the inventory from damage, should be exceeded during operational states and accident conditions.

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Containment of Radioactive Materials

I.2.I.5. Wet pool storage facilities should be designed to include features that prevent or limit the release of radioactive materials to the environment. These features could include mechanisms to maintain sub-atmospheric pressures inside the storage building, to provide for filtration of potential vent pathways, to prevent ingress and egress of pool water, and to minimize the number, size, and location of building penetrations.

Radiation protection

I.4.I.6. Where pool water provides radiation shielding for the protection of the workers and the public, the water level should be maintained so as to provide the required degree of shielding. For that reason, the design of a wet spent fuel storage facility should include provisions for an adequate and appropriately accessible supply of water, from redundant and diverse sources, of a quality acceptable for use in the facility.

I.5.I.7. Water storage pools should be designed to exclude penetrations below the minimum water level required for adequate shielding and cooling of stored spent fuel.

I.6.I.8. The design should exclude the permanent installation of piping or other equipment which could inadvertently, e.g. by acting as a siphon, lower the pool water elevation below the minimum required level.

I.7.I.9. The design of wet storage facilities should include provisions for the effective control of radioactive materials released into the pool water and the capability to purify the pool water. The controlled removal of dissolved and suspended radioactive materials might be necessary to limit radiation fields at the surface of the pool. The ability of permanent or temporary equipment to periodically, or as necessary, clean and remove radioactive deposits and sludges from pool liner surfaces should be provided.

I.8.I.10. The pool water make-up system should be designed to provide water at a rate exceeding the maximum rate of water removal possible as a consequence of losses during operation, including removal of water via the pool water removal system. Conversely, pool water removal systems should have capacities less than those of the pool water make-up systems. Furthermore, mixing spent fuels in the same zone with different limits or control mode for criticality should be avoided.

I.9.I.11. Where water pools are to be connected by sluice ways, the design of the sluice ways should afford containment of water and detection, collection, and removal of leakage. Sluice gates should be designed to withstand anticipated water pressures, to include those resulting from accident conditions, and the effects of earthquakes.

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~~I.10.~~I.12. Indications and alarms should be designed to alert plant personal of any unintended decrease in water level and when the minimum water level is reached.

Structure and Layout

~~I.9.~~I.13. The storage pool and other components important to the retention of the cooling water should be designed to withstand operational states and accident conditions, including impacts from collisions or dropped loads without significant leakage of water. Further, pool storage should provide for detecting leakage and implementing appropriate repairs or remedial actions, as required. The facility should provide the means for sampling groundwater, e.g. bore wells located around the facility.

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~~I.10.~~I.14. When burnup credit is given in the criticality safety analysis, the possibility of fuel assemblies being misplaced should be minimized by appropriate interlocks and administrative processes. For these cases the fuel handling equipment must be appropriately designed.

~~I.11.~~I.15. If stacking is proposed in a wet storage facility the mechanical stability of the spent fuel and any fuel rack or basket should be designed to withstand, without unacceptable structural deformation, the mass of a full stack. Static, impact and seismic loads should also be considered.

~~I.12.~~I.16. Water storage pools should be designed to exclude penetrations below the minimum water level required for adequate shielding and cooling of stored spent fuel.

~~I.13.~~I.17. The design should exclude the permanent installation of piping or other equipment which could inadvertently, e.g. by acting as a siphon, lower the pool water elevation below the minimum required level.

~~I.14.~~I.18. The pool water make-up system should be designed to provide water at a rate exceeding the maximum rate of water removal possible as a consequence of losses during operation, including removal of water via the pool water removal system. Conversely, pool water removal systems should have capacities less than those of the pool water make-up systems.

~~I.15.~~I.19. Where water pools are to be connected by sluice ways, the design of the sluice ways should afford containment of water and detection, collection, and removal of leakage. Sluice gates should be designed to withstand anticipated water pressures, to include those resulting from accident conditions, and the effects of earthquakes.

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~~I.16.~~I.20. The facility should be designed in such a way as to provide protection against overfilling of the storage pool.

~~I.17.~~I.21. Indications and alarms should be designed to alert plant personnel of any unintended decrease in water level and when the minimum water level is reached.

Materials

~~I.18.~~I.22. The materials of the following facility systems should be compatible with the pool water, and each other, or should be effectively protected against undue degradation:

(a) spent fuel containment system, structures, and components;

(b) storage racks or casks;

(c) cooling water systems, structures, and components;

(d) pool water make-up systems, structures, and components; and

(e) handling systems

Due consideration should also be given to the potential for chemicals leaching into the pool waters from materials present and the possible implications of their presence in pool.

The storage racks or casks should not contaminate the pool water. Easy decontamination of equipment exposed to, or in contact with pool water is related to the surface of the materials used. The designer should provide for easy decontamination when specifying the materials for such equipment.

~~I.19.~~I.23. The chemical composition of the pool water should be consistent with the protection of the spent fuel cladding, pool structure, and handling equipment. The pool water clarity required for pool operation should be maintained.

Handling

~~I.20.~~I.24. The design of handling systems and equipment should preclude the need for lubricants or other fluids or substances which could degrade or otherwise affect the purity of the pool water. Should lubricants be necessary, design measures should be provided to prevent the leakage and escape of lubricants into the pool water. Substances may be used which are fully compatible with the spent fuel, the equipment and the storage structures (i.e. water may be used).

~~I.21.~~I.25. Hollow handling tools intended for use under water should be designed so that they fill with water upon submergence (to maintain water shielding) and drain upon removal..

~~I.22.~~I.26. Fuel should be handled by equipment that minimizes the potential for a drop accident. Over-raising of spent fuel or other components should be prevented by design features and/or by incorporating dedicated interlocks to inhibit hoist motion in the event that high radiation fields are detected. This should include use of single failure-proof cranes and positive locking mechanisms on

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fuel assembly grapples and hooks. Operator failures should be avoided by applying the "four eyes principle" or check lists.

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SPECIFIC OPERATIONAL CONSIDERATIONS FOR WET STORAGE FACILITIES

~~I.23.~~I.27. There are several pool management features which contribute to the safe operation of wet storage facilities. These include operations that maintain design parameters and minimize corrosion of pool structures, systems and components, and promote radiation protection, such as shown in Table 3. The integrity of the spent fuel and its required subcritical and heat removal geometries and its related containment barriers, should be maintained during the lifetime of the facility and should be verified using appropriate methods.

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Subcriticality

~~I.24.~~I.28. Where soluble boron is used for criticality control, operational controls should be implemented to maintain water conditions in accordance with specified values of temperature, pH, redox, activity, and other applicable chemical and physical characteristics so as to prevent boron dilution ~~Operational controls should be implemented to maintain water conditions in accordance with specified values of temperature, pH, redox, activity, and other applicable chemical and physical characteristics so as to prevent boron dilution where soluble boron is used for criticality control~~ [35, 36].

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Radiation protection

~~I.25.~~I.29. Operational controls should include proper maintenance of underwater lighting and water clarity which are important from a radiation protection perspective to minimize worker dose when performing duties in and around the pool. The ability to perform activities that rely upon visual examination/inspection or sight without repetition and with minimal time will result in less worker exposure.

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Heat removal

~~I.26.~~I.30. It may be possible to damage the pool structure by cooling the pool water to a very low or freezing temperature. Damage may also result from high rates of temperature change exceeding the design limits. Such issues related to heat removal should be considered when defining operational limits and administrative procedures.

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~~I.27.~~I.31. Operational procedures should be such that the pool heat removal systems are monitored to ensure that operating conditions remain within the design specifications and to ensure maximum availability and avoid situations where the system is completely unavailable Impairments or degradation to pool cooling systems need a response in a timely manner to return the system to the designed operating conditions. Also, operational procedures should minimize the time when the pool cooling system is unavailable due to routine maintenance and/or repair.

~~I.28.~~I.32. Heat transfer considerations may increase in importance if spent fuel is in high density storage.

Containment

~~I.29.~~I.33. Operational controls should be implemented to avoid a decrease in pool water level which may result in[9]:

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(a) Increased radiation fields and dose rates to operating personnel;

(b) Impaired fuel cooling if the reduction in water level interrupts or reduces water flow to the heat exchangers of the pool cooling system; and

(c) Increased water temperature and, consequently, increased release of radioactive materials into the water because of corroded spent fuel and spent fuel cladding.

~~I.30.~~I.34. For sub-ground wet storage facilities operational controls should be implemented to avoid, minimize, and manage the potential for in-leakage of water which may result in:

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(a) Dilution of boron in a moderated pool environment and potential for criticality accidents where soluble boron is used for criticality control

(b) Corrosion and other degradation effects of materials important to safety.

~~I.31.~~I.35. The operating organization should undertake suitable routine monitoring of the parameters necessary to enable remedial action to be taken on a timely basis. Alarms should be in place to alert plant personal of any unintended decrease in water level and when the minimum water level is reached. Samples of groundwater from boreholes located around the facility should be periodically monitored for the presence of radioactivity.

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Shielding

~~I.32.~~I.36. Operational controls should be implemented that avoid and minimize the loss of shielding during facility activities. Loss of shielding can result in high radiation exposure. Operational controls should consider and place limits on:

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(a) Hoisting spent fuel higher than design limits during handling operations in the storage pool;

(b) Inadequate depth of pool water; and

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[9] List may not be comprehensive.

(c) Improper use of pool tools (e.g. hollow rather than flooded).

Drop of Loads

~~I.33.~~I.37. Operational controls in areas of prime concern should be implemented to specifically ensure that abnormal conditions, such as a cask drop, do not result in undue challenges to the storage facility safety systems. These areas include[3]:

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(a) The zones between the cask entrance airlock and the cask preparation area and the unloading pool area.

(b) The unloading pool area,

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Drop of a spent fuel element or assembly may result in[10]:

(a) Damage of spent fuel and the resulting contamination of the pool;

(b) Damage of the pool structure and eventual leakage of water;

(c) A criticality event if several spent fuel assemblies are displaced from the rack, and if there is deformation of the spent fuel array or unacceptably close proximity to spent fuel assemblies or arrays in adjacent racks; and

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Release of gaseous fission products.

In these areas the potential for mechanical damage resulting from a drop of a cask would be amplified by the non-compressible properties of the pool water. The major potential hazard resulting from such a drop could be damage of the spent fuel in the cask, loss of water from the pool either by direct expulsion or by gross leakage arising from structural damage, and damage of the pool structure.

(d) Operational controls and engineered safety features should be implemented to preclude the drop of a spent fuel element or an assembly of fuel elements onto a pool storage rack during transfer.

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SPECIFIC DESIGN CONSIDERATIONS FOR DRY STORAGE FACILITIES

Subcriticality

~~I.34.~~I.38. Fuel baskets and casks for spent fuel storage should be designed in[11]:

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(e) Damage of spent fuel and the resulting contamination of the pool;

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[10] List may not be comprehensive.
[11] List may not be comprehensive.

~~I.35.~~I.39. Damage of the pool structure and retrieval.

~~I.36.~~I.40. Dry spent fuel assemblies are displaced from the redistribution or unacceptably close proximity to spent fuel assemblies or external event can be minimized.

Heat removal

(f) The storage facility should be constructed in adjacent racks; and

~~I.37.~~I.41. Release of natural circulation design elements of a dry storage cask and the forced circulation and ventilation systems of a storage facility.

~~I.38.~~I.42. To the maximum practical extent, cooling systems for dry spent fuel storage should be passive and require minimal maintenance. Maximizing the passive design features for heat removal will minimize the need for monitoring and operational considerations. Passive systems rely on natural convection, conduction and radiant heat transfer. Should forced circulation of coolants be used, it should be demonstrated to be sufficiently reliable during normal and off-normal conditions with no adverse effects on systems, structures and components that are important to safety.

~~I.39.~~I.43. Where the integrity of spent fuel relies on a cask's internal gas medium, the design of the associated spent fuel storage cask should ensure the medium is maintained for the design life or provide provisions for monitoring and maintaining of both the presence and quality of the cooling medium for a time period as long as demonstrated to be necessary by the safety case.

Containment of Radioactive Materials

~~I.40.~~I.44. The storage facility and dry storage cask should be designed to facilitate monitoring of the spent fuel containment and detect containment failures. If continuous monitoring is not provided, periodic verification by observation or measurement should be carried out to ensure that the containment systems are performing satisfactorily. For dry storage casks this should include monitoring of seal integrity for bolted closure designs.

~~I.41.~~I.45. The storage facility should be designed in such a way as to incorporate containment barriers to prevent the release of radionuclides. This might include liners or canisters as an integral part of the dry storage system.

Radiation protection

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~~I.42.~~I.46. Spent fuel loading and unloading operations should be carried out by using equipment and methods that limit sky shine and reflections of radiation to workers and the public. .

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~~I.43.~~I.47. The dry storage facility should be monitored in order to detect increases in gamma and neutron fields that may indicate a degradation of containment or shielding.

~~I.44.~~I.48. Dry storage areas with a significant potential for generating or accumulating unacceptable concentrations of airborne radionuclides should either be maintained under sub-atmospheric pressures to prevent the spread of airborne radionuclides to other areas of the spent fuel storage facility, or ventilated and filtered in order to maintain concentrations of airborne radionuclides at acceptable levels Open dry storage facilities that do not use an overstructure or building should, at a minimum, provide for radiation monitoring at the site boundary to indicate any abnormal levels of airborne radionuclides.

Structure and Layout

~~I.45.~~I.49. Storage casks equipped with liners should be designed to prevent the accumulation of water between the liner and the body of the cask. Storage vaults and silos should be provided with features to facilitate drainage or a demonstration that the potential for water accumulation is not of concern, i.e., decay heat generated by the stored fuel is sufficient to evaporate and drive off any accumulated water.

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~~I.46.~~I.50. If stacking is proposed the mechanical stability of the spent fuel and any cask or basket should be designed to withstand without unacceptable structural deformation the mass of a full stack. Static, impact and seismic loads should be considered.

~~I.47.~~I.51. Ease of access should be considered in the design to facilitate the transfer of spent fuel to or from storage positions during normal operations or during recovery operations after anticipated operational occurrences or accident conditions. Sufficient clearances should be provided from all directions and on all sides to provide the required access.

~~I.48.~~I.52. Casks should be designed in such a way as to provide stability and prevent tip over

~~I.49.~~I.53. The dry storage system area should be planned and the storage system itself effectively sealed, such that unacceptable leakage of radionuclides and / or inert gases is prevented and ingress of water (moderator) and / or air is prevented.

~~I.50.~~I.54. The foundation of the dry storage area should be capable of withstanding the load of the loaded spent fuel casks and the handling equipment without excessive settling and degradation.

~~I.51.~~I.55. The design of an open dry spent fuel storage facility should be carried out in such a way as to provide for appropriate collection, monitoring and processing of surface runoff water.

~~I.52.~~I.56. Inclusion of a hot-cell in the design of a dry spent fuel storage facility should be considered to allow for unloading the cask and subsequent re-packaging of the fuel or repairs.

~~I.53.~~I.57. If a hot cell or other capabilities for unloading or repairs are not available, the casks should be designed for maintenance or repair. Alternatively, they may be designed and maintained for transport to a location where such facilities are available.

Materials

~~I.54.~~I.58. The storage system, particularly the storage cask, should be constructed of suitable materials, using appropriate design codes and standards and construction methods, to maintain shielding and containment functions under the storage and loading/unloading conditions expected during its design lifetime unless adequate maintenance and/or replacement methods during operation can be demonstrated. These conditions should include exposure to the atmosphere, internal and external humidity, fission products, temperature variations, the internal build-up of gas, and high radiation fields.

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~~I.55.~~I.59. Industry codes and standards used should be acceptable to the regulatory body. If codes and standards are not yet accepted by the regulatory body sufficient justification for their use should be provided.

~~I.56.~~I.60. The dry storage system, including any closures, especially cask closures, should be constructed of materials which provide chemical and radiological stability, and appropriate resistance to mechanical and thermal impacts.

~~I.57.~~I.61. The fuel storage container atmosphere should be adequately dried in order to attain and maintain the gaseous environment required to protect the integrity of the spent fuel. Drying of the fuel storage container atmosphere also ensures that any water entrained inside damaged fuel rods is adequately evacuated. This reduces the potential for additional fuel damage/degradation during the drying activity, where higher fuel temperatures may be experienced, and the subsequent storage term. Maintaining the required internal environment in the storage container is also key to ensuring continued functionality of the containment, particularly the seal(s). For this reasons, and to ensure retrieve ability of the fuel, it is critical that the condition of the spent fuel be correctly characterised and analysed/inspected if necessary prior to loading into a storage container.

Handling

~~I.58.~~I.62. The design of casks intended to be portable should include provisions for lifting and handling which minimizes the potential for a drop accident. This should include use of single failure-proof cranes and positive locking mechanisms on lifting yokes.. Lifting and handling mechanisms should withstand anticipated loadings and usage during the design life of the casks

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~~I.59.~~I.63. For those dry spent fuel storage facilities incorporating canisters that require shielding, consideration should be given to the need for on-site handling and for off-site transportation.

~~I.60.~~I.64. For multipurpose (storage, transport and maybe disposal) casks intended for transport and potential disposal after storage the means for appropriate handling at the end of the storage lifetime should be considered in the design.

SPECIFIC OPERATIONAL CONSIDERATIONS FOR DRY STORAGE FACILITIES

~~I.61.~~I.65. To limit corrosion, radiolysis phenomena and criticality issues, spent fuel should be dried to the greatest extent possible prior to be put in a dry storage

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~~I.62.~~I.66. There are several elements in the management of a dry spent fuel storage facility which contribute to the safe operation. Some of the key elements are listed in Table 4. Since dry storage facilities are by design principally passive there are fewer specific operational considerations.

Subcriticality

~~I.63.~~I.67. In most cases, it can be shown by deterministic arguments that dry storage facilities remain subcritical. The effect of water ingress to areas where fuel may be present, possibly as a result of climate change and associated potential increase in the level of naturally occurring bodies of water adjacent to the facility, should be analysed. This can be done either deterministically or using a probabilistic analysis based upon considering external environmental events or man-induced accidents combined with an induced breach in the containment barriers. Additionally, if spent fuel is either loaded or unloaded from a dry storage cask in a pool environment, then subcriticality should be evaluated with credible optimum moderation.

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Heat removal

~~I.64.~~I.68. Heat removal from the spent fuel cask and/or spent fuel storage facility is affected by conduction, radiation, and natural or, in some cases, forced convection. Operational controls should consist of verifying that there are no impairments to the flow of the cooling medium. The cask internal cooling medium typically is an inert gas whereas the external cooling medium for dry storage is typically air. If heat removal requires forced circulation, additional operational controls and maintenance will be required on air moving systems. Maximizing the passive design features for heat removal will minimize the need for operational considerations.

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~~I.65.~~I.69. Operating temperatures should be monitored to ensure the dissipation of spent fuel decay heat to the environment to maintain the integrity of materials important to safety.

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~~I.66.~~I.70. For casks relying upon a gas medium for internal convective cooling the quality/density of the gas should be monitored and maintained if maintenance of the gas medium is not ensured by the design.

Containment

~~I.67.~~I.71. For dry storage cask double seal systems, monitoring should be implemented and should detect the loss of effectiveness of any of the seals in order to prevent potential releases of radioactive materials to the environment. For single seal systems and ventilation systems, release of radioactive materials (e.g. ^{85}Kr, ^{134}Cs and ^{137}Cs) should be monitored.

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~~I.68.~~I.72. For dry cask storage systems with welded closure lids monitoring may not be necessary

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Shielding

~~I.69.~~I.73. Operational controls should be implemented to avoid the loss of shielding during spent fuel storage. The loss of shielding can lead to high radiation exposure. Specifically, operational controls should address the potential for[12]:

(a) Handling errors when closing or sealing dry storage structures;

(b) Improper operation or failure of protective interlocks on shielding cell; and

(c) Melting of neutron shielding material due to high temperatures.

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Drop of Loads

~~I.70.~~I.74. Operational controls should be implemented to avoid a drop of spent fuel during transfer from the cask to the storage rack (or vice versa in the case of cask loading for dry storage). A drop of spent fuel can result in[5]:

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[12] List may not be comprehensive

~~8~~(a) Partial defects in the spent fuel cladding, leading to leaks, and in case of cask loading in a storage pool, result in fission product contamination of the storage pool water;

~~9~~(b) Spent fuel deformation (e.g. bending) or damage which may lead to difficulties in subsequent spent fuel handling;

~~10~~(c) An increased probability or potential for the occurrence of a criticality accident if new or low burnup spent fuel is inadvertently dropped in the vicinity of other spent fuel in the pool storage racks; and

~~11~~(d) Personnel radiation exposure due to the release of volatile radionuclides.

I.~~71~~75. Processes should be established to evaluate the effect of any dropped fuel on the integrity of the cladding of the dropped fuel and on any other structure or component impacted by the drop. The results of the evaluation should be used to inform the future management of the dropped fuel.

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APPENDIX II

SPECIFIC FUEL AND ADDITIONAL CONSIDERATIONS

GENERAL

~~2.5.~~II.1. Fuel element types that have to be considered for storage are numerous. These differ by the type of fuel, the enrichment in ^{235}U for fresh uranium fuel, the cladding material and geometry. After irradiation in a reactor, large variations occur in heat generation, gamma and neutron dose rates and in criticality safety requirements. In selecting a storage mode due consideration should be given to the specific properties of the respective fuel.

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MOX FUEL

~~2.6.~~II.2. Fuel made from a mixture of uranium and recycled plutonium oxide (MOX fuel) is increasingly being utilized in light water reactors. Although the fuel rods and fuel assemblies are essentially identical in structure and in form to analogous uranium oxide fuels, they differ from the latter in the radionuclide inventory and by substantially higher decay heat generation and higher neutron radiation rates. These properties can significantly reduce the number of spent MOX fuel assemblies that can be loaded into a dry storage cask, when cooling times are short. To facilitate the most efficient storage of MOX fuel and reduce the number of dry storage casks necessary the operating organization of a spent fuel storage facility should optimize the cooling time, to allow sufficient reduction in decay heat generation rate, before the spent MOX fuel is loaded into a dry storage system.

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~~2.7.~~II.3. Safety against criticality constitutes an important design requirement. For the nuclear reactivity analysis special consideration has to be given in the definition of an enveloping plutonium and uranium ratio.

~~2.8.~~II.4. Spent MOX fuel may be loaded amongst uranium fuel assemblies. In that case, the MOX assemblies should be positioned at specific positions to allow for the effective dissipation of heat and to provide for adequate radiation shielding.

~~2.9.~~II.5. Compared to uranium fuel, the increased heat generation, the high alpha activity and the higher build up of gaseous fission products of spent MOX fuel will impose additional stress on the cladding material. Therefore, for each type of cladding, the cladding integrity should be demonstrated before storage takes place, regardless of the storage approach; wet or dry.

FUEL WITH HIGH BURNUP

~~2.10.~~II.6. Most safety measures necessary for the storage of MOX fuel are also applicable to the storage of high burnup fuel (typical burnup above 55 GWd/t uranium for LWR).

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BURNUP CREDIT

~~2.11.~~II.7. Burnup credit is a methodology that takes credit for the reduction in spent fuel nuclear reactivity as a result of fission. It is a move away from the more conservative ‘fresh fuel’ assumption and, consequently is a choice to adopt a more realistic approach. This choice requires full justification with accurate experimental data, approved calculation methods and validated and verified benchmarked computer codes according to international standards. A licence application for the storage of spent fuel with the inclusion of burnup credit should be supported by an adequate safety assessment that demonstrates achieving the required safety level.

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~~2.12.~~II.8. Approval to consider burnup credit in the safety assessment should only be granted if based on design engineered safety features and operational controls. Operational controls provide defence in depth and increase confidence in maintaining subcritical conditions. Additional controls may be needed to verify that the spent fuel elements to be stored are consistent with the limiting burnup value.

~~2.13.~~II.9. Approval to consider burnup credit in the safety assessment should be granted in an incremental manner. Simple cases should be prioritized before considering more complex cases, such as spent fuel with mixed enrichments. This would allow for the accumulation of the necessary experience with fuel that can easily be characterized, such as standard PWR fuel.

FUEL FROM RESEARCH REACTORS

~~2.14.~~II.10. The basic safety aspects for storage of spent fuel from power reactors are applicable for storage of spent fuel from research reactors. A proper grading, taking the differences between the fuel types into account, has to be applied. Issues related specifically to the storage of research reactor fuel, e.g. lower heat generation, higher enrichment, need particular attention.

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~~2.15.~~II.11. Fuel composition, cladding material, shape and size of fuel assemblies vary significantly in research reactors. In a research reactor different fuel elements can be loaded to the research reactor and thus a variety of spent fuel is generated. This may comprise, for example, fuel assemblies with different cladding material (Al, SS, Zr) or with different fuel composition. In certain research reactors, reconstitution of an irradiated fuel assembly (replacement of pins) is carried out.

~~2.16.~~II.12. In addition to the guidance provided in this document, it is essential that all aspects related to the specific fuel assemblies used in the research reactor are taken into consideration.

~~2.17.~~II.13. Detailed assessment of all fuel assemblies, including reconstituted assemblies, should be carried out for storage. Proper design provisions for storage of research reactor fuel assemblies commensurate with the shape, size clad-type, and fuel composition should be made. Design provisions for safe storage of any separated pins resulting from reconstitution of fuel should also be made.

~~2.18.~~II.14. Due to the higher enrichment of fuel used in research reactors, the potential for inadvertent criticality may be higher. Therefore the design of a spent fuel storage facility should incorporate features that will add additional subcriticality margin during storage as noted in earlier sections of this Safety Guide.

~~2.19.~~II.15. The compatibility of the research reactor fuel cladding with wet storage conditions needs to be assessed in order to assure integrity.

~~2.20.~~II.16. Since aluminium and its alloys, which are widely used as cladding material for research reactor fuel, have relatively less corrosion resistance, meticulous control of pool water composition is required to ensure the integrity of the fuel cladding. In view of this, it should be preferable ~~in the longer term~~ to store spent research reactor fuel in a dry storage environment.

~~2.21.~~II.17. Spent research reactor fuel should be dried to the greatest extent possible prior to transferring it to dry storage. This may require placement in a suitably designed canister and may require specific treatment prior to transferring to the dry storage facility. The dry storage facility should be designed to ensure that the environment surrounding the fuel will inhibit corrosion and thus eliminate the possible release of air or water borne radionuclides.

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ANNEX 1

Short term storage

Short term storage (conventional storage) is defined in this report as storage that could last up to approximately fifty years, since this period is representative for:

- typical design life for conventional storage structures and facilities;
- a period over which one may be reasonably confident that the operator will have sufficient funds to continue operating;
- within the realm of conventional regulatory experience;
- the time to produce an adequate quantity of material to make it economical to process (interim or buffer storage);
- a period over which wastes are held to allow treatment and conditioning plants to be developed (e.g., a fuel encapsulation plant)(interim storage); and
- the time to decide whether the material is a resource or a waste and to allow the development of the required processing techniques (strategic or interim storage).

To satisfy safety considerations a short term storage concept must include an end point that will be reached within the approximately fifty ~~year~~years time period. Where this is not possible then the concept should be compared against the safety requirements of a long term waste storage facility.

Long term storage

Long term storage is considered in this report as storage beyond approximately fifty years, and with a defined end point. The storage endpoint is important since it becomes the basis for the design life of the facility, packaging requirements, financial guarantees and the planning basis for subsequent disposal facilities. Long term storage should not be expected to last more than approximately one hundred years. This timeframe is based on technical experience with civil construction. However, it is a fact that many existing industrial and civil analogues exist that have lifetimes of 100-150 years and more. Archeological analogues can be found with lifetimes of 1000-2000 years. Societal acceptance of longer design life, which is based on experience with existing industrial operations and facilities, is also an important factor to consider. The one hundred year period is judged to be adequate to allow enough time to determine future management steps.

ANNEX 2

OPERATIONAL AND SAFETY CONSIDERATIONS FOR A WET SPENT FUEL STORAGE FACILITY

Element	Applicable safety considerations
1. Control of the amount of spent fuel loaded in the pool, taking account of decay heat, nuclear reactivity and floor static loadings	Subcriticality, heat removal
2. Protection of pool floors and walls from impact loads	Containment, radiation protection, spent fuel assembly structural integrity
3. Control of pool water (specific activity, temperature, chemical composition)	Containment, radiation protection, spent fuel assembly structural integrity
4. Control of pool water level	Radiation protection, heat protection
5. Maintenance of ventilation systems	Containment
6. Maintenance of pool heat removal systems	Containment, heat removal
7. Maintenance of handling equipment	Radiation protection, containment, spent fuel assembly structural integrity
8. Maintenance of underwater lighting	Radiation protection
9. Administrative controls to prevent misplacing spent fuel	Subcriticality
10. Spent Fuel integrity	Radiation Protection

OPERATIONAL AND SAFETY CONSIDERATIONS FOR A DRY SPENT FUEL STORAGE FACILITY

Element	Applicable safety considerations
1. Controlling the type and amount of spent fuel in the storage compartments	Subcriticality, heat removal
2. Monitoring gamma and neutron radiation fields near the location of spent fuel in the storage area	Radiation protection
3. Monitoring heat removal and heat dissipation from	Heat removal, radiation

spent fuel to the environment	protection, containment, spent fuel assembly structural integrity
4. Direct monitoring of spent fuel containment integrity (if permitted by the design)	Radiation protection, containment
5. Indirect monitoring of atmosphere in volumes/spaces inside facility containing sealed spent fuel casks (if present in the design)	Radiation protection, containment, spent fuel assembly structural integrity
6. Maintenance and monitoring of the inert gas in sealed casks (if present and possible by the design)	Heat removal, spent fuel integrity

An example of sections defining operating procedures

~~5~~(a) Title description with revision number, date and approval status;

~~6~~(b) Purpose of the procedure;

~~7~~(c) Initial conditions required before the procedure can be used;

~~8~~(d) Precautions and limitations that must be observed;

~~9~~(e) Limitations and action levels on parameters being controlled (e.g. pool water composition) and corrective measures to return parameters to within normal range;

~~10~~(f) Procedures providing completely detailed, step by step operating instructions;

~~11~~(g) Acceptance criteria, where applicable, for judging success or failure of activities;

~~12~~(h) Checklists for complex procedures, either included or referenced;

~~13~~(i) References used in producing the procedure; and

~~14~~(j) Testing to verify radiation dose levels and heat removal performance after spent fuel loading.

~~15~~(k) Monitoring of boreholes around the facility.

~~16~~(l) Monitoring of stack discharge.

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Safety Fundamentals

- Fundamental Safety Principles, SF-1

Safety Requirements

- Predisposal Management of Radioactive Waste
- Safety of Nuclear Power Plants: Design
- Safety of Nuclear Fuel Cycle Facilities
- The Management System for Facilities and Activities

Safety Guides

- Storage of Radioactive Waste
- The Management System for the Processing, Handling and Storage of Radioactive Waste
- Safety Case and Safety Assessment for Predisposal Management of Radioactive Waste
- Safety Assessment for Facilities and Activities

Hierarchical linkage of Safety Guide on Storage of Spent Fuel with related Safety Series Standard documents

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ANNEX 3

SITE CONDITIONS, PROCESSES AND EVENTS FOR CONSIDERATION IN A SAFETY ASSESSMENT (EXTERNAL NATURAL PHENOMENA)

In making use of this list it should be recognized that the initiating events given would not necessarily be applicable to all facilities and all sites. The list is provided for use as an aid to memory.

(1) The meteorology and climatology of the site and region:

- (i) Precipitation (averages and extremes, including frequency, duration and intensity):
  - — rain, hail, snow and ice;
  - — snow cover and ice cover (including potential for blocking inlets or outlets);
  - — drought.
- (ii) Wind (averages and extremes, including frequency, duration and intensity):
  - — tornadoes, hurricanes and cyclones.
- (iii) Rate and duration of the input of direct solar radiation (insolation, averages and extremes).
- (iv) Temperature (averages and extremes, including frequency and duration):
  - — permafrost and the cyclic freezing and thawing of soil.
- (v) Barometric pressure (averages and extremes, including frequency and duration).
- (vi) Humidity (averages and extremes, including frequency and duration):
  - — fog and frost.
- (vii) Lightning (frequency and intensity).

(2) The hydrology and hydrogeology of the site and region:

- (i) Surface runoff (averages and extremes, including frequency, duration and intensity):
  - — flooding (frequency, duration and intensity);
  - — erosion (rate).
- (ii) Groundwater conditions (averages and extremes, including frequency and duration).
- (iii) Wave action (averages and extremes, including frequency, duration and intensity):
  - — high tides, storm surges and tsunami;
  - — flooding (frequency, duration and intensity);
  - — shore erosion (rate).

(3) The geology of the site and region:

- (i) Lithology and stratigraphy:
  - — the geotechnical characteristics of site materials.
- (ii) Seismicity:
  - — faults and zones of weakness;
  - — earthquakes (frequency and intensity).
- (iii) Vulcanology:

— volcanic debris and ash.

(iv) Historical mining and quarrying:

— ground subsidence.

(4) The geomorphology and topography of the site:

(i) Stability of natural material:

— slope failures, landslides and subsidence;

— avalanches.

(ii) Surface erosion.

(iii) The effects of the terrain (topography) on weather conditions or on the consequences of extreme weather.

(5) The terrestrial and aquatic flora and fauna of the site (in terms of their effects on the facility):

(i) Vegetation (terrestrial and aquatic):

— the blocking of inlets and outlets;

— damage to structures.

(ii) Rodents, birds and other wildlife:

— direct damage due to burrowing, chewing, etc.

— accumulation of nesting debris, guano, etc.

(6) The potential for:

(i) Naturally occurring fires and explosions at the site.

(ii) Methane gas or natural toxic gas (from marshland or landfill sites).

(iii) Dust storms or sand storms (including the possible blocking of inlets and outlets).

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ANNEX 4

SITE CONDITIONS, PROCESSES AND EVENTS FOR CONSIDERATION IN A SAFETY ASSESSMENT (EXTERNAL HUMAN INDUCED PHENOMENA)

In making use of this list it should be recognized that the initiating events given would not necessarily be applicable to all facilities and all sites. The list is provided for use as an aid to memory.

(1) Explosion:
- (i) Solid substance;
- (ii) Gas, dust or aerosol cloud.

(2) Fire:
- (i) Solid substance;
- (ii) Liquid substance;
- (iii) Gas, dust or aerosol cloud.

(3) Aircraft crash.

(4) Missiles due to structural or mechanical failure in nearby installations.

(5) Flooding:
- (i) The structural failure of a dam;
- (ii) The blockage of a river.

(6) Ground subsidence or collapse due to tunnelling or mining.

(7) Ground vibration.

(8) The release of any corrosive, toxic and/or radioactive substance:
- (i) Liquid;
- (ii) Gas, dust or aerosol cloud.

(9) Geographic and demographic data:
- (i) Population density and expected changes over the lifetime of the facility;
- (ii) Industrial and military installations and related activities and the effects on the facility of accidents at such installations;
- (iii) Traffic;
- (iv) Transport infrastructure (highways, airports and/or flight paths, railway lines, rivers and canals, pipelines and the potential for impacts or accidents involving hazardous material).

(10) Power supply and the potential loss of power.

(11) Civil strife:
- (i) Terrorism, sabotage and perimeter incursions;
- (ii) The failure of infrastructure;
- (iii) Civil disorder;
- (iv) Strikes and blockades;
- (v) Health issues (e.g. endemic diseases or epidemics).

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ANNEX 5

POSTULATED INITIATING EVENTS FOR CONSIDERATION IN A SAFETY ASSESSMENT (INTERNAL PHENOMENA)

In making use of this list it should be recognized that the initiating events given would not necessarily be applicable to all facilities and all sites. The list is provided for use as an aid to memory.

(1) The acceptance (inadvertent or otherwise) of incoming waste, waste containers, process chemicals, conditioning agents, etc., that do not meet the specifications (acceptance criteria) included in the design basis.

(2) The processing of waste that meets acceptance criteria but that is subsequently processed in an inappropriate way for the particular type of waste (either inadvertently or otherwise).

(3) A criticality event due to the inappropriate accumulation of fissile material, change of geometrical configuration, introduction of moderating material, removal of neutron absorbing material or various combinations of these.

(4) Explosion due to the evolution of explosive gas mixtures as a result of:

- (i) Radiolysis.
- (ii) Off-gassing or volatilization.
- (iii) Chemical reactions from inappropriate mixing or contact with:
  - — different waste streams;
  - — waste and conditioning agents;
  - — waste container material and conditioning agents;
  - — process chemicals;
  - — waste, waste containers, conditioning agents, process chemicals and the prevailing conditions of the work environment or storage environment.
- (iv) The inclusion of items such as bottles of compressed gas in the input to incinerators or compactors.

(5) Fire due to:

- (i) Spontaneous combustion;
- (ii) Local hot spots generated by malfunctions of structures, systems or components.
- (iii) Sparks from machinery, equipment or electrical circuits.
- (iv) Sparks from human activities such as welding or smoking.
- (v) Explosions.

(6) Gross incompatibilities between the components of a process system and the materials introduced into the system.

(7) The degradation of process materials (chemicals, additives or binders) due to improper handling or storage.

(8) The failure to take account of the non-radiological hazards presented by the waste (physical, chemical or pathogenic).

(9) The generation of a toxic atmosphere by chemical reactions due to the inappropriate mixing or contact of various reagents and materials.

(10) Dropping waste packages or other loads due to mishandling or equipment failure, with consequences to the dropped waste package and possibly to other waste packages or to the structures, systems and components of the facility.

(11) Collisions of vehicles or suspended loads with structures, systems and components of the facility or with waste packages, waste containment vessels and pipes.

(12) Failures of structures, systems and components due to:

- (i) The loss of structural competence or mechanical integrity.
- (ii) Vibrations originating within the facility.
- (iii) Pressure imbalances (pressure surges or pressure collapses).
- (iv) Internal corrosion or erosion or the chemical effects of the work or storage environment.

(13) The generation of missiles and flying debris due to the explosion of pressurized components or the gross failure of rotating equipment.

(14) The malfunctioning of heating or cooling equipment, leading to unintended temperature excursions in process systems or storage systems.

(15) The malfunctioning of process control equipment.

(16) The malfunctioning of equipment that maintains the ambient conditions in the facility, such as the ventilation system or dewatering system.

(17) The malfunctioning of monitoring or alarm systems so that an adverse condition goes unnoticed.

(18) Incorrect settings (errors or unauthorized changes) on monitors, alarms or control equipment.

(19) The failure to function when called upon of emergency equipment such as the fire suppression system, pressure relief valves and ducts.

(20) The failure of the power supply, either the main system or various subsystems.

(21) The malfunctioning of key equipment for handling waste, such as transfer cranes or conveyors.

(22) The malfunctioning of structures, systems and components that control releases to the environment, such as filters or valves.

(23) The failure properly to inspect, test and maintain structures, systems and components.

(24) Incorrect operator action due to inaccurate or incomplete information.

(25) Incorrect operator action in spite of having accurate and complete information.

(26) Sabotage by employees.

(27) The failure of systems and components such as incinerator linings, compactor hydraulics or cutting machinery that poses the risk of significant additional radiation exposure of personnel called on to assist in effecting repairs or replacements.

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(28) Encountering an unanticipated radiation source in decommissioning (e.g. different in nature or amount) and not recognizing immediately the changed circumstances.

(29) Removing or weakening a structure or component in decommissioning without realizing the possible effects on the structural competence of other structures and components.

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CONTRIBUTORS TO DRAFTING AND REVIEW

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BODIES FOR THE ENDORSEMENT OF SAFETY STANDARDS
(To be inserted later)

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