This publication has been superseded by SSG-15 (Rev. 1).

IAEA Safety Standards

for protecting people and the environment

Storage of Spent Nuclear Fuel

Specific Safety Guide

No. SSG-15

IAEA

International Atomic Energy Agency

IAEA SAFETY STANDARDS AND RELATED PUBLICATIONS

IAEA SAFETY STANDARDS

Under the terms of Article III of its Statute, the IAEA is authorized to establish or adopt standards of safety for protection of health and minimization of danger to life and property, and to provide for the application of these standards.

The publications by means of which the IAEA establishes standards are issued in the **IAEA Safety Standards Series**. This series covers nuclear safety, radiation safety, transport safety and waste safety. The publication categories in the series are **Safety Fundamentals**, **Safety Requirements** and **Safety Guides**.

Information on the IAEA's safety standards programme is available at the IAEA Internet site

http://www-ns.iaea.org/standards/

The site provides the texts in English of published and draft safety standards. The texts of safety standards issued in Arabic, Chinese, French, Russian and Spanish, the IAEA Safety Glossary and a status report for safety standards under development are also available. For further information, please contact the IAEA at PO Box 100, 1400 Vienna, Austria.

All users of IAEA safety standards are invited to inform the IAEA of experience in their use (e.g. as a basis for national regulations, for safety reviews and for training courses) for the purpose of ensuring that they continue to meet users' needs. Information may be provided via the IAEA Internet site or by post, as above, or by email to Official.Mail@iaea.org.

RELATED PUBLICATIONS

The IAEA provides for the application of the standards and, under the terms of Articles III and VIII.C of its Statute, makes available and fosters the exchange of information relating to peaceful nuclear activities and serves as an intermediary among its Member States for this purpose.

Reports on safety and protection in nuclear activities are issued as **Safety Reports**, which provide practical examples and detailed methods that can be used in support of the safety standards.

Other safety related IAEA publications are issued as **Radiological Assessment Reports**, the International Nuclear Safety Group's **INSAG Reports**, **Technical Reports** and **TECDOCs**. The IAEA also issues reports on radiological accidents, training manuals and practical manuals, and other special safety related publications.

Security related publications are issued in the **IAEA Nuclear Security Series**.

The **IAEA Nuclear Energy Series** consists of reports designed to encourage and assist research on, and development and practical application of, nuclear energy for peaceful uses. The information is presented in guides, reports on the status of technology and advances, and best practices for peaceful uses of nuclear energy. The series complements the IAEA's safety standards, and provides detailed guidance, experience, good practices and examples in the areas of nuclear power, the nuclear fuel cycle, radioactive waste management and decommissioning.

STORAGE OF SPENT NUCLEAR FUEL

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

AFGHANISTAN
ALBANIA
ALGERIA
ANGOLA
ARGENTINA
ARMENIA
AUSTRALIA
AUSTRIA
AZERBAIJAN
BAHRAIN
BANGLADESH
BELARUS
BELGIUM
BELIZE
BENIN
BOLIVIA
BOSNIA AND HERZEGOVINA
BOTSWANA
BRAZIL
BULGARIA
BURKINA FASO
BURUNDI
CAMBODIA
CAMEROON
CANADA
CENTRAL AFRICAN REPUBLIC
CHAD
CHILE
CHINA
COLOMBIA
CONGO
COSTA RICA
CÔTE D'IVOIRE
CROATIA
CUBA
CYPRUS
CZECH REPUBLIC
DEMOCRATIC REPUBLIC OF THE CONGO
DENMARK
DOMINICA
DOMINICAN REPUBLIC
ECUADOR
EGYPT
EL SALVADOR
ERITREA
ESTONIA
ETHIOPIA
FINLAND
FRANCE
GABON
GEORGIA
GERMANY
GHANA
GREECE
GUATEMALA
HAITI
HOLY SEE
HONDURAS
HUNGARY
ICELAND
INDIA
INDONESIA
IRAN, ISLAMIC REPUBLIC OF
IRAQ
IRELAND
ISRAEL
ITALY
JAMAICA
JAPAN
JORDAN
KAZAKHSTAN
KENYA
KOREA, REPUBLIC OF
KUWAIT
KYRGYZSTAN
LAO PEOPLE'S DEMOCRATIC REPUBLIC
LATVIA
LEBANON
LESOTHO
LIBERIA
LIBYA
LIECHTENSTEIN
LITHUANIA
LUXEMBOURG
MADAGASCAR
MALAWI
MALAYSIA
MALI
MALTA
MARSHALL ISLANDS
MAURITANIA
MAURITIUS
MEXICO
MONACO
MONGOLIA
MONTENEGRO
MOROCCO
MOZAMBIQUE
MYANMAR
NAMIBIA
NEPAL
NETHERLANDS
NEW ZEALAND
NICARAGUA
NIGER
NIGERIA
NORWAY
OMAN
PAKISTAN
PALAU
PANAMA
PARAGUAY
PERU
PHILIPPINES
POLAND
PORTUGAL
QATAR
REPUBLIC OF MOLDOVA
ROMANIA
RUSSIAN FEDERATION
SAUDI ARABIA
SENEGAL
SERBIA
SEYCHELLES
SIERRA LEONE
SINGAPORE
SLOVAKIA
SLOVENIA
SOUTH AFRICA
SPAIN
SRI LANKA
SUDAN
SWEDEN
SWITZERLAND
SYRIAN ARAB REPUBLIC
TAJIKISTAN
THAILAND
THE FORMER YUGOSLAV REPUBLIC OF MACEDONIA
TUNISIA
TURKEY
UGANDA
UKRAINE
UNITED ARAB EMIRATES
UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
UNITED REPUBLIC OF TANZANIA
UNITED STATES OF AMERICA
URUGUAY
UZBEKISTAN
VENEZUELA
VIETNAM
YEMEN
ZAMBIA
ZIMBABWE

The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world''.

IAEA SAFETY STANDARDS SERIES No. SSG-15

STORAGE OF SPENT NUCLEAR FUEL

SPECIFIC SAFETY GUIDE

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2012

Marketing and Sales Unit, Publishing Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna, Austria
fax: +43 1 2600 29302
tel.: +43 1 2600 22417
email: sales.publications@iaea.org
http://www.iaea.org/books

Printed by the IAEA in Austria
February 2012
STI/PUB/1503

IAEA Library Cataloguing in Publication Data

Storage of spent nuclear fuel : specific safety guide. — Vienna : International Atomic Energy Agency, 2012.
p. ; 24 cm. — (IAEA safety standards series, ISSN 1020–525X ; no. SSG-15)
STI/PUB/1503
ISBN 978–92–0–115110–0
Includes bibliographical references.

1. Spent reactor fuels — Storage. 2. Radiation — Safety measures. 3. Spent reactor fuels — Management. I. International Atomic Energy Agency. II. Series.

IAEAL 12–00729

FOREWORD

by Yukiya Amano
Director General

The IAEA's Statute authorizes the Agency to "establish or adopt… standards of safety for protection of health and minimization of danger to life and property" — standards that the IAEA must use in its own operations, and which States can apply by means of their regulatory provisions for nuclear and radiation safety. The IAEA does this in consultation with the competent organs of the United Nations and with the specialize d agencies concerned. A comprehensive set of high quality standards under regular review is a key element of a stable and sustainable global safety regime, as is the IAEA's assistance in their application.

The IAEA commenced its safety standards programme in 1958. The emphasis placed on quality, fitness for purpose and continuous improvement has led to the widespread use of the IAEA standards throughout the world. The Safety Standards Series now includes unified Fundamental Safety Principles, which represent an international consensus on what must constitute a high level of protection and safety. With the strong support of the Commission on Safety Standards, the IAEA is working to promote the global acceptance and use of its standards.

Standards are only effective if they are properly applied in practice. The IAEA's safety services encompass design, siting and engineering safety, operational safety, radiation safety, safe transport of radioactive material and safe management of radioactive waste, as well as governmental organization, regulatory matters and safety culture in organizations. These safety services assist Member States in the application of the standards and enable valuable experience and insights to be shared.

Regulating safety is a national responsibility, and many States have decided to adopt the IAEA's standards for use in their national regulations. For 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 regulatory bodies and operators around the world to enhance safety in nuclear power generation and in nuclear applications in medicine, industry, agriculture and research.

Safety is not an end in itself but a prerequisite for the purpose of the protection of people in all States and of the environment — now and in the future. The risks associated with ionizing radiation must be assessed and controlled without unduly limiting the contribution of nuclear energy to equitable and sustainable development. Governments, regulatory bodies and operators everywhere must ensure that nuclear material and radiation sources are used beneficially, safely and ethically. The IAEA safety standards are designed to facilitate this, and I encourage all Member States to make use of them.

NOTE BY THE SECRETARIAT

The IAEA safety standards reflect an international consensus on what constitutes a high level of safety for protecting people and the environment from harmful effects of ionizing radiation. The process of developing, reviewing and establishing the IAEA standards involves the IAEA Secretariat and all Member States, many of which are represented on the four IAEA safety standards committees and the IAEA Commission on Safety Standards.

The IAEA standards, as a key element of the global safety regime, are kept under regular review by the Secretariat, the safety standards committees and the Commission on Safety Standards. The Secretariat gathers information on experience in the application of the IAEA standards and information gained from the follow-up of events for the purpose of ensuring that the standards continue to meet users' needs. The present publication reflects feedback and experience accumulated until 2010 and it has been subject to the rigorous review process for standards.

Lessons that may be learned from studying the accident at the Fukushima Daiichi nuclear power plant in Japan following the disastrous earthquake and tsunami of 11 March 2011 will be reflected in this IAEA safety standard as revised and issued in the future.

THE IAEA SAFETY STANDARDS

BACKGROUND

Radioactivity is a natural phenomenon and natural sources of radiation are features of the environment. Radiation and radioactive substances have many beneficial applications, ranging from power generation to uses in medicine, industry and agriculture. The radiation risks to workers and the public and to the environment that may arise from these applications have to be assessed and, if necessary, controlled.

Activities such as the medical uses of radiation, the operation of nuclear installations, the production, transport and use of radioactive material, and the management of radioactive waste must therefore be subject to standards of safety.

Regulating safety is a national responsibility. However, radiation risks may transcend national borders, and international cooperation serves to promote and enhance safety globally by exchanging experience and by improving capabilities to control hazards, to prevent accidents, to respond to emergencies and to mitigate any harmful consequences.

States have an obligation of diligence and duty of care, and are expected to fulfil their national and international undertakings and obligations.

International safety standards provide support for States in meeting their obligations under general principles of international law, such as those relating to environmental protection. International safety standards also promote and assure confidence in safety and facilitate international commerce and trade.

A global nuclear safety regime is in place and is being continuously improved. IAEA safety standards, which support the implementation of binding international instruments and national safety infrastructures, are a cornerstone of this global regime. The IAEA safety standards constitute a useful tool for contracting parties to assess their performance under these international conventions.

THE IAEA SAFETY STANDARDS

The status of the IAEA safety standards derives from the IAEA's Statute, which authorizes the IAEA to establish or adopt, in consultation and, where appropriate, in collaboration with the competent organs of the United Nations and with the specialized agencies concerned, standards of safety for protection of health and minimization of danger to life and property, and to provide for their application.

With a view to ensuring the protection of people and the environment from harmful effects of ionizing radiation, the IAEA safety standards establish fundamental safety principles, requirements and measures to control the radiation exposure of people and the release of radioactive material to the environment, to restrict the likelihood of events that might lead to a loss of control over a nuclear reactor core, nuclear chain reaction, radioactive source or any other source of radiation, and to mitigate the consequences of such events if they were to occur. The standards apply to facilities and activities that give rise to radiation risks, including nuclear installations, the use of radiation and radioactive sources, the transport of radioactive material and the management of radioactive waste.

Safety measures and security measures[1] have in common the aim of protecting human life and health and the environment. Safety measures and security measures must be designed and implemented in an integrated manner so that security measures do not compromise safety and safety measures do not compromise security.

The IAEA safety standards reflect an international consensus on what constitutes a high level of safety for protecting people and the environment from harmful effects of ionizing radiation. They are issued in the IAEA Safety Standards Series, which has three categories (see Fig. 1).

Safety Fundamentals

Safety Fundamentals present the fundamental safety objective and principles of protection and safety, and provide the basis for the safety requirements.

Safety Requirements

An integrated and consistent set of Safety Requirements establishes the requirements that must be met to ensure the protection of people and the environment, both now and in the future. The requirements are governed by the objective and principles of the Safety Fundamentals. If the requirements are not met, measures must be taken to reach or restore the required level of safety. The format and style of the requirements facilitate their use for the establishment, in a harmonized manner, of a national regulatory framework. Requirements, including numbered 'overarching' requirements, are expressed as 'shall' statements. Many requirements are not addressed to a specific party, the implication being that the appropriate parties are responsible for fulfilling them.

Safety Guides

Safety Guides provide recommendations and guidance on how to comply with the safety requirements, indicating an international consensus that it is necessary to take the measures recommended (or equivalent alternative measures). The Safety

---

[1] See also publications issued in the IAEA Nuclear Security Series.

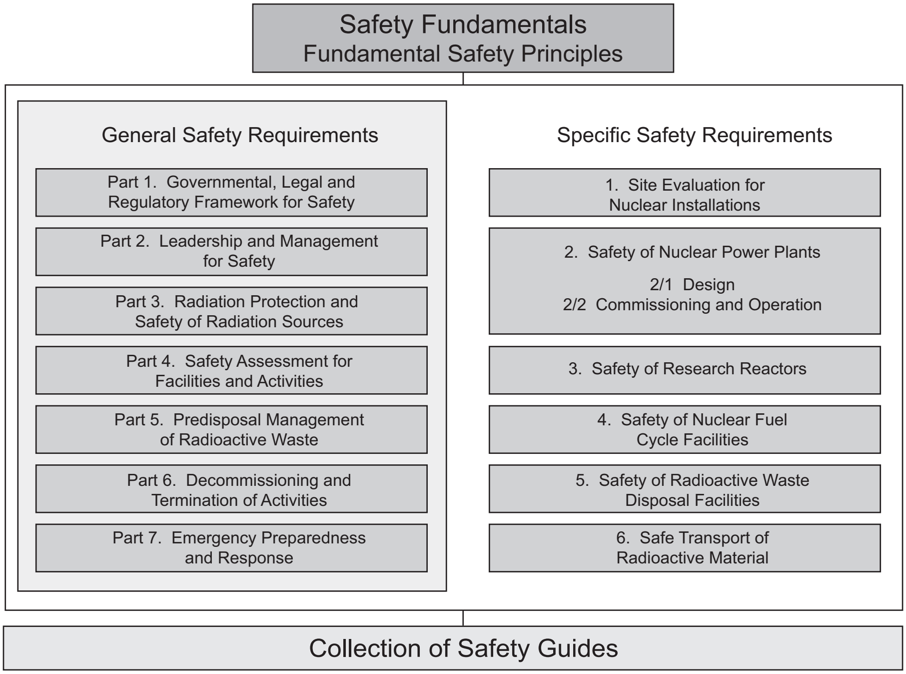

FIG. 1. The long term structure of the IAEA Safety Standards Series.

Guides present international good practices, and increasingly they reflect best practices, to help users striving to achieve high levels of safety. The recommendations provided in Safety Guides are expressed as ‘should’ statements.

APPLICATION OF THE IAEA SAFETY STANDARDS

The principal users of safety standards in IAEA Member States are regulatory bodies and other relevant national authorities. The IAEA safety standards are also used by co-sponsoring organizations and by many organizations that design, construct and operate nuclear facilities, as well as organizations involved in the use of radiation and radioactive sources.

The IAEA safety standards are applicable, as relevant, throughout the entire lifetime of all facilities and activities — existing and new — utilized for peaceful purposes and to protective actions to reduce existing radiation risks. They can be used by States as a reference for their national regulations in respect of facilities and activities.

The IAEA's Statute makes the safety standards binding on the IAEA in relation to its own operations and also on States in relation to IAEA assisted operations.

The IAEA safety standards also form the basis for the IAEA's safety review services, and they are used by the IAEA in support of competence building, including the development of educational curricula and training courses.

International conventions contain requirements similar to those in the IAEA safety standards and make them binding on contracting parties. The IAEA safety standards, supplemented by international conventions, industry standards and detailed national requirements, establish a consistent basis for protecting people and the environment. There will also be some special aspects of safety that need to be assessed at the national level. For example, many of the IAEA safety standards, in particular those addressing aspects of safety in planning or design, are intended to apply primarily to new facilities and activities. The requirements established in the IAEA safety standards might not be fully met at some existing facilities that were built to earlier standards. The way in which IAEA safety standards are to be applied to such facilities is a decision for individual States.

The scientific considerations underlying the IAEA safety standards provide an objective basis for decisions concerning safety; however, decision makers must also make informed judgements and must determine how best to balance the benefits of an action or an activity against the associated radiation risks and any other detrimental impacts to which it gives rise.

DEVELOPMENT PROCESS FOR THE IAEA SAFETY STANDARDS

The preparation and review of the safety standards involves the IAEA Secretariat and four safety standards committees, for nuclear safety (NUSSC), radiation safety (RASSC), the safety of radioactive waste (WASSC) and the safe transport of radioactive material (TRANSSC), and a Commission on Safety Standards (CSS) which oversees the IAEA safety standards programme (see Fig. 2).

All IAEA Member States may nominate experts for the safety standards committees and may provide comments on draft standards. The membership of the Commission on Safety Standards is appointed by the Director General and includes senior governmental officials having responsibility for establishing national standards.

A management system has been established for the processes of planning, developing, reviewing, revising and establishing the IAEA safety standards. It articulates the mandate of the IAEA, the vision for the future application of the

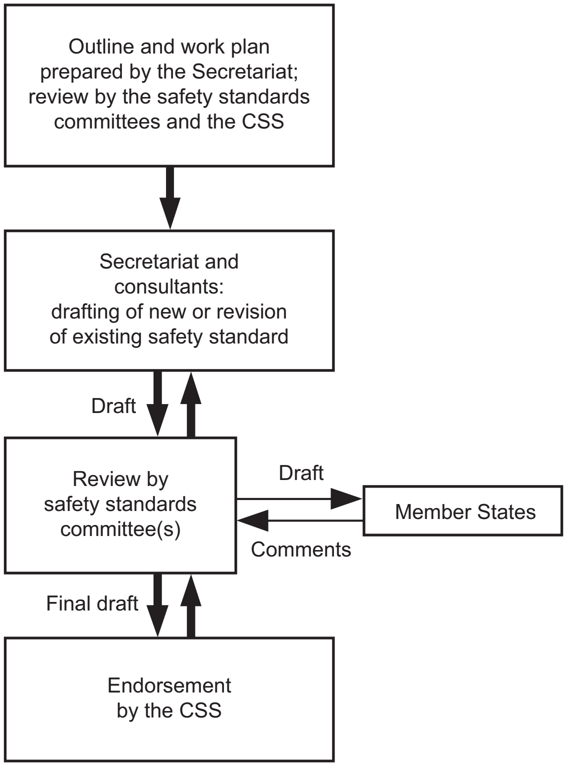

FIG. 2. The process for developing a new safety standard or revising an existing standard.

safety standards, policies and strategies, and corresponding functions and responsibilities.

INTERACTION WITH OTHER INTERNATIONAL ORGANIZATIONS

The findings of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the recommendations of international expert bodies, notably the International Commission on Radiological Protection (ICRP), are taken into account in developing the IAEA safety standards. Some safety standards are developed in cooperation with other bodies in the United Nations system or other specialized agencies, including the Food and Agriculture Organization of the United Nations, the United Nations Environment Programme, the International Labour Organization, the OECD Nuclear Energy Agency, the Pan American Health Organization and the World Health Organization.

INTERPRETATION OF THE TEXT

Safety related terms are to be understood as defined in the IAEA Safety Glossary (see http://www-ns.iaea.org/standards/safety-glossary.htm). Otherwise, words are used with the spellings and meanings assigned to them in the latest edition of The Concise Oxford Dictionary. For Safety Guides, the English version of the text is the authoritative version.

The background and context of each standard in the IAEA Safety Standards Series and its objective, scope and structure are explained in Section 1, Introduction, of each publication.

Material for which there is no appropriate place in the body text (e.g. material that is subsidiary to or separate from the body text, is included in support of statements in the body text, or describes methods of calculation, procedures or limits and conditions) may be presented in appendices or annexes.

An appendix, if included, is considered to form an integral part of the safety standard. Material in an appendix has the same status as the body text, and the IAEA assumes authorship of it. Annexes and footnotes to the main text, if included, are used to provide practical examples or additional information or explanation. Annexes and footnotes are not integral parts of the main text. Annex material published by the IAEA is not necessarily issued under its authorship; material under other authorship may be presented in annexes to the safety standards. Extraneous material presented in annexes is excerpted and adapted as necessary to be generally useful.

CONTENTS

1. INTRODUCTION

BACKGROUND

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 waste in some circumstances or a potential future energy resource in others and, as such, management options may involve direct disposal (as part of what is generally known as the 'once through fuel cycle') or reprocessing (as part of what is generally known as the 'closed fuel cycle'). Either management option will involve a number of steps, which will necessarily include storage of the spent fuel for some period of time. This time period for storage can differ, depending on the management strategy adopted, 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 design of 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 States.

1.2. Irrespective of the consideration of spent fuel (either waste or an energy resource), the safety aspects for storage remain the same as those for radioactive waste, which are established in GSR Part 5 [1].

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. At the design stage, due consideration also needs to be given to the future decommissioning of the facility.

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, where it will await reprocessing or disposal (if it is considered to be radioactive waste). The spent fuel storage pools of some reactors have sufficient capacity to accommodate all the spent fuel that will be generated during the lifetime of the reactor.

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

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, for example 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 lifetime of the storage facility. Nevertheless, storage cannot be considered the ultimate solution for the management of spent fuel, which requires a defined end point such as reprocessing or disposal in order to ensure safety. The design lifetime of nuclear installations is generally of the order of decades and experience with the storage of spent fuel of up to around fifty years has accrued. While design lifetimes of up to one hundred years have been considered and adopted for certain spent fuel storage facilities, in view of the rate of industrial and institutional change, periods beyond around fifty years are deemed to be ‘long term’ in the context of this Safety Guide (see also Annex I).

1.7. This Safety Guide supersedes the Safety Series publication numbers 116, 117 and 118, which were published in 1994 and covered the design, operation and safety assessment of spent fuel storage facilities, respectively. It additionally incorporates recommendations addressing the impact of the new developments described in para. 1.6. It complements the Safety Guide on storage of radioactive waste [2].

OBJECTIVE

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 nuclear fuel storage facility (wet and dry), by considering different types of spent nuclear fuel from nuclear reactors, including research reactors, and different storage periods, including storage beyond the original design lifetime of the storage facility. This Safety Guide presents guidance and recommendations on how to meet the requirements established in the following IAEA Safety Requirements publications: Predisposal Management of Radioactive Waste [1], Safety of Nuclear Fuel Cycle Facilities [3], Safety Assessment for Facilities and Activities [4] and The Management System for Facilities and Activities [5].

SCOPE

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

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

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 systems, are provided in

[1] The terms ‘degraded fuel’ 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.

Refs [6] and [7] and in publications in the IAEA Nuclear Security Series. The Safety Guide considers physical protection and accounting for and control of nuclear material only to highlight their potential implications for safety.

STRUCTURE

1.12. Section 2 of this Safety Guide addresses the application of the fundamental safety objective and principles and criteria to the storage of spent nuclear fuel. The roles and responsibilities of the organizations involved in the storage of spent nuclear fuel are set out in Section 3. Section 4 provides recommendations on the management systems necessary to provide assurance of safety. Section 5 provides recommendations on safety assessment and Section 6 provides recommendations on safety considerations in respect of design, construction, operation and decommissioning of spent fuel storage facilities, including considerations for long term storage. Appendix I addresses considerations specific to wet and dry storage of spent nuclear fuel and Appendix II addresses considerations in respect of spent fuel with particular characteristics. Annex I provides explanations of the concepts of short term and long term storage. Annex II summarizes safety considerations for wet and dry spent fuel storage facilities. Annex III provides an example of the sections that may be included in the operating procedures for a spent fuel storage facility. Annex IV provides an overview of related IAEA safety standards. Annexes V–VII provide listings of events for consideration in a safety assessment for a spent fuel storage facility.

1.13. For convenience, the text of each safety requirement of Ref. [1] that is applicable to the storage of spent nuclear fuel is reproduced in this Safety Guide, followed by the related recommendations.

2. PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT

2.1. National requirements for radiation protection are required to be established, keeping in view the fundamental safety objective and fundamental safety principles set out in Ref. [8] and in compliance with the International Basic Safety Standards [9]. In particular, doses to persons as a consequence of the storage of spent fuel are required to be kept within specified dose limits and radiation protection is required to be optimized within dose constraints.

2.2. If several nuclear installations (e.g. nuclear power plants, spent fuel storage facilities, reprocessing facilities) are located at the same site, the dose constraints for public exposure should take into account all sources of exposure that could be associated with activities at the site, leaving an appropriate margin for foreseeable future activities at the site that may also give rise to exposure. Particularly in such cases, the regulatory body should require the operating organization(s) of the nuclear installation(s) on the site to develop constraints, subject to regulatory approval. Alternatively, the regulatory body may establish the dose constraint(s). Requirements on dose constraints are established in Ref. [9] and recommendations are provided in Ref. [10].

2.3. The design of a spent fuel storage facility and the storage of spent fuel must be such that workers, the public and the environment, present and future, will be protected from harmful effects of radiation exposure from all sources associated with current activities with spent fuel at the site, with sufficient margins [8, 9].

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 should be included when estimating doses to workers and to the public.

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

2.6. In the generation and storage of spent fuel, as well as in subsequent management steps, a safety culture that encourages a questioning and learning attitude to protection and safety and that discourages complacency should be fostered and maintained [3, 5, 9, 11, 12].

3. ROLES AND RESPONSIBILITIES

GENERAL

Requirement 1 of GSR Part 5 (Ref. [1]): 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 of GSR Part 5 (Ref. [1]): 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.

3.1. Storage of spent fuel should be undertaken within an appropriate national legal and regulatory framework that provides for a clear allocation of responsibilities [13], including responsibilities for meeting international obligations and for verifying compliance with these obligations, and which ensures the effective regulatory control of the facilities and activities concerned [1, 3]. 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 [14].

3.2. The management of spent fuel may entail the transfer of spent fuel from one operating organization to another and various interdependences exist between the various steps in the management of spent fuel. The legal framework should include provision to ensure a clear allocation of responsibility for safety throughout the entire process, in particular with regard to storage of spent fuel and its transfer between operating organizations. Continuity of responsibility for safety should be ensured by means of a system of authorization by the regulatory body. For transfers between States, authorizations from the respective national regulatory bodies are required [14, 15].

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 separate.

3.4. A mechanism for providing adequate financial resources should be established to cover any future costs, in particular, the costs associated with the spent fuel storage and decommissioning of the storage facility 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. Consideration should also be given to provision of the necessary financial resources in the event of premature shutdown of the spent fuel storage facility.

RESPONSIBILITIES OF THE GOVERNMENT

Requirement 2 of GSR Part 5 (Ref. [1]): National policy and strategy on radioactive waste management

To ensure 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 [8] 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.

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 policy and strategies. The policy and strategies should cover all types of spent fuel and spent fuel

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

storage facility in the State, with account taken of the interdependences between the various stages of spent fuel management, the time periods involved and the options available.

3.6. The government is responsible for establishing a regulatory body independent from the owners of the spent fuel or the operating organizations managing the spent fuel, with adequate authority, power, staffing and financial resources to discharge its assigned responsibilities [13].

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.

3.8. In the event that circumstances change and storage is required beyond the period originally envisaged in the national strategy, a re-evaluation of the national storage strategy should be initiated.

RESPONSIBILITIES OF THE REGULATORY BODY

Requirement 3 of GSR Part 5 (Ref. [1]): 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.

3.9. Regulatory responsibilities may include contributing to the technical input for the establishment of 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 how to meet requirements relating to the safe storage of spent fuel.

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 and the technical and financial resources for the lifetime of the spent fuel storage facility, to the extent that such confirmation is within the statutory obligations of the regulatory body.

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 lifetime of the storage facility. The initial decommissioning plan should be conceptual and should be reviewed by the regulatory body for its overall completeness rather than for 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 ensured when the decommissioning takes place. The decommissioning plan should be updated regularly by the licensee and updates should be reviewed by the regulatory body. If a facility is shut down and no longer to be used for its intended purpose, a final decommissioning plan should be submitted to the regulatory body for review and approval.

3.12. General recommendations for regulatory inspection and enforcement actions relating 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 licence conditions, such as those relating to 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 arrangements for emergency preparedness and response. Such verification 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 verify 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].

3.13. 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 facility and about regulatory processes and should consult these parties, as appropriate, in an open and inclusive manner. The need for confidentiality (e.g. for security reasons) should be respected.

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

(a) A licence issued for the entire lifetime of the storage system and/or facility, which encompasses the whole anticipated operating period, including periodic review of safety assessments, as elaborated in Section 5; or
(b) A licence issued for a specified time period with the possibility for its renewal after expiry.

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 coordinated, 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 OPERATING ORGANIZATION[3]

Requirement 4 of GSR Part 5 (Ref. [1]): Responsibilities of the operator

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] The operating organization is assumed to be the licensee. If the facility is operated under contract, the interface between responsibilities of the licensee and those of the contracted operational management should be clearly defined, agreed on and documented.

[4] As indicated in para. 1.1, no distinction is made in respect of safety between spent fuel considered waste or considered a resource material.

3.16. The operating organization is responsible for the safety of all activities associated with the storage of spent fuel (including activities undertaken by contractors) and for the specification and implementation of the programmes and procedures necessary to ensure safety. The operating organization should maintain a high level of safety culture and demonstrate safety. In some instances, the operating organization may be the owner of the spent fuel and in other cases the owner may be a separate organization. In the latter instance, consideration should be given to interdependences, including any activity carried out prior to receipt of the spent fuel at a storage facility, such as its characterization or packaging, or subsequent transport of the spent fuel from the facility, to ensure that conditions for safety will be met.

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

(a) Application to the regulatory body for permission to site, design, construct, commission, operate, modify or decommission a spent fuel storage facility;
(b) Conduct of appropriate safety and environmental assessments in support of the application for a licence;
(c) Operation of the spent fuel storage facility in accordance with the requirements of the safety case, the licence conditions and the applicable regulations;
(d) Development and application of acceptance criteria for the storage of spent fuel, as approved by the regulatory body;
(e) Providing periodic reports as required by the regulatory body (e.g. information on the actual inventory of spent fuel, any transfers of spent fuel into and out of the facility, any events that occur at the facility and which have to be reported to the regulatory body) and communicating with interested parties and the general public.

3.18. Prior to 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 also demonstrates that the proposed activities will be in compliance with the safety requirements and criteria set out in national laws and regulations. The operating organization should use

[5] The safety case is a collection of arguments and evidence in support of the safety of a facility or activity. This collection of arguments and evidence may be known by different names (such as safety report, safety dossier, safety file) in different States and may be presented in a single document or a series of documents (see Section 5).

the safety assessment to establish specific operational limits and conditions. The operating organization may wish to set an 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 that will facilitate decommissioning should be taken into consideration at the design stage. Such features should be included in the decommissioning plan, together with information on arrangements regarding how the availability of the necessary human and financial resources and information will be ensured, for presentation in the safety case.

3.20. For existing facilities without a decommissioning plan, such a plan should be prepared as soon as possible. Requirements on decommissioning are established in Ref. [18] and recommendations are provided in Ref. [19].

3.21. The operating organization should establish the requirements for training and qualification of its staff and contractors, including for 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 pertaining to it. 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 of the storage facility and storage activities 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 material and other potentially hazardous material 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, which is commensurate with the significance of the modifications. As part of the process, the potential consequences of such modifications should be evaluated, including consequences for the safety of other facilities and also for the retrieval, reprocessing or disposal of spent fuel.

3.26. The operating organization is required to put in place appropriate mechanisms for ensuring that sufficient financial resources are available to undertake all necessary tasks throughout the lifetime of the facility, including its decommissioning [13].

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

3.28. The operating organization should draw up emergency plans on the basis of the potential radiological impacts of accidents [20] and should be prepared to respond to accidents at all times, as indicated in the emergency plans (see paras 6.73 and 6.74).

RESPONSIBILITIES OF THE SPENT FUEL OWNER

Requirement 6 of GSR Part 5 (Ref. [1]): 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 operating organization and the spent fuel owner, if they differ, should be clearly defined, agreed upon and documented. The spent fuel owner, namely, a body having legal title to the spent fuel, including financial liabilities (usually the spent fuel producer), should be responsible for the overall strategy for the management of its spent fuel. In determining the overall strategy, the owner should take into account interdependences between all stages of spent fuel management, the 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 necessary and specifically before the end of the storage period.

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

ACCOUNTING FOR AND CONTROL OF NUCLEAR MATERIAL AND PHYSICAL PROTECTION SYSTEMS

Requirement 21 of GSR Part 5 (Ref. [1]): System of accounting for and control of nuclear material

For facilities subject to agreements on nuclear material accounting, 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 as not to compromise the safety of the facility.

Requirement 5 of GSR Part 5 (Ref. [1]): 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 for deterrence and detection of the intrusion of unauthorized persons and for protection against sabotage from within and outside the facility will be designed and installed during the construction and operation of the spent fuel storage facility. The implications of such systems and arrangements for the safety of the facility should be assessed and it should be ensured that no safety function would be compromised nor would the overall level of safety at the facility be significantly reduced on account of such systems and arrangements.

4. MANAGEMENT SYSTEM

GENERAL

Requirement 7 of GSR Part 5 (Ref. [1]): Management systems

Management systems shall be applied for all steps and elements of the predisposal management of radioactive waste.

4.1. The requirements on management systems for all stages in the lifetime of a spent fuel storage facility are established in Ref. [5]. Recommendations on management systems related to the storage of spent fuel are provided in Ref. [21].

4.2. A management system is required to be established, implemented, assessed and continually improved by the operating organization [5] and it 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 their achievement. The management system should make provision for siting, design, commissioning, operation, maintenance and decommissioning 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

---

[6] Safeguards agreements between the IAEA and non-nuclear-weapon States party to the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) contain the obligation of the State to establish and maintain a national system of accountancy for, and control of, nuclear material. The IAEA document describing the structure and content of such NPT safeguards agreements, INFCIRC/153(Corr.), also known as the ‘Blue Book’, sets out the basic requirement for a State’s system of accounting for and control of nuclear material.

the quality of the records and of subsidiary information on spent fuel inventories is preserved, with account taken of the duration of the storage period and the consecutive management steps, for example, reprocessing or disposal. The management system should also include provision to ensure that the fulfilment of its goals can be demonstrated.

4.3. The long term nature of spent fuel management operations means that particular consideration should be given to establishing and maintaining confidence that the performance of the spent fuel storage facilities and activities will meet the safety requirements over the lifetime of the facility to the end of its decommissioning (e.g. by creation of 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 spent 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, the operating organization retains its responsibility for all activities at all times and continuous commitment by the organization remains 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) Provision of adequate resources (the adequacy of resources for maintenance of facilities and equipment may need to be periodically reviewed over operational periods that may extend over decades);
(b) Preservation of technology and knowledge and transfer of such knowledge to people joining the programme or the organization in the future;
(c) Retention or transfer of ownership of spent fuel and spent fuel management facilities;
(d) Succession planning for the programme's or the organization's technical and managerial human resources;
(e) Continuation of arrangements for interacting with interested parties.

RESOURCE MANAGEMENT

4.6. Spent fuel management activities will require financial and human resources and the necessary infrastructure at the site where the 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 of the full range of activities involved in the management of spent fuel and the potentially long duration of such activities.

4.7. Arrangements for funding of 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 of the spent fuel should establish an appropriate funding mechanism.

4.8. Management systems for spent fuel management activities should include provision 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 of the spent fuel 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, interest rates and technological developments.
(e) It may be difficult to determine appropriate risk and contingency factors to be built into estimates of future costs, owing to the uncertainties associated with 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 spent fuel management activities, the necessary financial arrangements may be complex and may vary over the lifetime of the facility. It may be problematic to establish an adequate degree of confidence in all the arrangements so that the necessary continuity of funding throughout the entire series of activities is ensured.

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

4.10. In the design of facilities for long term spent fuel management, consideration should be given to the incorporation of measures that will facilitate 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, spare parts for equipment that may eventually no longer be manufactured and equipment upgrades to meet new regulations and operational improvements, and to 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.

PROCESS IMPLEMENTATION

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 casks or problems associated with criticality or decay heat). The availability of any specialized equipment that may be necessary over a long time period while spent fuel is in storage or that may be necessary in the future should be assessed.

4.12. Records concerning 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, flooding or other natural or human initiated occurrences. Storage arrangements for records should meet the requirements prescribed by the national authorities or the regulatory body and the status of the records should be periodically assessed. If records are inadvertently destroyed, 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 relationship between the owner of the spent fuel and the operating organization of the facility changes (e.g. public organizations are privatized, new organizations are created, existing organizations are combined or restructured, responsibilities are transferred between organizations, operating organizations undergo internal reorganization of the management structure, or resources are reallocated).

5. SAFETY CASE AND SAFETY ASSESSMENT

GENERAL

Requirement 13 of GSR Part 5 (Ref. [1]): 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 of GSR Part 5 (Ref. [1]): 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 of GSR Part 5 (Ref. [1]): 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.

5.1. In demonstrating the safety of the spent fuel storage facility and related activities, a safety case should be developed as development of the facility progresses and the supporting safety assessment should be carried out in a structured and systematic manner. Proposed facilities, processes, operations, activities, and the like, should be examined to determine whether they can be implemented safely and whether they meet all requirements regarding safety. If storage casks are to be used, there may be one or separate safety cases and/or safety assessment(s) for the storage casks, the storage building or facility and the subsequent transport arrangements if the cask will be used eventually for transport as well as for storage. This will depend on the national regulatory approach. However, irrespective of the approach taken, the interdependences should be taken into consideration to ensure that an integrated approach to safety is adopted and that 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 [4].

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

5.3. The prime responsibility for safety throughout the lifetime of a facility lies with the operating organization [8]. This includes responsibility for both ensuring and demonstrating the safety of a facility in the safety case.

5.4. Long term storage (see para. 1.6 and Annex I) may involve a period of time that exceeds the normal design lifetime of civil structures, including short term storage facilities, and this will have implications for the selection of construction materials, operating methods, and quality assurance and quality control requirements, etc. Specific issues that should be given particular consideration in the safety case for a facility for long term storage of spent fuel include the anticipated lifetime of the facility, the importance of passive safety features, retrievability and management systems. Consideration should also be given to the provision of support services when the spent fuel storage facility remains in operation after other facilities at the site have been closed, in particular for storage facilities at reactor sites.

5.5. The rationale for selection of the assessment time frame should be explained and justified. Depending on the purpose of the assessment (for design studies, licensing, etc.), for ease of modelling or presentation it might be convenient to divide the overall time frame of the safety assessment into shorter ‘time windows’ with various end points.

5.6. In determining the assessment time frame, account should be taken of the characteristics of the particular storage facility or activity, the site and the spent fuel to be stored. Other factors that should be considered include the following:

(a) For most long term storage systems (including storage casks, engineered constructions and the surrounding environment), potential health and environmental impacts may increase for a period of time after commissioning of the facility. In the long term, depending on the nature of the facility, potential impacts may decrease, in particular through decay of the radionuclide inventory of the spent fuel. The safety assessment calculations should consider the maximum, or peak, dose or risk associated with the facility or activity.
(b) A further consideration that may influence decisions on assessment time frames is the return period of natural external hazards, such as extreme meteorological events or earthquakes.
(c) Several factors that can significantly affect the results of the safety assessment may change with time, including external hazards from human activities such as the construction of other facilities nearby, natural events such as changes in water levels, and changes in the availability of support facilities and infrastructure due to shutdown and decommissioning of collocated facilities. Potential changes such as these should be considered in the safety assessment. As a means to assess the possible evolution of the long term storage, one or more scenarios postulated to reflect different evolution paths may be considered in the safety assessment. Assessment time windows may be defined, as appropriate, to reflect potential changes at the storage facility.
(d) The location, habits and characteristics of the reference person in radiological impact assessment may be changed over time. Consequently, the reference person should be considered hypothetical, but individuals and populations in the future should be afforded at least the same level of protection as that required currently. The habits and characteristics assumed for the reference person 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.

5.7. The operating organization should demonstrate as soon as possible that, to the extent possible, passive safety features are applied. In the assessment of long term safety, the degradation of passive barriers over time should be taken into account.

5.8. The complementary performance of the different elements providing safety functions should be evaluated. Each element should be independent of the others, to the extent possible, 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 element and should 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.

5.9. As in the case of disposal of radioactive waste, the environment may also offer additional protective functions (e.g. underlying clay layers which would provide a sorption capacity for contaminants in the event of any leakages from the facility). Such aspects should be taken into account during the siting of the facility and should be considered in the safety case.

5.10. 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. In the safety case, a plan for the safe handling of the spent fuel, following the period of storage, should be considered and the potential effects of degradation of the spent fuel and/or any elements of the containment on the ability to retrieve and handle the spent fuel should be assessed (see also Section 6).

5.11. 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. Prevention of intentional human intrusion requires adequate security arrangements and these should be addressed in the safety case.

5.12. As 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.

5.13. Because of the long time frames potentially involved, a plan for adequate record keeping over the expected time frame for storage should be considered in the safety case.

5.14. Periodically, the safety case should be reviewed to assess the continuing adequacy of the storage capacity; account should be taken of the predicted spent fuel arising, the expected lifetime of the storage facility and the availability of reprocessing or disposal options.

5.15. It may be necessary to reassess the anticipated impacts of decommissioning after operational experience has been gained.

5.16. The requirement to perform safety assessment derives from national programme requirements and the realization that the safety assessment can contribute directly to safety, as through this appropriate measures are identified that can be put in place to protect 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 its being a separate activity. The results of the safety assessment can be used to determine any necessary changes in the plans or design so that compliance with all requirements is ensured. The results are also used to establish controls and limitations on the design, construction and operation of the facility.

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

5.18. 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 failure and operator error or human induced or natural events (both within and external to the facility). In identifying the relevant postulated initiating events, generic lists should be consulted (see Annexes III, IV and V). Such lists should not be relied on solely, 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 events need to be evaluated in the safety assessment.

5.19. Safety assessment should cover the storage facility and the type of spent fuel to be stored and the storage arrangements. In this regard, the types, quantities, initial enrichment, burnup, 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 included in the safety assessment of spent fuel storage facilities.

5.20. Safety assessment for a spent fuel storage facility should cover 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 would storage for a shorter duration. Similarly, 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 change of nuclear reactivity over a long time).

5.21. A facility specific safety case and supporting assessment should generally include aspects such as:

(a) 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 items important to the safety of the spent fuel storage facility, in accordance with the requirements of its licence) and a specification of applicable regulations and guidance.
(b) A description of spent fuel handling and storage activities and any other operations at the facility.
(c) Systematic identification of hazards and scenarios associated with operational states and accident conditions and external events (e.g. fires, handling accidents and seismic events).
(d) An evaluation of hazards and scenarios, including screening of their combinations that may result in a release of radioactive material, to eliminate those of low likelihood or low potential consequences.
(e) Assessment of the probabilities and potential consequences of the release(s) of radioactive material identified in the hazard evaluation by quantitative analysis and comparison of the results of the assessment with regulatory limitations.
(f) Establishment of operational limits, conditions and administrative controls based on the safety assessment. If necessary, the design of the spent fuel storage facility should be modified and the safety assessment should be updated. Such controls should include acceptance criteria for spent fuel casks, including canisters containing failed fuel.
(g) Documentation of safety analyses and the safety assessment for inclusion in the documentation supporting the licensing of the facility.
(h) The commissioning programme.
(i) Organizational control of operations.
(j) Procedures and operational manuals for activities with significant safety implications.
(k) A programme for periodic maintenance, inspection and testing.

(l) The expected values for subcriticality, heat removal capacity and calculated radiation doses inside and at the boundary of the spent fuel storage facility.
(m) Monitoring programmes, including a programme for shielding verification, a programme for surveillance of the condition of stored spent fuel and a programme for surveillance of stored spent fuel assemblies, if appropriate.
(n) A programme for feedback of operational experience.
(o) The training programme for staff.
(p) Safety implications of aspects of accounting for and control of nuclear material.
(q) Physical protection arrangements for the facility.
(r) The emergency preparedness and response plan.
(s) The management system.
(t) Provisions for occupational radiation protection.
(u) Provisions for the management of radioactive waste and for decommissioning.

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

5.23. The safety assessment should include an assessment of hazards in operational states and accident conditions. It should provide an assessment of doses at the site boundary and of the potential for exposure in areas within the site to which there is to be unrestricted access. In normal operation, for spent fuel storage facilities, there should be nothing that will cause a rapid increase in reactivity in the stored fuel, and thus relatively few credible mechanisms for such a sudden excursion followed by a release of radioactive material.

5.24. As appropriate, limitations on authorized discharges should be established for the spent fuel storage facility, in accordance with the recommendations provided in Ref. [22].

5.25. If the initial safety assessment yields results that are close to or that exceed the limiting performance objectives, it may be necessary to carry out a more rigorous evaluation of the suitability of any generic data sources that may have been used, and/or an inventory reduction or additional safety systems and controls may be necessary.

Requirement 16 of GSR Part 5 (Ref. [1]): 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.

5.26. The safety case and supporting safety assessment, including the management systems used for their implementation, should be periodically reviewed in accordance with regulatory requirements. The review of management systems should include aspects of safety culture. In addition, the safety case and supporting safety assessment should be reviewed and updated:

(a) When there is any significant change to the facility or to its radionuclide inventory that may affect safety.
(b) When changes occur in the site characteristics that may impact on the storage facility, e.g. industrial development or changes in the surrounding population.
(c) When significant changes in knowledge and understanding occur (such as from research data or from feedback of operating experience).
(d) When there is an emerging safety issue due to a regulatory concern or an incident.
(e) Periodically, at predefined periods, as specified by the regulatory body. Some States specify that a periodic safety review be carried out not less frequently than once in ten years.

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

5.28. For storage beyond the original design lifetime, a re-evaluation of the initial design (and of the current design if it is significantly different), operations, maintenance, ageing management, safety assessment and any other aspect of the spent fuel storage facility relating to safety should be performed. If, during the design lifetime, an extension to the storage period is foreseen, a precautionary approach should be applied, in particular through validation of the adequacy of the design assumptions for the extended period envisaged.

DOCUMENTATION OF THE SAFETY CASE

Requirement 15 of GSR Part 5 (Ref. [1]): 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.

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

6. GENERAL SAFETY CONSIDERATIONS FOR STORAGE OF SPENT NUCLEAR FUEL

GENERAL

Requirement 11 of GSR Part 5 (Ref. [1]): 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 degradation of the waste containment.

[7] See para. 1.6.

Requirement 5 of GSR Part 5 (Ref. [1]): 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 of GSR Part 5 (Ref. [1]): System of accounting for and control of nuclear material

For facilities subject to agreements on nuclear material accounting, 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 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 of. The design features and the operation of the facility should be such as to provide containment of radioactive material to ensure that radiation protection of workers, members of the public and the environment is optimized within the dose constraints in accordance with the requirements established in Ref. [9] to maintain subcriticality, to ensure removal of decay heat and to ensure retrievability of the spent fuel. These safety functions should be maintained during all operational states and accident conditions.

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

(i) *Wet storage in pools at, or remote from, a reactor site.* The spent fuel is stored in standard storage racks or in compact storage racks in which closer spacing of the fuel assemblies or fuel elements is allowed in order to increase the storage capacity.
(ii) *Dry storage in either storage or dual purpose (i.e. storage and transport) casks at, or remote from, a reactor site.* Casks are modular in nature. Such 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 a metal or concrete body and metal liner or metal canister and lids. They are usually cylindrical in shape, circular in cross-section, with the long axis arranged either vertically

or horizontally. The fuel position is maintained by means of 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.

(iii) *Dry storage in vault type storage facilities.* A vault is a massive, radiation shielded facility in which 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 storage cavities. This heat is released to the atmosphere either directly or via appropriate filtration, depending on the system design. Some systems also use a secondary cooling circuit. However, if natural convection is to be used, the need for active components, e.g. pumps and ventilators, should be minimized through higher operational reliability of the system and corresponding cost reduction.

6.3. Although designs of spent fuel storage facilities may differ, in general they should consist of relatively simple, preferably passive, inherently safe systems intended to provide adequate safety over the design lifetime of the facility, which may span several decades. The lifetime of a 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.

6.4. In general, the storage facility should be designed to fulfil the main safety functions, i.e. maintaining of subcriticality, removal of heat, containment of radioactive material and shielding from radiation and, in addition, retrievability of the fuel. The design features should at least, if possible, include the following features:

(a) Systems for removal of heat from the spent fuel should be driven, if possible, by the energy generated by the spent fuel itself (e.g. natural convection).
(b) A multibarrier approach should be adopted in ensuring containment, with account taken of all elements, including the fuel matrix, the fuel cladding, the storage casks, the storage vaults and any building structures that can be demonstrated to be reliable and competent.

(c) Safety systems should be designed to achieve their safety functions with minimum need for monitoring.
(d) Safety systems should be designed to function with minimum human intervention.
(e) The storage building, or the cask in the 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 be such that retrieval of the spent fuel or spent fuel package for inspection or reworking is possible.
(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, spent fuel package or the storage system.
(j) The spent fuel storage system should allow for inspections.
(k) The spent fuel storage system should be designed to avoid or minimize the generation of secondary waste streams.

6.5. Security and access controls are required at spent fuel storage facilities to prevent unauthorized access by individuals and the unauthorized removal of radioactive material, and such controls should be compatible with the safety measures applied at the facility.

DESIGN OF SPENT FUEL STORAGE FACILITIES

Design process

6.6. 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 accident conditions that are credible, with account taken of natural phenomena. Only verified and validated methods should be used for predicting the safety of operational states or the consequences of accidents. The input data selected should be conservative but realistic. If possible, the degree of 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 assessment results to uncertainties should be evaluated.

6.7. As part of the overall process leading to an acceptable design, the design 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 [4].

6.8. It should be demonstrated in the safety case that in the design all 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 conclusions reached. 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 technologies, be safely constructed, commissioned, operated and decommissioned in accordance with the design specifications and the requirements of the regulatory body.

6.9. Procedures relating to the control of design modifications in subsequent stages of the lifetime of the facility should also be defined. Such modifications might be necessary to take into account the findings of the safety case. Items important to safety, including structures, systems and components, should be identified and classified according to their relative importance.

6.10. For storage beyond the original design lifetime of the facility, testing, examination and/or an evaluation may be necessary to assess the integrity of the spent fuel or the storage cask. Careful consideration should be given to the approach to be adopted to prevent unnecessary occupational exposure and to prevent accidental release of radioactive material. Potential problems with the integrity of the spent fuel or of storage casks should be considered in advance of the need for physical actions, such as placing the spent fuel into new casks. In some cases, rather than placing the fuel into a new cask, it may be necessary to move the storage casks to another storage facility for which the building provides, or structures within the building provide, the necessary containment and isolation. If an extension to the storage period in dry storage casks is under consideration, assessment of the integrity of the casks and the spent fuel, including survey of the casks for leaktightness, may be sufficient to demonstrate that the storage period may be extended. In such cases, an immediate inspection of the content of the casks may not be necessary. In considering an extension of 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 on opening the cask and removing the contents or inspecting them in situ. If 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.

6.11. 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 in the storage facility may be caused by radiation, heat generation and chemical or galvanic reactions. Changes in the stored spent fuel and storage cask may include:

(a) Generation of gases that may cause hazards, by chemical and radiolytic effects (e.g. the generation of hydrogen gas by radiolysis) and buildup of overpressure;
(b) Generation of combustible or corrosive substances;
(c) Corrosion of metals;
(d) Degradation of the spent fuel containment system.

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

Requirement 10 of GSR Part 5 (Ref. [1]): 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 both during normal operation and in accident conditions that could occur in the handling, storage, transport and disposal of waste.

Requirement 17 of GSR Part 5 (Ref. [1]): 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.

Paragraph 2.4 of NS-R-5 (Ref. [3]): Defence in depth

The concept of defence in depth shall be applied at the facility for the prevention and mitigation of accidents (Principle 8 of Ref. [8]).

Siting

6.12. The Safety Requirements publication on Site Evaluation for Nuclear Installations [23] and the associated Safety Guides [24–29] contain criteria and methods that could be used in a graded approach in the siting of spent fuel storage facilities.

Defence in depth

6.13. The concept of defence in depth should be applied to all safety activities, whether organizational, behavioural or design related, to ensure that if a failure were to occur, it would be detected and compensated for or corrected by appropriate measures [30]. Defence in depth should be applied in the siting of a spent fuel storage facility and in its design, as well as when considering subcriticality, heat removal, containment and radiation protection issues.

6.14. Application of the concept of defence in depth in the design of spent fuel storage should entail provision of a series of levels of defence (inherent features, equipment and procedures) aimed at preventing accidents and ensuring appropriate protection and mitigation of consequences in the event that prevention fails [30].

6.15. The facility should have a reserve storage capacity, which should be included in the design or should be otherwise available, e.g. to allow for reshuffling of spent fuel casks or unpackaged spent fuel elements for inspection, retrieval or maintenance work. The reserve capacity should be such that the largest type of storage cask can be unloaded or, in the case of a modular storage facility, that at least one module can be unloaded.

Structural integrity

6.16. In order for safety systems and safety related items to perform properly, the components of the spent fuel storage facility should maintain their structural integrity in all operational states and accident conditions. Therefore, the integrity of the components and their related systems should be demonstrated by means of 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 changes in material properties with time (e.g. concrete shrinkage).

6.17. 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 control of fabrication of components and of construction of the spent fuel storage facility. In order to detect and terminate deviations from normal operational states, specific systems should be provided, as determined in the safety case.

6.18. The integrity of the spent fuel and the geometries required to maintain subcriticality and heat removal, and its related containment barriers, should be maintained throughout the lifetime of the facility and should be verified using appropriate methods, including both prospective analysis and ongoing surveillance.

6.19. The allowable stresses for given loading conditions should comply with the applicable codes and standards. If no such standards apply, justification should be provided for the allowable stress levels selected.

6.20. Structural materials and welding methods should be selected on the basis of accepted codes and standards. Consideration should be given to potential cumulative effects of radiation on materials likely to be subjected to significant radiation fields. In addition, potential thermal effects on material degradation should also be considered.

6.21. 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, should be such as to minimize chemical and galvanic reactions, which might degrade the integrity of the spent fuel during its storage, and should not contaminate the spent fuel with substances that might significantly degrade the integrity of the spent fuel during its storage.

6.22. 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 oxidation of exposed UO_2 to U_3O_8, with consequent increase in volume and particulate formation, should be considered. In addition, any effects of changes in the storage environment (e.g. wet to dry or dry to wet) should be assessed.

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

6.24. The construction materials should allow for easy decontamination of surfaces. Compatibility of decontamination materials with the operating environment should be considered for all operational states and accident conditions. The integrity of systems that are connected to spent fuel storage systems, such as the heat removal system, is also important. Tube failures and leaks in the spent fuel storage system should be prevented, as these could provide a path for chemical species detrimental to either fuel or containment integrity, such as chloride ions, to enter a spent fuel storage pond.

Structural and mechanical loads

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

(a) Determination of structural and mechanical loads due to the fuel, fuel storage casks and various components of the spent fuel storage facility under operational states and accident conditions;
(b) Evaluation of the foundations;
(c) A full structural evaluation of the safety systems of the spent fuel storage facility;
(d) Evaluations of supporting features such as cranes, transfer vehicles and protective buildings.

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

6.26. It should be ensured that consideration be given to all situations in which handling mechanisms could malfunction, thereby leaving fuel elements or casks inadequately shielded or irrecoverable. Consideration should also be given to the possibility of casks becoming wedged and immovable within the spent fuel storage facility. In addition to the issue of shielding in such circumstances, consideration should be given to whether handling equipment and systems can enable recovery from such situations or whether they could be damaged by the application of excessive stresses.

Thermal loads and processes

6.27. In view of the decay heat generated by spent fuel, all thermal loads and processes should be given appropriate consideration in the design. Typical items for consideration include:

(a) Thermally induced stresses;
(b) Internally and externally generated pressures;
(c) Heat transfer requirements;
(d) Evaporation/water make-up requirements;
(e) The effect of temperature on subcriticality.

Time dependent material processes

6.28. The anticipated lifetime of the storage facility will be a determining factor for aspects such as corrosion, creep, fatigue, shrinkage, radiation induced changes and associated radiations fields. In the design of the storage facility, consideration should be given to the impact of such processes.

Subcriticality

6.29. A safety requirement on all designs for spent fuel storage facilities is to maintain subcriticality of the entire system under all credible circumstances [3].

6.30. 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 in all operational states and for credible accident conditions.

6.31. Where spent fuel cannot be maintained subcritical by means of safe geometrical configurations alone, additional means such as fixed neutron absorbers and/or the use of a burnup credit (see Appendix II, paras II.7–II.9) could be applied. If fixed neutron absorbers are used, it should be ensured by means of proper design and fabrication that the absorbers will not become separated or displaced in operational states or in accident conditions. Consideration should also be given to the effects of ageing, corrosion and handling on the fixed neutron absorbers.

6.32. Subcriticality can be influenced by internal and external hazards that have the potential to reconfigure the pre-existing spent fuel assembly array in such a way as to increase the potential for criticality. Consideration should also be given to routine fuel movements that could bring the fuel being moved into close proximity with stored fuel or in which fuel could be dropped and 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 put in place to ensure that subcriticality will be maintained under all such conditions.

6.33. An adequate margin of subcriticality in the effective neutron multiplication factor k_{eff} that is acceptable to the regulatory body should be maintained for operational states and credible accident conditions.[8] For a dry spent fuel storage facility, the minimum margin should be maintained even in the event of water flooding of the locations where the spent fuel is stored, unless flooding is precluded by location or design. The potential for rearrangement or compaction of fuel pins should also be considered in demonstrating the required subcriticality margin.

6.34. The most appropriate approach to estimating the required multiplication factors will depend on a number of factors, including the spent fuel properties, as well as the circumstances being addressed, e.g. normal operation or accident conditions. In determining subcriticality, a conservative estimate should be made of the effective neutron multiplication factor, with account taken of the following:

(a) If the initial enrichment of fissile material within a fuel assembly and/or between fuel assemblies is variable, appropriate consideration of this variability in the modelling should be used. Alternatively, the highest enrichment may be used to provide a conservative characterization of the fuel assembly.
(b) Where uncertainties exist in any data relating to the fuel (in terms of design, geometries, nuclear data, etc.), conservative values for the data should be determined and should be used in all subcriticality calculations. If necessary, a sensitivity analysis should be performed to quantify the effects of such uncertainties.

[8] After inclusion of uncertainties in the calculations and data, a margin of 5% or less is applied in many States.

(c) Any geometric deformations of the fuel and storage equipment that could 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. It should be ensured that the system will remain 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 owing 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 may be allowed in view of the double contingency principle[9].
(f) The inventory of the spent fuel storage facility should be assumed to be at the maximum capacity of the design.
(g) Credit should not be claimed for neutron absorbing parts or components of the spent fuel storage facility unless they are permanently installed, their neutron absorbing capabilities can be determined and it has been demonstrated that they would not be degraded by any postulated initiating events.
(h) Consideration of reactivity changes of the fuel assembly may be included, although no allowance for the presence of burnable absorbers should be made unless on the basis of a 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.
(i) All fuel should be assumed to be at a burnup and enrichment value that results 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 that directly or indirectly confirms the calculated values for the content of fissile material or depletion level. For application of burnup credit in long term storage, possible changes in the nuclide composition of the spent fuel with storage time should be taken into account.
(j) Assumptions of neutronic decoupling for different storage areas should be substantiated by appropriate calculations.

[9] By virtue of this principle, two unlikely independent and concurrent incidents are beyond the scope of the required analysis.

6.35. The infinite multiplication factor[10] may be used as a conservative estimate of k_{eff}.

6.36. The determination 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 specify appropriate conservative conditions. For example, boiling water reactor fuel with burnable poison may have increased reactivity by burning of poison. Also, uranium–thorium MOX fuel or fuel from research reactors may have very specific properties that need to be considered.

Heat removal

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

6.38. In the design of heat removal systems for a spent fuel storage facility, appropriate provision should be made for maintaining fuel temperatures within acceptable limits during handling and transfer of spent fuel.

6.39. The heat removal system should be designed for adequate removal of the heat likely to be generated by the maximum inventory of spent fuel anticipated during operation. In determining the necessary heat removal capability of the facility, 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 take account of 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 facility.

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

6.40. 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 in the design. For example, natural cooling may be adequate later in a facility's lifetime, even if forced cooling was initially necessary. An analysis should be performed to determine how long forced cooling will be required, with due consideration given to maintaining operability of the forced cooling system and the potential effects of its failure.

6.41. The use of redundant and/or diverse heat removal systems may be appropriate, depending on the type of storage system used and the potential for fuel overheating over an extended period of time.

Containment of radioactive material

6.42. In the design of spent fuel storage and handling systems, adequate and appropriate measures should be provided for containing radioactive material so as to prevent an uncontrolled release of radionuclides to the environment. The spent fuel cladding should be protected during storage against degradation in normal operational states and accident conditions and, later, during retrieval of the spent fuel. Containment should be ensured by at least two independent static barriers. As necessary, and as far as possible, the effectiveness of the spent fuel storage containment system should be monitored to determine whether corrective action is necessary to maintain safe storage conditions.

6.43. Ventilation and off-gas systems should be provided where necessary to ensure collection of airborne radioactive particulate material in 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 or sulphur dioxide in the external environment, which could be detrimental to the integrity of the spent fuel cladding or another safety related component.

Radiation protection

6.44. The design of a spent fuel storage facility should be such as to provide for radiation protection of workers and the public and protection of the environment in accordance with the requirements of national legislation, the requirements established in Ref. [9] and the recommendations presented in Ref. [29].

6.45. In order to meet these requirements and recommendations in the design of spent fuel handling systems in a storage facility:

(a) Appropriate ventilation, including efficient, appropriately qualified and designed air filtration systems and provision for their periodic checking, should, as necessary, be included in the design to maintain the concentrations of airborne radioactive material and the related exposure of workers and the public at acceptable levels.
(b) Provision should be made for the monitoring of radioactive effluents.
(c) Measures for spent fuel handling should be designed to avoid a buildup of contamination to unacceptable levels and to provide for remedial measures should such a buildup occur.
(d) Handling of spent fuel and casks should be carried out in an environment in which important parameters (e.g. temperature, concentration of impurities, intensity of radiation) are controlled.
(e) Areas in which spent fuel and casks are to be handled or stored should be provided with suitable radiation monitoring systems for the protection of workers.
(f) The storage facility should not contain any operation room to which access is gained solely through the storage area.
(g) Water monitoring and filtration should be provided for wet storage facilities.

6.46. Shielding should be provided to meet the recommendations in Ref. [29]. To meet these recommendations, the following provisions should be included:

(a) In determining the source term for analysis for shielding design, consideration should be given to the bounding conditions for enrichment, burnup and cooling times for gamma and neutron radiation, the inventory at the maximum design capacity of the spent fuel storage facility, the effects of axial burnup on gamma and neutron sources, and the activation of non-fuel hardware.
(b) Suitable shielding should be provided for normal operation 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) In analysis for shielding design, 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.
(f) Consideration should be given to the radiological impact of deposits of activation products.

Layout

6.47. Design aspects associated with the layout of a spent fuel storage facility are set out in the following:

(a) Handling and storage areas for spent fuel should be secured against unauthorized access and unauthorized removal of fuel.
(b) The area used for storage should not be part of an access route to other operating areas.
(c) Transport routes for handling spent fuel on the facility site and within the facility should be arranged to be as direct and as short as practicable, so as to avoid the need for complex or unnecessary moving and handling operations.
(d) The need to move heavy objects over stored spent fuel and items important to safety should be minimized by the layout.
(e) The layout should be such that all spent fuel handling operations, the storage of spent fuel and the required personnel access are optimized.
(f) The layout should be such as to provide for the decontamination of surfaces of spent fuel elements (removal of deposits of radioactive material) and appropriate maintenance and repair of spent fuel handling equipment and storage casks.
(g) Sufficient space should be provided to permit inspection of spent fuel and inspection and maintenance of components, including spent fuel handling equipment.
(h) The layout should facilitate access to any stored fuel without the need to move or handle other stored fuel.
(i) Division of the storage area into sectors should be such as to facilitate access to any stored fuel and to avoid application of the ‘first in last out’ concept to enable different storage configurations.
(j) Retrieval of spent fuel or spent fuel packages, as well as the possible need for spent fuel encapsulation or conditioning, should be addressed in the layout of the facility.
(k) Sufficient space should be provided to allow for movement of the spent fuel and storage casks and the transfer of these from one item of handling equipment to another.
(l) Sufficient space should be provided for the safe handling of shipping and/or storage casks. This may be achieved by using a separate cask loading and unloading area or by including a dedicated space within the spent fuel storage facility.

(m) Sufficient 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 of fuel assemblies may also be required.
(n) Appropriate arrangements for containment measures and the safe storage of degraded or failed fuel should be provided.
(o) The layout should provide for an easy exit by personnel in an emergency.
(p) Penetrations should be designed in such a way as to prevent the ingress of foreign material (e.g. rain, inorganic solutions, organic materials) that could reduce subcriticality margins, impair heat transfer or increase corrosion and degradation of the storage facility in ways that might reduce the effectiveness of the main safety functions or prevent inspection or repair.
(q) The floor area on which any transport vehicle with a heavy spent fuel cask may move or be parked should be designed with adequate floor loading margins. Such areas should be clearly marked to avoid overloading a floor area designed to accept a lower floor loading.

Handling

6.48. Spent fuel handling and transfer equipment and systems include:

(a) Fuel handling machines;
(b) Fuel transfer equipment;
(c) Fuel lifting devices;
(d) Fuel assembly dismantling devices;
(e) Handling devices for all operations associated with transport of casks or inspection of spent fuel or casks;
(f) Provision for the safe handling of degraded or failed fuel or casks.

6.49. Handling equipment should be designed to minimize the probability and consequence of accidents and other incidents, and to minimize the potential for damaging spent fuel, spent fuel assemblies and storage or transport casks. Consideration should be given to the following:

(a) Equipment should not have sharp edges or corners that 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 to facilitate maintenance.
(d) Speed limitations should be specified for equipment for moving spent fuel.

(e) Systems should be so designed that spent fuel cannot be dropped in the event 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 to permit manual operation in an emergency.
(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.
(h) Equipment should be provided with suitable interlocks or physical limitations to prevent dangerous or incompatible operations, such as to prevent movement 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 to prevent the lifting of spent fuel assemblies or other components over spent fuel, the 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) Environmental conditions (noise, brightness) in working areas should provide for optimal conditions of work.

6.50. Where operating personnel will require information on the non-visible state of the equipment or components in order to verify the safety of a planned operation, as stated in the safety case, provision should be made in the design for effectively transmitting such information to the operating personnel, through appropriately located indicator systems or by alternative means.

6.51. In the design of spent fuel handling equipment, provision should be made 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.

6.52. To minimize the probability of an accidental drop of any load, equipment for transferring spent fuel to a spent fuel storage facility should be designed to ensure that the equipment is capable of withstanding conditions of normal operation, anticipated operational occurrences and accident conditions. Equipment should be designed such that, in the event of an accidental drop of a load, the containment or the shielding of fuel casks will not be damaged in a manner that could result in unacceptable radiation exposure of workers or the public. In addition, the design should be such that an accidental drop will neither prevent fuel retrieval nor cause significant damage to the spent fuel or spent fuel storage facility.

6.53. Assumptions made that are critical to operational safety should be documented at the design stage to facilitate the subsequent development of operating procedures. Justification should be provided, through detailed analyses using appropriate techniques, in support of these assumptions and conclusions concerning the operational safety of the spent fuel storage facility.

6.54. In order to ensure safe operation, spent fuel handling and storage systems should include the following:

(a) Measures to limit radioactive releases and radiation exposure of workers and the public in operational states and accident conditions in accordance with the principle of optimization of protection established in Ref. [8] or limits established by the regulatory body, with particular consideration being given to the use of remote techniques in areas of high radiation to reduce occupational exposure;
(b) Measures to prevent anticipated operational occurrences and design basis accidents from developing into severe accidents;
(c) Provision for ease of operation and maintenance of essential equipment (in particular, items important to safety);
(d) Provision for ready retrieval of spent fuel from storage through equipment and procedures.

6.55. Consideration should be given to 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.

6.56. The dropping of spent fuel during transfer from the cask to the storage rack (or vice versa in the case of cask loading for dry storage) could result in impacts that should be avoided, such as:

(a) Partial defects in the spent fuel cladding, leading to leaks and resulting contamination of the pool by fission products;
(b) Deformation (e.g. bending) or damage of the spent fuel, which could lead to difficulties in its subsequent handling;
(c) An increased potential for a criticality accident if spent fuel with low burnup were to impact alongside a storage basket or other spent fuel in the storage racks;
(d) Radiation exposure of workers due to the release of fission products.

Ventilation systems

6.57. Ventilation systems should be designed to maintain a safe and comfortable working environment and should be operated in such a way as to limit the potential for release of radioactive material.

6.58. Ventilation systems should be operated in such a way as to control the accumulation of flammable and/or explosive gases (e.g. hydrogen gas formed by radiolysis). Consideration should also be given to the potential for the drawing in of hazardous gases from external sources.

6.59. Ventilation systems should be designed to satisfy the recommendations provided in Ref. [31]. Their operation should be compatible with requirements for fire protection.

Communications

6.60. Adequate means of communication should be provided by design to meet the requirements for operation of the spent fuel storage facility and for emergency preparedness and response.

Instrumentation and control

6.61. When practicable, control and protection functions should be designed to be mutually independent. If this is not feasible, detailed justification should be provided for the use of shared and interrelated systems. Account should be taken of ergonomic factors in the design of alarms and indications to the operating personnel. Control and monitoring equipment should be calibrated for its intended use.

Fire protection

6.62. The operation of the fuel handling and storage areas should be carried out in accordance with the fire protection recommendations provided in Ref. [31]. Fire protection measures should be implemented in such a way as to limit risks to personnel and the risk of damage to items important to safety, spent fuel storage areas, spent fuel handling systems and support systems.

6.63. Fire protection systems of appropriate capacity and capability should be provided.

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

Radioactive waste management

6.65. The systems of the spent fuel storage facility should be designed and operated so as:

(a) To avoid or minimize the potential for generating radioactive waste;
(b) To provide safe and adequate means for handling radioactive waste [1].

6.66. The methods employed for processing such waste should be compatible with the requirements of the receiving waste facility.

Lighting

6.67. Provision should be made for adequate and reliable lighting in support of operation and to facilitate inspection and/or physical protection of spent fuel storage areas.

6.68. For wet storage in pools, the pool area should be provided with the necessary lighting equipment, including underwater lighting near work areas and provision for replacement of underwater lamps.

6.69. Materials used in underwater lighting should be compatible with the environment in which they are used and, in particular, should not undergo unacceptable corrosion or cause any unacceptable contamination of the pool water.

Monitoring

6.70. Area monitoring should include measurements of radiation dose rates and airborne radionuclides. In controlled areas, fixed, continuously operating instruments with local alarms and unambiguous readouts should be installed to provide information on radiation dose rates. Any such instruments should have characteristics and ranges that are sufficient to cover potential radiation levels in the area.

6.71. Instrumentation for detecting external contamination on workers should be provided at exits from locations where there is a potential for such contamination. Instruments for area monitoring and personnel monitoring should be demonstrated to be fit for purpose and should comply with appropriate manufacturing standards.

6.72. Provision should be made for the decontamination of personnel, equipment and components.

Emergency preparedness

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

6.74. 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 personnel. Inspections should be performed regularly to ascertain whether equipment and other resources necessary in the event of an emergency are available and in working order.

Support systems

6.75. In addition to the design features of a spent fuel storage facility considered above, a number of other support systems may be necessary to ensure the operation and safety of spent fuel storage facilities, e.g. emergency electrical power. It should be ensured that such support systems are available.

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

COMMISSIONING OF SPENT FUEL STORAGE FACILITIES

Requirement 18 of GSR Part 5 (Ref. [1]): 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 and components, and the facility as a whole, perform as planned.

General

6.77. 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, in commissioning, operating procedures are verified and the readiness of staff to operate the spent fuel storage facility is demonstrated. The operating procedures should cover both operational states and accident conditions.

6.78. The basis for commissioning should be established at an early stage in 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 approval by the regulatory body. The responsibilities of the various 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) Provision and approval of documentation;
(c) Responsibilities;
(d) Safety during testing;
(e) Control of test work;
(f) Recording and review of test results;
(g) Interaction with the regulatory body;
(h) Management of equipment providing temporary commissioning aids and its removal before commencement of operation (and after completion of tests).

6.79. Arrangements for testing should include the following:

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

6.80. For modular storage systems, most of the commissioning will have been completed on loading of the first storage module. Some of the commissioning processes may become a part of regular operation as new modules are brought into service. However, a change in module design may require some of the commissioning steps to be repeated for the new design.

6.81. Some commissioning steps may continue into the operation stage of the spent fuel storage facility. For example, it may not be justified to test and verify the heat removal capacity of a storage pool 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

6.82. Commissioning will usually be completed in several stages:

(a) Completion of construction;
(b) Equipment testing;
(c) Demonstration of performance;
(d) Non-active commissioning;
(e) Active commissioning.

6.83. In the stage of completion of construction, the spent fuel storage facility should undergo detailed physical inspection to confirm compliance with the detailed design. Factors such as physical dimensions and levels of background radiation should be determined. A systematic check against 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 facility, this check can also be important when considering possible future modifications and ultimate decommissioning of the facility.)

6.84. In the equipment testing stage, the equipment and systems of the spent fuel storage facility should be energized and the various controls, directions of rotation, directions of flow, currents, interlocks, etc., tested. Activities such as load testing of casks and spent fuel assembly lifting equipment should also be carried out and the safe control of equipment should be demonstrated during these tests. If necessary, it should also be demonstrated that the physical interaction between items of equipment is limited.

6.85. In the performance demonstration stage, after individual items of equipment 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 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 of personnel to conduct maintenance work safely and effectively should also be demonstrated.

6.86. The non-active commissioning stage should provide a formal demonstration that the facility personnel, equipment and procedures function in the manner intended, especially those identified in the safety case, as important to the safety of facility operation. All safety features that can be tested without the presence of spent fuel should be checked before the spent fuel storage facility is put into operation.

6.87. Once non-active commissioning has been satisfactorily accomplished, the active commissioning stage is commenced with the introduction of radioactive material into the spent fuel storage facility. All tests and any resulting amendments should be completed before the introduction of radioactive material. The introduction of radioactive material effectively marks the start of the operation of the facility and, hence, from this stage, the relevant safety requirements for facility operation apply [1, 3]. Active commissioning should involve a range of tests to demonstrate that the design criteria for radiation protection have been met.

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

OPERATION OF SPENT FUEL STORAGE FACILITIES

Requirement 9 of GSR Part 5 (Ref. [1]): 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 of GSR Part 5 (Ref. [1]): 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

6.89. Spent fuel storage facilities should be operated in accordance with written procedures prepared by the operating organization. These documents and their updates should be prepared in cooperation 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 appropriately. These procedures should, as a minimum, be such as to ensure compliance with the operational limits and conditions for the spent fuel storage facility and, more generally, with the safety assessment.

6.90. Instructions and procedures should be prepared 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 the designated responsible person can readily perform each action in the proper sequence. Responsibilities for approval of any deviations from operating procedures that may be necessary for operational reasons should be clearly specified.

6.91. Adequate arrangements should be made for the review and approval of operating procedures, the systematic evaluation of operating experience, including that of other facilities, and the taking of corrective actions in a timely and appropriate manner to prevent and counteract developments adverse to safety. Provision should be made for controlling the distribution of operating procedures, in order to guarantee that operating personnel have access to only the latest approved edition.

6.92. The maintenance and modification of any item of equipment, process or document of the spent fuel storage facility should be subject to specified procedures. These procedures should be subject to authorization before they are implemented. The procedures should describe the categorization of the modification in accordance with its safety significance. Depending upon the safety categorization, each modification will be subject to varying levels of review and approval by management of the facility and the regulatory body.

6.93. The maintenance or modification of any item of equipment should be appropriately recorded and documented together with its commissioning test results. The documents should be revised immediately after completion of the maintenance or modification.

Operational aspects

6.94. The operating organization should ensure that operating procedures relating to the maintaining of 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 that should be considered in this review include:

(a) The types of spent fuel to be stored;
(b) Spent fuel geometries necessary to ensure subcriticality;
(c) Spent fuel container types (if used);
(d) Handling operations for the spent fuel;
(e) The potential for abnormal operation;
(f) Spent fuel parameters (e.g. initial enrichment, final enrichment, burnup);
(g) Dependence of subcriticality on neutron absorbers.

6.95. 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 failure may be more probable when the spent fuel and spent fuel cladding are 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. composition of the pool water and/or atmosphere in the storage area and moisture or water on spent fuel cladding) is undertaken to prevent and provide notice of such undesirable conditions. Procedures should be provided for detecting and dealing with degraded and failed fuel.

6.96. 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 such fuel is accepted, in addition to containment considerations there may be implications for criticality, which should be fully assessed. Where appropriate, the receipt, handling and storage of such fuel should be made subject to specific procedures.

6.97. Operating procedures should be developed for containment systems in the spent fuel storage facility (e.g. closure seals on storage casks and canisters, and ventilation and filtration systems) to provide for their monitoring. Such monitoring should be such that the operating organization will be able to determine when corrective actions are necessary to maintain safe storage conditions.

6.98. There are other safety considerations that should be taken into account in the development of operating procedures and contingency and emergency arrangements. It should be noted that many events would be addressed either as anticipated operational occurrences or as design basis accidents. However, some of these events could also lead to severe accidents, which are beyond the design basis. Whilst the probability of such beyond design basis accidents occurring is extremely low, in the preparation of operating procedures and contingency plans the operating organization should consider events such as the following:

(a) Crane failure with a water filled and loaded cask, suspended outside the pool;
(b) Loss of safety related facility process systems such as supplies of electricity, process water, compressed air and ventilation;
(c) Explosions due to the buildup of radiolytic gases;
(d) Fires leading to the damage of items important to safety (to reduce the risk of fire, the amount of combustible material or waste should be controlled, as should be the amount of other flammable materials (see para. 6.64));
(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 human induced events (airplane crash, sabotage, etc.);
(h) Failure of the physical protection system.

Consideration should also be given to the possible misuse of chemicals (e.g. unintended introduction into the pool water of acidic or alkaline fluids used for the regeneration of ion exchange resin).

6.99. In addition to providing operating procedures and contingency procedures as described above, the operating organization should also develop an emergency plan in accordance with the requirements established in Ref. [20].

6.100. 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 by means of an appropriate feedback procedure. Any new standards, regulations or regulatory guidance should also be reviewed to check for their applicability for safety at the facility.

6.101. The integrity of stored spent fuel should be monitored in the operation of a spent fuel storage facility. When spent fuel is stored in sealed casks, the means for accounting for and control of nuclear material or for verifying the related sealing operations will be available. Such means should not impair the integrity of the spent fuel.

6.102. Operational limits and conditions for a spent fuel storage facility should be developed on the basis of the following:

(a) Design specifications and operating parameters and the results of commissioning tests;
(b) The sensitivity of items important to safety and the consequences of events following the failure of items, the occurrence of specific events or variations in operating parameters;
(c) The accuracy and calibration of instrumentation equipment for measuring safety related operating parameters;
(d) Consideration of the technical specifications for each item important to safety and the need to ensure that such items continue to function in the event of any specified fault occurring or recurring;
(e) The need for items important to safety to be available to ensure safety in operational states including maintenance;
(f) Specification of the equipment that should be available to enable a full and proper response to postulated initiating events or design basis accidents;

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

Table 1 provides examples of technical operational limits and conditions that may be applicable for a spent fuel storage facility.

6.103. Operational limits and conditions form an important part of the basis on which operation is authorized and as such should be incorporated into the technical and administrative arrangements that are binding on the operating

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 applicable 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 burnup of spent fuel Minimum allowable water level in storage pool Requirements for radiation monitors, alarms and interlocks Minimum cooling period after discharge of the spent fuel from the reactor Maximum radionuclide concentrations in pool water Maximum radiation dose rates on cask surfaces and a specified distance (e.g. 1–2 m) from the cask Minimum tightness of spent fuel cask
Heat removal	Specified availability of cooling systems with specified maximum and minimum system temperatures Minimum cooling period after discharge of the spent fuel from the reactor and maximum burnup of the spent fuel Maximum temperature of concrete and of the cask surface Minimum tightness of spent fuel cask
Water composition	Specification of water composition that will prevent corrosion of spent fuel and storage components, ensure adequate water clarity and prevent microbial growth

organization and operating personnel. Operational limits and conditions for spent fuel storage facilities, which result from the need to meet legal and regulatory requirements, should be developed by the operating organization and subject to approval by the regulatory body as part of the licence conditions. The operating organization may wish to set an administrative margin below the operational limits as an operational target to remain within the approved limits and conditions.

6.104. The aim of operational limits and conditions should be to manage and control the hazards associated with the facility. Operational limits and conditions should be directed towards:

(a) Preventing situations that might lead to the unplanned exposure of workers and the public to radiation;
(b) Mitigating the consequences of any such events, if they were to occur.

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

6.106. Operational limits and conditions should be kept under review and may also have to be revised as necessary in accordance with the national regulatory framework for the following reasons:

(a) In the light of operating experience;
(b) Following modifications made to the spent fuel storage facility and the type of spent 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;
(d) If there are changes in legal or regulatory conditions.

As a result of operating experience, technological progress or changes, corresponding changes to operational conditions may be necessary. Such changes should be justified through safety assessment and should be subject to approval by the regulatory body.

Maintenance, inspection and testing

6.107. A management system (see also Section 4) covering operation and maintenance, and using approved procedures, should be established for controlling:

(a) Maintenance and inspection of the lifting attachments on the casks and of the lifting apparatus (e.g. slings, beams, chains and hooks);
(b) Maintenance of cranes and spent fuel grabs at the facility;
(c) Periodic load testing of cranes and other attachments;
(d) Maintenance, inspection and testing of other safety related equipment.

6.108. 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 should be provided to all structures, systems, areas and components requiring periodic maintenance, inspection and testing. Such access should be adequate for the safe operation of all necessary tools and equipment and for the installation of spares.

6.109. Before the operation of any spent fuel storage facility is commenced, the operating organization should prepare a programme for maintenance, inspection and testing. In the programme, starting dates for all inspections should be specified and these should be re-evaluated in the light of results from commissioning tests. The safety case for the spent fuel storage facility will form a basis for preparation of the programme in terms of the items, i.e. structures, systems and components, that should be included and the periodicity of planned activities for each item.

6.110. Provision should be made 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.

6.111. The programme of periodic maintenance, inspection and testing should be subjected to periodic review, with account taken of operating experience. All such activities should be covered in an integrated manner by the management system, with account taken of manufacturers' recommendations.

6.112. The standard and frequency of activities for periodic maintenance, inspection and tests should be such that the level of reliability and effectiveness is ensured and remains in accordance with the design assumptions and intent so that a consistently high level of safety is maintained throughout the lifetime of the spent fuel storage facility.

6.113. Equally, the reliability and effectiveness of any component should not be significantly affected by the frequency of testing, which may result in premature wear and failure or induced maintenance errors, or which could cause unavailability to an unacceptable degree if the component is inoperative during maintenance and testing.

6.114. If maintenance, inspection or testing of the spent fuel storage facility can be carried out only while certain equipment is in a shutdown state, the maintenance schedule should be drawn up accordingly.

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

6.116. Suitably qualified and experienced operating personnel should be deployed in the approval and implementation of the maintenance, inspection and testing programme and in the approval of associated working procedures and acceptance criteria.

Operational radiation protection

6.117. An operational radiation protection programme should be put in place that ensures that areas of the facility are classified according to the radiation levels and that access control is in place in accordance with the level of classification. It should cover the monitoring of radiation levels in the facility and should include provision to ensure that personnel working in the facility are provided with appropriate dosimetry. A programme of work planning should also be put in place to ensure that radiation exposure is kept as low as reasonably achievable.

Characterization and acceptance of spent fuel

> **Requirement 12 of GSR Part 5 (Ref. [1]): 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.**

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

Item of equipment	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, snow or other effects that may impair the heat removal capability Leak detection and monitoring Detection of corrosion of storage structures and tools
Loop components for cleaning, heat removal and monitoring of cavity of transport cask	Flexible pipes for overpressure reliability Calibration, for example, of: — Temperature and pressure gauges — Specified radiation monitoring equipment required for casks (e.g. for measurement of selected radionuclides, such as ^{85}Kr, ^{134}Cs and ^{137}Cs) Flow rate measurement equipment
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 for functionality of locking mechanism Verification of mechanical integrity of tool
Radiation monitoring equipment	Calibration and function tests of fixed or portable equipment
Storage racks	Confirmation of presence and condition of neutron absorbers (if appropriate) Inspection of mechanical wear of casks, baskets and racks, if appropriate
Video cameras	Confirmation of functionality of cameras
Security	Confirmation of functionality of perimeter fences and/or gates

6.118. Acceptance criteria should be developed for the spent fuel storage facility and the spent fuel, with account taken of all relevant operational limits and conditions and future demands for reprocessing or disposal, including retrieval of the spent fuel. Before spent fuel is transferred to a storage facility, acceptance must be given by the operating organization of the facility and the regulatory body. Contingency plans should be developed and made available to cover how to deal safely with spent fuel that does not comply with acceptance criteria.

6.119. The operating organization of a spent fuel storage facility should be given detailed information concerning the characteristics of the spent fuel received for storage. This information should be supplied by the nuclear facility that generated the spent fuel (i.e. nuclear power plant or research reactor). The minimum information that should be provided is the following:

(a) Design of the fuel, including scale drawings;
(b) Construction materials, the radionuclide inventory, including the initial masses of the fissile content, the burnup and the cooling time of the fuel;
(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 that could affect fuel handling or storage (e.g. damage to fuel cladding or structural damage);
(f) Confirmation that the fuel can be correctly handled upon receipt at the spent fuel storage facility;
(g) Specific instructions for storage (e.g. for degraded or failed fuel);
(h) Surface contamination level and dose rate for the fuel assemblies.

Fuel can be considered damaged if it displays, inter alia, one or more of the following characteristics: pinholes, cracks, mechanical deviations, missing fuel assembly components, bowing, fretting, or serious physical damage. Full and detailed criteria should be established to determine whether fuel is to be considered damaged.

6.120. Upon receipt, spent fuel casks should be checked to determine gamma and neutron radiation levels, leakage and surface contamination and to ensure that they are consistent with the accompanying documentation. Characterization of the spent fuel, for example by means of process control and process monitoring, should be applied as part of the management system for the facility.

6.121. In addition, information concerning the fuel transport cask should also be transmitted by the consignor of the spent fuel to the operating organization of the spent fuel storage facility. This information should include the following:

(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;
(c) Cask identification (e.g. serial number) and certification of compliance with current transport regulations [15];
(d) Requirements and procedures for cask handling and sealing;
(e) Results of the most recent inspection of the cask.

6.122. In cask handling, consideration should be given to carrying out the following operations to ensure safety:

(a) Before a cask is loaded with spent fuel: decontamination, as required.
(b) In loading and unloading of a cask, under both wet and dry conditions: sampling of the internal gas before the closure lid is removed and examination of the spent fuel, as appropriate.
(c) After a cask has been emptied: decontamination, as required, and routine cask maintenance and recertification operations.

6.123. For facilities receiving spent fuel from a number of sites, the operating organization of the spent fuel storage facility should ensure that each consignor provides data on the characteristics of the spent fuel in a clearly understandable form that allows the operating organization to demonstrate that subcritical conditions will be maintained in the handling and storage of the spent fuel. The operating organization should also ensure that the data provided are supported by an approved management system and have been verified, as appropriate.

6.124. Loss of containment has the potential for both exposing workers to radiation and releasing radioactive material to the environment. Mechanisms by which loss of containment might occur should be understood by the operating organization and its personnel and should be addressed, as appropriate, in operating procedures.

Fuel integrity

6.125. The integrity of spent fuel may become degraded and lead to a release of radioactive material to the storage environment. There are a number of causes for the degradation of fuel, including:

(a) Manufacturing defects, such as defects due to incomplete welds or leaking end plugs;
(b) Embrittlement of the cladding material due to interaction with hydrogen or to high irradiation;

(c) General corrosion of the cladding as a result of improper chemical composition of the cooling water;
(d) Mechanical damage, e.g. as a consequence of stress corrosion or handling accidents;
(e) Unrevealed failures that arose during irradiation in the reactor.

6.126. 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 should be made readily available for the canning of leaking or damaged fuel assemblies.

6.127. Spent fuel assemblies that have become damaged as a result of mechanical events should be kept separate from intact fuel and appropriate monitoring should be provided to detect any failure of the outer containment. 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.

6.128. For storage of spent fuel that has been characterized as degraded or failed, consideration should be given in the design to the condition of the fuel. This may include additional engineered methods for the safe handling of damaged fuel during loading and unloading, e.g. instrument tube tie rods for assemblies where stress corrosion cracking of the top nozzle 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, for degraded fuel, the primary containment feature, i.e. the spent fuel cladding, cannot be relied upon for control of the spent fuel material. Stored degraded spent fuel should be monitored and to carry out monitoring appropriately, the following should be ensured:

(a) Appropriate design of the storage in order to facilitate monitoring;
(b) Monitoring of the efficiency of the containment as close as possible to each containment barrier;
(c) Periodic checking of the state of the stored spent fuel (e.g. by sampling, by destructive testing, by placing corrosion test pieces in the storage location, by use of reference objects).

Record of documents

6.129. Operational data of a spent fuel storage facility should be collected and maintained in accordance with the recommendations relating to the management system provided in Section 4.

6.130. Records of maintenance, inspection and testing should be retained, in order to provide a basis on which to review and justify the programme of maintenance, inspection and testing, and should be made subject to periodic examination to establish whether structures, systems and components have the required reliability.

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

6.132. 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 period.

Retrieval of spent fuel

6.133. The storage facility should be operated in such a way as to allow retrieval of spent fuel or spent fuel packages at the end of the anticipated storage period and at the end of the lifetime of the storage facility.

6.134. If spent fuel or a 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 the spent fuel package.

6.135. A spent fuel storage facility should be considered to be an operating facility until all the spent fuel and/or spent fuel packages have been removed.

Transport after storage

6.136. After storage, and before subsequent transport, the integrity of the spent fuel and the storage and/or transport casks and the associated paperwork should be examined. The following issues should be addressed:

(a) Ownership and responsibility for the safe retention of records;
(b) The inspection and surveillance regime applied;
(c) Control of the storage environment;
(d) Conventional safety issues, such as periodic inspection of handling equipment;

(e) Nuclear safety issues, such as any degradation of the spent fuel itself, of the spent fuel support structure and the neutron shielding materials.

6.137. The safety functions of the storage and/or transport casks should be assessed periodically to demonstrate compliance with current safety standards and the approval requirements and conditions of the transport licence [15]. Possible degradation of casks should be assessed and consideration should be given to the following:

(a) Spent fuel and fuel support structure.
(b) The containment system: metal seals and restraining systems 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 in density and composition, etc.
(f) Design features incorporated to ensure subcriticality.

Storage beyond the original design lifetime

6.138. If storage of spent fuel is envisaged beyond the original design lifetime of the facility, the nuclear reactivity of the fuel should be reassessed and taken into account in the decision making, as necessary. In this case, an appropriately wide safety margin or additional safety provisions may be applied.

6.139. It is essential that the operating organization develop expertise to manage difficulties that may arise from the effects of storage beyond the original design lifetime.

6.140. Paragraph 3.29 of Fundamental Safety Principles [8] states 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' will depend to a large extent on national circumstances. Aspects to be taken into account, particularly if long term storage of spent fuel is anticipated to span many generations, are the following:

(a) Provision of adequate financial resources to ensure safe management of the spent fuel over this storage period;
(b) Maintaining of regulatory control;
(c) Transfer and maintenance of knowledge and technical capability;

(d) Continuation of education of specialists in spent fuel management, even if electricity generation by nuclear power ceases to be part of the national energy strategy.

6.141. Safe operation of a spent fuel storage facility should be ensured for its entire lifetime. This is generally longer than the average lifetime of a commercial company. Consequently, in the event that the operating organization ceases to exist, for example after several decades, transfer of ownership of the spent fuel and the spent fuel storage facility to a government institute may be considered.

6.142. For storage of spent fuel, a safety assessment should be carried out and the safety case developed prior to licensing of the facility. For long term storage, a reassessment of the safety case may become necessary, for example in the event of degradation of the facility or any of its components or structures important for 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.

6.143. 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.

6.144. Prolonged irradiation of cladding material, gaskets or other materials relevant to ensuring the containment of the spent fuel may result in degradation of safety functions. An ageing management programme should be set up to deal with ageing related degradation. The programme should specify the monitoring necessary for early detection of any deficiency.

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

6.146. The longer the envisaged storage period, the greater the uncertainties in the assumptions made about safety parameters. In order to provide the operational or regulatory decisions with a scientific basis, research and development projects should be undertaken that are aimed at reducing these uncertainties, if they are of specific importance. For example, accelerated irradiation experiments on materials used in the spent fuel storage or long time sealing tests with intentionally aggressive media can provide useful information on their sensitivity to ageing effects.

DECOMMISSIONING OF SPENT FUEL STORAGE FACILITIES

Requirement 20 of GSR Part 5 (Ref. [1]): Shutdown and decommissioning of facilities

The operator shall develop, in the design stage, an initial plan for the shutdown and decommissioning of the predisposal radioactive waste management facility 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.

6.147. Decommissioning of nuclear facilities comprises:

(a) Preparation and approval of the decommissioning plan;
(b) The actual conduct of decommissioning;
(c) The management of waste resulting from decommissioning activities;
(d) Release of the site for unrestricted or restricted use.

6.148. An initial version of the decommissioning plan should be prepared during the design of the spent fuel storage facility in accordance with requirements and recommendations on decommissioning [18, 19].

6.149. 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 human induced accidents and other incidents and natural events;
(c) Modifications to systems and structures affecting the decommissioning plan;
(d) Amendments to regulations and changes in government policy;
(e) Cost estimates and financial provisions.

6.150. A comprehensive decommissioning strategy should be developed for sites also having other facilities to ensure that interdependences are taken into account in the planning for individual facilities [18].

6.151. A final decommissioning plan is required to be submitted for approval within two years of shutdown of the spent fuel storage facility, unless an alternative schedule for the submission of the final decommissioning plan has been agreed with the regulatory body [18].

6.152. Even when the bulk of the residual process material has been removed, a significant amount of contaminated material may remain. The expeditious removal of this material should be considered, as it would reduce the need for monitoring and surveillance. Other activities associated with decommissioning may be conducted concurrently with the removal of this material, but the potential for adverse interaction between concurrent activities should be identified and assessed.

6.153. Dismantling and decontamination techniques are required to be chosen such that generation of waste and airborne contamination are minimized and protection of workers and the public is optimized [18].

6.154. Before a site is released, for example for unrestricted use, it should be monitored and, if necessary, cleaned up [32]. A final survey should be performed to demonstrate that the end point criteria, as established by the regulatory body, have been met.

Appendix I

SPECIFIC SAFETY CONSIDERATIONS FOR WET OR DRY STORAGE OF SPENT NUCLEAR FUEL

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

DESIGN OF WET STORAGE FACILITIES

Subcriticality

I.2. For facilities for which 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 in such conditions. For water storage pools, subcriticality should be demonstrated for all credible water densities, including events for which boiling of pool water cannot be excluded in the safety assessment.

I.3. Criticality safety of pool storage should not rely on the use of soluble neutron poison. If this is not possible or if the operating organization chooses to use a soluble neutron poison such as borated water for criticality control, the design of the facility should include engineering features to preclude an increase in the reactivity of stored fuel caused by inadvertent dilution of the pool water by the addition of non-borated water.

Heat removal

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 heat removal systems should be to ensure that no temperature limit, as set to protect structures, systems, components and the fuel from damage, will be exceeded in operational states and accident conditions.

Containment of radioactive material

I.5. Wet pool storage facilities should be designed to include features that prevent or limit the release of radioactive material to the environment. Such features could include mechanisms to maintain subatmospheric pressures inside the storage building, to provide for filtration of potential venting pathways and to prevent ingress and egress of pool water, and can be used to minimize the number, size and location of building penetrations.

Radiation protection

I.6. Where pool water is used to provide radiation shielding for the protection of 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 provision for an adequate and appropriately accessible supply of water, from redundant and diverse sources and of a quality acceptable for use in the facility.

I.7. Water storage pools should not be designed with penetrations below the minimum water level required for adequate shielding and cooling of stored spent fuel.

I.8. The design should not allow the permanent installation of piping or other equipment that could inadvertently, e.g. by acting as a siphon, lower the pool water level below the minimum required level.

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

I.10. The system for providing make-up water to the pool 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, the pool water removal system should have a capacity less than that of the pool water make-up system. Furthermore, mixing spent fuels in the same zone with different limits or a different control mode for criticality should be avoided.

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

I.12. Indications and alarms should be provided to alert facility personal of any unintended decrease in water level and when the minimum water level is reached.

Structure and layout

I.13. The storage pool and other components important to the retention of cooling water should be designed to withstand conditions in both operational states and accident conditions, including impacts from collisions or dropped loads, without significant leakage of water. Further, the storage pool should be designed to provide for the detection of leakages and the implementation of appropriate repairs or remedial actions, as necessary. The means for sampling groundwater at the facility should be provided, e.g. boreholes located around the facility.

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

I.15. If stacking is proposed for 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 in the design of spent fuel and fuel racks or baskets.

I.16. The facility should be designed in such a way as to prevent overfilling of the storage pool.

Materials

I.17. 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) The 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;
(e) Handling systems.

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

It should be ensured that the storage racks or casks will not contaminate the pool water. The ease of 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.18. The chemical composition of the pool water should be consistent with the protection of the spent fuel cladding, pool structure and handling equipment. The clarity of pool water necessary for pool operation should be maintained.

Handling

I.19. The design of handling systems and equipment should preclude the need for lubricants or other fluids or substances that could degrade the quality or otherwise affect the purity of the pool water. If lubricants are necessary, design measures should be provided to prevent their leakage and escape into the pool water. Substances should be used that are fully compatible with the spent fuel, the equipment and the storage structures (e.g. water may be used).

I.20. Hollow handling tools intended for use under water should be designed so that they fill with water upon submergence (to maintain the water shielding effect) and drain upon removal.

I.21. 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 incorporation of 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 the grapples and hooks of the fuel assembly. Operator failures should be avoided by applying the ‘four eyes principle’ or by use of check lists.

OPERATION FOR WET STORAGE FACILITIES

I.22. There are several pool management features that 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 those shown in Table II–1 of Annex II. The integrity of the spent fuel and the geometry necessary to maintain subcriticality and for heat removal and its related containment barriers should be maintained throughout the lifetime of the facility and should be verified using appropriate methods.

Subcriticality

I.23. 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.

Radiation protection

I.24. Operational controls should include proper maintenance of underwater lighting and water clarity, which are important for radiation protection of workers performing duties in and around the pool. The ability to perform activities that rely upon visual examination and/or inspection without need for repetition and in minimal time will result in reductions in the exposure of workers.

Heat removal

I.25. Damage to the pool structure may occur if pool water is cooled to a very low temperature or until it freezes. Damage may also result from high rates of temperature change that exceed the design limits. Such issues relating to heat removal should be considered in the specification of operational limits and in the development of administrative procedures.

I.26. Operating 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. Impairment or damage to pool cooling systems should be responded to in a timely manner to return the system to intended operating conditions. Furthermore, operating procedures should be such that the time for which the pool cooling system is unavailable due to routine maintenance and/or repair is minimized.

I.27. Heat transfer considerations may increase in importance if spent fuel is placed in high density storage.

Containment

I.28. Operational controls should be implemented to avoid a decrease in the pool water level. A decrease in the pool water level could result, inter alia, in:

(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;
(c) Increased water temperature and, consequently, increased release of radioactive material into the water owing to corrosion of spent fuel and spent fuel cladding.

I.29. For wet storage facilities below ground level, operational controls should be implemented to avoid, minimize and manage the potential for in-leakage of water which may result in:

(a) Dilution of boron in a moderated pool environment and the potential for a criticality accident where soluble boron is used for criticality control;
(b) Corrosion and other degradation effects of materials important to safety.

I.30. 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 put in place to alert facility personnel of any unintended decrease in water level and of when the minimum water level is reached. Samples of groundwater from boreholes located around the facility should be periodically collected and activity levels monitored.

Shielding

I.31. Operational controls that avoid and minimize the potential for a loss of shielding during facility activities should be implemented. Loss of shielding can result in high radiation exposure. Operational controls should address and set limits to preclude:

(a) The hoisting of spent fuel higher than design limits during handling operations in the storage pool;
(b) Inadequate depth of pool water;
(c) Improper use of pool tools (e.g. empty rather than flooded).

Dropping of loads

I.32. Operational controls should be implemented to ensure that events, such as a cask drop, do not result in undue challenges to the storage facility safety systems. Areas of prime concern in this regard include, inter alia:

(a) The zones between the entrance airlock to the cask handling area and the cask preparation area and the unloading area at the pool;
(b) The unloading pool area.

The dropping of a spent fuel element or assembly may result, inter alia, in:

(a) Damage of spent fuel and resulting contamination of the pool;
(b) Damage of the pool structure and possible 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 of spent fuel assemblies or arrays in adjacent racks;
(d) Release of gaseous fission products.

A further potential hazard resulting from such a drop is loss of water from the pool either by direct expulsion or by gross leakage arising from structural damage.

I.33. 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.

DESIGN OF DRY STORAGE FACILITIES

Subcriticality

I.34. Fuel baskets and containers for spent fuel storage should be designed in such a way as to ensure that the spent fuel will remain in a configuration which has been determined to be subcritical during loading, transfer, storage and retrieval.

I.35. Dry spent fuel storage facilities should be designed either to exclude the introduction of a moderator or in such a way that consequences likely to result from the redistribution or the introduction of a moderator as a consequence of an internal or external event can be accommodated.

Heat removal

I.36. The storage facility should be constructed in a location for which there has been due consideration of climate changes and associated potential increase in ambient temperatures and/or the level of naturally occurring bodies of water adjacent to the facility, and maintained in a manner which permits adequate heat dissipation. Design features should include provision to maintain cooling during adverse weather conditions, including high winds that might affect the performance of natural circulation design elements of a dry storage cask and the forced circulation and ventilation systems of a storage facility.

I.37. To the maximum extent practicable, cooling systems for dry spent fuel storage should be passive and should require minimal maintenance. Maximization of 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. If forced circulation of coolants is used, it should be demonstrated to be sufficiently reliable during normal operation and accident conditions, with no adverse effects on systems, structures and components that are important to safety.

I.38. 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 should make provision for the monitoring and maintaining of both the presence and the quality of the medium for the time period demonstrated as necessary by the safety case.

Containment of radioactive material

I.39. The storage facility and dry storage casks should be designed to facilitate monitoring of the spent fuel containment and detection of 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.40. The storage facility should be designed in such a way as to incorporate containment barriers to prevent the release of radionuclides. This could include liners or canisters as an integral part of the dry storage system.

Radiation protection

I.41. Spent fuel loading and unloading operations should be carried out using equipment and methods that limit ‘sky shine’ and reflection of radiation to workers and the public.

I.42. 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.43. Dry storage areas with a significant potential for generating or accumulating unacceptable concentrations of airborne radionuclides should be either maintained at subatmospheric 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. For open dry storage facilities that do not use an overstructure or building as a minimum, radiation monitoring should be provided at the site boundary to detect any abnormal levels of airborne radionuclides.

Structure and layout

I.44. 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 it should be demonstrated that the potential for water accumulation is not of concern, i.e. that decay heat generated by the stored fuel is sufficient to evaporate and drive off any accumulated water.

I.45. If stacking is proposed for a dry fuel storage facility, 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 in the design of spent fuel and casks or baskets.

I.46. Ease of access should be considered in the design to facilitate the transfer of spent fuel to or from storage positions in normal operation or during recovery operations after anticipated operational occurrences or accident conditions.

Sufficient clearances should be provided in all directions and on all sides so as to provide the necessary access.

I.47. Casks should be designed in such a way as to provide stability and prevent them from tipping over.

I.48. 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.49. The foundations of the dry storage area should be capable of withstanding the weight of the loaded spent fuel casks and the handling equipment without excessive settling and degradation.

I.50. The design of an open dry spent fuel storage facility should be such as to provide for appropriate collection, monitoring and processing of surface runoff water.

I.51. 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 repackaging of the fuel or repairs.

I.52. 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 in order to enable their transport to a location where such facilities are available.

Materials

I.53. 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 and unloading conditions expected throughout its design lifetime, unless adequate maintenance and/or replacement methods during operation can be demonstrated. These loading and unloading conditions include exposure to the atmosphere, internal and external humidity, fission products, temperature variations, internal buildup of gas and high radiation fields.

I.54. 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.55. The dry storage system, including any closures, especially cask closures, should be constructed of materials that provide chemical and radiological stability and appropriate resistance to mechanical and thermal impacts.

I.56. 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 or degradation during the drying activity, where higher fuel temperatures may be experienced, and in subsequent storage. Maintaining of 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 retrievability of the fuel, the condition of the spent fuel should be correctly characterized and analysed and/or inspected if necessary prior to its loading into a storage container.

Handling

I.57. The design of casks intended to be portable should include provision for lifting and handling that minimizes the potential for a drop accident. This should include the use of single-failure-proof cranes and positive locking mechanisms on lifting yokes. Lifting and handling mechanisms should be able to withstand anticipated loadings and usage during the design lifetime of the casks.

I.58. For dry spent fuel storage facilities incorporating canisters for which shielding is necessary, consideration should be given to the need for on-site handling and for off-site transportation.

I.59. For multipurpose casks intended for storage, transport and potential disposal after storage, the means for appropriate handling at the end of the storage period should be considered in the design.

OPERATION OF DRY STORAGE FACILITIES

I.60. To limit corrosion, radiolysis phenomena and criticality issues, spent fuel should be dried to the greatest extent possible prior to being put in dry storage.

I.61. There are several elements in the management of a dry spent fuel storage facility that contribute to its safe operation. Some of the key elements are listed in Table II–2 of Annex II. Since dry storage facilities are by design principally passive, there are fewer specific operational considerations than for wet storage facilities.

Subcriticality

I.62. In most cases, it can be shown by deterministic arguments that dry storage facilities remain subcritical. The effect of possible water ingress to areas where fuel may be present, for example, as a result of climate change and an associated increase in the levels 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 on consideration of external environmental events or human 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 assuming credible optimum moderation.

Heat removal

I.63. Heat is removed from spent fuel casks and/or the spent fuel storage facility by conduction, radiation and natural or, in some cases, forced convection. Operational controls should consist of verification that there are no impairments to the flow of the cooling medium. The internal cooling medium for casks is typically an inert gas, whereas the external cooling medium for dry storage is typically air. If forced circulation is necessary for heat removal, additional operational controls and maintenance will be required on air moving systems. Maximization of the passive design features for heat removal will minimize the need for operational considerations.

I.64. 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.

I.65. For casks relying upon a gas medium for internal convective cooling, the quality and/or density of the gas should be monitored and maintained if maintenance of the gas medium is not ensured by the design.

Containment

I.66. For double seal systems for dry storage casks, monitoring should be implemented to detect any loss of effectiveness of any of the seals and thereby prevent releases of radioactive material to the environment. For single seal systems and ventilation systems, releases of radioactive material (e.g. ^{85}Kr, ^{134}Cs and ^{137}Cs) should be monitored.

I.67. For dry cask storage systems with welded closure lids, monitoring may not be necessary.

Shielding

I.68. Operational controls should be implemented to avoid a loss of shielding in spent fuel storage. A loss of shielding can lead to high radiation exposure. Specifically, operational controls should address the potential for, inter alia, the following:

(a) Handling errors when closing or sealing dry storage casks or containers;
(b) Improper operation or failure of protective interlocks on shielding cells;
(c) Melting of neutron shielding material due to high temperatures.

Dropping of loads

I.69. Operational controls should be implemented that avoid the dropping 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 could result, inter alia, in:

(a) Partial defects in the spent fuel cladding, leading to leaks and, in case of cask loading in a storage pool, resulting in contamination of the storage pool water by fission products;
(b) Deformation (e.g. bending) or damage of the spent fuel, which could lead to difficulties in its subsequent handling;
(c) An increased potential for the occurrence of a criticality accident if new spent fuel or spent fuel with low burnup were to be inadvertently dropped in the vicinity of other spent fuel in the pool storage racks;
(d) Radiation exposure of workers due to the release of volatile radionuclides.

I.70. 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 in the future management of the dropped fuel.

Appendix II

CONDITIONS FOR SPECIFIC TYPES OF FUEL AND ADDITIONAL CONSIDERATIONS

GENERAL

II.1. There are numerous types of fuel element that have to be considered for storage. They differ by the type of fuel, the enrichment in ^{235}U for fresh uranium fuel, the cladding material and the geometry. After irradiation in a reactor, there will be large differences in heat generation, in 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.

MOX FUEL

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 their radionuclide inventory and by their 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 to 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.

II.3. Protection against criticality constitutes an important design requirement. In the analysis of nuclear reactivity, special consideration has to be given to the nuclide vector of plutonium as well as to the specification of an enveloping plutonium and uranium ratio.

II.4. Spent MOX fuel may be loaded amongst uranium fuel assemblies. In such cases, the MOX assemblies should be placed only at specific positions to allow for the effective dissipation of heat and to provide for adequate radiation shielding.

II.5. Compared with uranium fuel, the increased heat generation, the high alpha activity and the higher buildup 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, irrespective of whether the wet or dry storage is used.

FUEL WITH HIGH BURNUP

II.6. Most safety measures necessary for the storage of MOX fuel are also applicable to the storage of high burnup fuel (a high burnup may be defined as a level higher than 55 GW·d/t uranium for light water reactors).

BURNUP CREDIT

II.7. The use of burnup credit in the safety assessment means that credit is given for the reduction in spent fuel nuclear reactivity as a result of fission. It differs from the more conservative 'fresh fuel' assumption and, consequently, may be considered a more realistic approach. A decision to take credit for burnup should be fully justified with accurate experimental data, approved calculation methods and validated and verified benchmarked computer codes in accordance with international standards. This applies to both inventory determination calculations and criticality calculations. 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 that the required safety level will be achieved.

II.8. Approval to consider burnup credit in the safety assessment should be granted only if based on design engineered safety features and operational controls. Operational controls provide defence in depth and contribute to maintaining subcritical conditions. The minimum required burnup value should be verified by independent measurement.

II.9. Approval to consider burnup credit in the safety assessment should be granted in an incremental manner. Priority should be given to consideration of simple cases 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 pressurized water reactor fuel.

FUEL FROM RESEARCH REACTORS

II.10. The basic safety aspects for the storage of spent fuel from power reactors are applicable for the storage of spent fuel from research reactors. A proper graded approach, which takes the differences between the fuel types into account, should be applied. Issues relating specifically to the storage of research reactor fuel, for example, lower heat generation, higher enrichment and the use of cladding materials that are less corrosion resistant, should be given particular consideration.

II.11. Fuel composition, cladding material and shapes and sizes of fuel assemblies differ significantly in research reactors. In a research reactor, different fuel elements can be loaded into the research reactor and thus a variety of spent fuel is generated. This may comprise, for example, fuel assemblies with different cladding materials (e.g. Al, stainless steel, Zr) or with different fuel compositions. In certain research reactors, reconstitution of an irradiated fuel assembly (e.g. by replacement of pins) is carried out.

II.12. In addition to the recommendations provided in this Safety Guide, it is essential that all aspects relating to the specific fuel assemblies used in the research reactor are taken into consideration.

II.13. A detailed assessment of all fuel assemblies, including reconstituted assemblies, should be carried out for storage. Proper provision in the design should be made for storage of research reactor fuel assemblies in accordance with their shape, size, clad type and fuel composition. Provision for safe storage of any separated pins resulting from the reconstitution of fuel should also be made in the design.

II.14. Owing 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 margins in storage, as noted in paras 6.33 and 6.34 of this Safety Guide.

II.15. The compatibility of the cladding of the research reactor fuel with wet storage conditions should be assessed in order to ensure integrity.

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

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 specific treatment before it is transferred. 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 airborne or waterborne radionuclides.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Predisposal Management of Radioactive Waste, IAEA Safety Standards Series No. GSR Part 5, IAEA, Vienna (2009).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Storage of Radioactive Waste, IAEA Safety Standards Series No. WS-G-6.1, IAEA, Vienna (2006).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Nuclear Fuel Cycle Facilities, IAEA Safety Standards Series No. NS-R-5, IAEA, Vienna (2008).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Assessment for Facilities and Activities, IAEA Safety Standards Series No. GSR Part 4, IAEA, Vienna (2009).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, The Management System for Facilities and Activities, IAEA Safety Standards Series No. GS-R-3, IAEA, Vienna (2006).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, The Convention on the Physical Protection of Nuclear Material, INFCIRC/274 (1980) and its amendment (2005).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/Revision 5), IAEA Nuclear Security Series No. 13, IAEA, Vienna (2011).

[8] EUROPEAN ATOMIC ENERGY COMMUNITY, FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANIZATION, INTERNATIONAL MARITIME ORGANIZATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, UNITED NATIONS ENVIRONMENT PROGRAMME, WORLD HEALTH ORGANIZATION, Fundamental Safety Principles, IAEA Safety Standards Series No. SF-1, IAEA, Vienna (2006).

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, IAEA Safety Standards Series No. GSR Part 3, Interim Edition, IAEA, Vienna (2011).

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, Management of Waste from the Use of Radioactive Material in Medicine, Industry, Agriculture, Research and Education, IAEA Safety Standards Series No. WS-G-2.7, IAEA, Vienna (2005).

[11] INTERNATIONAL NUCLEAR SAFETY ADVISORY GROUP, Safety Culture, INSAG Series No. 75-INSAG 4, IAEA, Vienna (1991).

[12] INTERNATIONAL NUCLEAR SAFETY ADVISORY GROUP, Key Practical Issues in Strengthening Safety Culture, INSAG Series No. 15, IAEA, Vienna (2002).

[13] INTERNATIONAL ATOMIC ENERGY AGENCY, Governmental, Legal and Regulatory Framework for Safety, IAEA Safety Standards Series No. GSR Part 1, IAEA, Vienna (2010).

[14] Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, INFCIRC/546, IAEA, Vienna (1997).

[15] INTERNATIONAL ATOMIC ENERGY AGENCY, Regulations for the Safe Transport of Radioactive Material, 2009 Edition, IAEA Safety Standards Series No. TS-R-1, IAEA, Vienna (2009).

[16] INTERNATIONAL ATOMIC ENERGY AGENCY, Regulatory Inspection of Nuclear Facilities and Enforcement by the Regulatory Body, IAEA Safety Standards Series No. GS-G-1.3, IAEA, Vienna (2002).
[17] INTERNATIONAL ATOMIC ENERGY AGENCY, Documentation for Use in Regulating Nuclear Facilities, IAEA Safety Standards Series No. GS-G-1.4, IAEA, Vienna (2002).
[18] INTERNATIONAL ATOMIC ENERGY AGENCY, Decommissioning of Facilities Using Radioactive Material, IAEA Safety Standards Series No. WS-R-5, IAEA, Vienna (2006).
[19] INTERNATIONAL ATOMIC ENERGY AGENCY, Decommissioning of Nuclear Fuel Cycle Facilities, IAEA Safety Standards Series No. WS-G-2.4, IAEA, Vienna (2001).
[20] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANIZATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, UNITED NATIONS OFFICE FOR THE COORDINATION OF HUMANITARIAN AFFAIRS, WORLD HEALTH ORGANIZATION, Preparedness and Response for a Nuclear or Radiological Emergency, IAEA Safety Standards Series No. GS-R-2, IAEA, Vienna (2002).
[21] INTERNATIONAL ATOMIC ENERGY AGENCY, The Management System for the Processing, Handling and Storage of Radioactive Waste, IAEA Safety Standards Series No. GS-G-3.3, IAEA, Vienna (2008).
[22] INTERNATIONAL ATOMIC ENERGY AGENCY Regulatory Control of Radioactive Discharges to the Environment, IAEA Safety Standards Series No. WS-G-2.3, IAEA, Vienna (2000).
[23] INTERNATIONAL ATOMIC ENERGY AGENCY, Site Evaluation for Nuclear Installations, IAEA Safety Standards Series No. NS-R-3, Vienna (2003).
[24] INTERNATIONAL ATOMIC ENERGY AGENCY, External Human Induced Events in Site Evaluation for Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-3.1, IAEA, Vienna (2002).
[25] INTERNATIONAL ATOMIC ENERGY AGENCY, Dispersion of Radioactive Material in Air and Water and Consideration of Population Distribution in Site Evaluation for Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-3.2, IAEA, Vienna (2002).
[26] INTERNATIONAL ATOMIC ENERGY AGENCY, Seismic Hazards in Site Evaluation for Nuclear Installations, IAEA Safety Standards Series No. SSG-9, IAEA, Vienna (2010).
[27] INTERNATIONAL ATOMIC ENERGY AGENCY, Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations, IAEA Safety Standards Series No. SSG-18, IAEA, Vienna (2011).
[28] INTERNATIONAL ATOMIC ENERGY AGENCY, Geotechnical Aspects of Site Evaluation and Foundations for Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-3.6, IAEA, Vienna (2004).
[29] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation Protection Aspects of Design for Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-1.13, IAEA, Vienna (2005).

[30] INTERNATIONAL ATOMIC ENERGY AGENCY, Predisposal Management of High Level Radioactive Waste, IAEA Safety Standards Series No. WS-G-2.6, IAEA, Vienna (2003).
[31] INTERNATIONAL ATOMIC ENERGY AGENCY, Protection against Internal Fires and Explosions in the Design of Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-1.7, IAEA, Vienna (2004).
[32] INTERNATIONAL ATOMIC ENERGY AGENCY, Release of Sites from Regulatory Control on Termination of Practices, IAEA Safety Standards Series No. WS-G-5.1, IAEA, Vienna (2006).

Annex I

SHORT TERM AND LONG TERM STORAGE

SHORT TERM STORAGE

Short term storage (conventional storage) is defined in this Safety Guide as storage that can last up to approximately 50 years, since this period is representative with respect to:

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

To satisfy safety considerations, a short term storage concept needs to include an end point that will be reached within a time period of approximately fifty years. If this is not possible, the safety considerations should be compared against the safety considerations for a long term waste storage facility.

LONG TERM STORAGE

Long term storage is considered in this Safety Guide to be storage beyond approximately 50 years, and with a defined end point. The storage end point is important since it determines the basis for the design lifetime of the facility, packaging requirements and financial guarantees, and the planning basis for subsequent disposal facilities. Long term storage is not expected to last more than approximately 100 years. This time frame is based on technical experience with civil construction. However, it is a fact that many existing industrial and civil analogues have lifetimes of 100–150 years and more. Archaeological analogues can be found with lifetimes of 1000–2000 years. Societal acceptance of longer design lifetimes, which is based on experience with existing industrial operations and facilities, is also an important factor to consider. The 100 year period is judged to be adequate to allow enough time to determine future fuel management steps.

Annex II

OPERATIONAL AND SAFETY CONSIDERATIONS FOR WET AND DRY SPENT FUEL STORAGE FACILITIES

TABLE II–1. OPERATIONAL AND SAFETY CONSIDERATIONS FOR A WET SPENT FUEL STORAGE FACILITY

Element	Applicable safety functions
1. Control of the amount of spent fuel loaded in the pool, with account taken 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, structural integrity of spent fuel assemblies
3. Control of pool water (specific activity, temperature, chemical composition)	Containment, radiation protection, structural integrity of spent fuel assemblies
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, structural integrity of spent fuel assemblies
8. Maintenance of underwater lighting	Radiation protection
9. Administrative controls to prevent misplacement of spent fuel	Subcriticality
10. Spent fuel integrity	Radiation protection

TABLE II–2. OPERATIONAL AND SAFETY CONSIDERATIONS FOR A DRY SPENT FUEL STORAGE FACILITY

Element	Applicable safety functions
1. Control of the type and amount of spent fuel in the storage compartments	Subcriticality, heat removal
2. Monitoring of gamma and neutron radiation fields near the location of spent fuel in the storage area	Radiation protection
3. Monitoring of heat removal and heat dissipation from spent fuel to the environment	Heat removal, radiation protection, containment, structural integrity of spent fuel assemblies
4. Direct monitoring of spent fuel containment integrity (if permitted by design)	Radiation protection, containment
5. Indirect monitoring of atmosphere in volumes and/or spaces inside the facility containing sealed spent fuel casks (if present)	Radiation protection, containment, structural integrity of spent fuel assemblies
6. Maintenance and monitoring of inert gas in sealed casks (if present and permitted by design)	Heat removal, spent fuel integrity

Annex III

EXAMPLE OF THE SECTIONS IN OPERATING PROCEDURES FOR A SPENT FUEL STORAGE FACILITY

An example of the sections that may be included in the operating procedures for a spent fuel storage facility is as follows:

(a) Title description with revision number, date and approval status;
(b) Purpose of the procedure;
(c) Initial conditions required before the procedure can be used;
(d) Precautions and limitations that must be observed;
(e) Limitations and action levels on parameters being controlled (e.g. pool water composition) and corrective measures to return parameters to within normal range;
(f) Procedures providing completely detailed, step by step operating instructions;
(g) Acceptance criteria, where applicable, for judging the success or failure of activities;
(h) Checklists for complex procedures, either included or referenced;
(i) References used in developing the procedure;
(j) Testing to verify radiation dose levels and heat removal performance after spent fuel loading;
(k) Monitoring of bore wells around the facility;
(l) Monitoring of stack discharge.

Annex IV

RELATED PUBLICATIONS IN THE IAEA SAFETY STANDARDS SERIES

Safety Fundamentals

- Fundamental Safety Principles, IAEA Safety Standards Series No. SF-1

Safety Requirements

- Predisposal Management of Radioactive Waste, IAEA Safety Standards Series No. GSR Part 5
- Safety of Nuclear Power Plants: Design, IAEA Safety Standards Series No. SSR 2/1
- Safety of Nuclear Fuel Cycle Facilities, IAEA Safety Standards Series No. NS-R-5
- The Management System for Facilities and Activities, IAEA Safety Standards Series No. GS-R-3
- Safety Assessment for Facilities and Activities, IAEA Safety Standards Series No. GSR Part 4

Safety Guides

- Storage of Radioactive Waste, IAEA Safety Standards Series No. WS-G-6.1
- The Management System for the Processing, Handling and Storage of Radioactive Waste, IAEA Safety Standards Series No. GS-G-3.3

Annex V

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

In making use of this list, it is to be recognized that the initiating events included will not necessarily be applicable to all facilities and to all sites:

(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 the 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 the 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 materials:
    — 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 accumulation (from marshland or landfill sites);
  (iii) Dust storms or sand storms (including the possible blocking of inlets and outlets).

Annex VI

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

In making use of this list, it is to be recognized that the initiating events included would not necessarily be applicable to all facilities and all sites:

(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 generated as a result of 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) Geographical 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).

Annex VII

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

In making use of this list it is to be recognized that the initiating events included would not necessarily be applicable to all facilities and all sites:

(1) The acceptance (inadvertent or otherwise) of incoming spent fuel, spent fuel containers, process chemicals, conditioning agents, etc., that do not meet the specifications (acceptance criteria) included in the design basis.
(2) The processing of spent fuel that meets acceptance criteria but which is subsequently processed in an inappropriate way for the particular type of spent fuel (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 spent fuel streams;
      — Spent fuel and conditioning agents;
      — Spent fuel cask material and conditioning agents;
      — Process chemicals;
      — Spent fuel, spent fuel casks, conditioning agents, process chemicals and the prevailing conditions of the working 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 spent fuel (physical, chemical or pathogenic).
(9) The generation of a toxic atmosphere by chemical reactions due to inappropriate mixing or contact of various reagents and materials.
(10) Dropping of spent fuel elements or other loads due to mishandling or equipment failure, with consequences to the dropped spent fuel elements and possibly to other spent fuel elements 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 spent fuel elements, spent fuel casks and pipes.
(12) Failures of structures, systems and components due to:
  (i) A loss of structural integrity 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 working or storage environment.
(13) The generation of missiles and flying debris due to explosion of pressurized components or catastrophic 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 the dewatering system.
(17) The malfunctioning of monitoring or alarm systems that allows an adverse condition to go unnoticed.
(18) Incorrect settings (errors or unauthorized changes) on monitors, alarms or control equipment.
(19) The failure of emergency equipment, such as the fire suppression system, pressure relief valves and ducts, to function when called upon.
(20) The failure of the power supply, either the main system or various subsystems.
(21) The malfunctioning of key items of equipment for handling spent fuel, 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 a risk of significant additional radiation exposure of personnel called on to assist in effecting repairs or replacements.
(28) Encountering an unanticipated radiation source in decommissioning (e.g. different in nature or amount) and with immediate recognition of the changed circumstances.
(29) Removal or weakening of a structure or component in decommissioning without realization of the possible effects on the structural integrity of other structures and components.

CONTRIBUTORS TO DRAFTING AND REVIEW

Carreton, J.P.	Institute for Radiation Protection and Nuclear Safety, France
Codée, H.D.K.	Centrale Organisatie Voor Radioactief Afval, Netherlands
Dolinar, G.	Atomic Energy of Canada Limited, Canada
Fisher, C.	United Kingdom Nirex, United Kingdom
Jones, G.	International Atomic Energy Agency
Hanaki, I.	Nuclear and Industrial Safety Agency, Japan
Hedberg, B.	Swedish Nuclear Power Inspectorate, Sweden
Lietava, P.	State Office for Nuclear Safety, Czech Republic
Maruoka, K.	Japan Nuclear Energy Safety Organization, Japan
Metcalf, P.E.	International Atomic Energy Agency
Raicevic, J.	International Atomic Energy Agency
Regan, C.M.	Nuclear Regulatory Commission, United States of America
Rowat, J.H.	International Atomic Energy Agency
Selling, H.	Ministry of Housing, Spatial Planning and the Environment, Netherlands
Shirai, K.	Central Research Institute of the Electric Power Industry, Japan
Warnecke, E.	International Atomic Energy Agency

BODIES FOR THE ENDORSEMENT OF IAEA SAFETY STANDARDS

An asterisk denotes a corresponding member. Corresponding members receive drafts for comment and other documentation but they do not generally participate in meetings. Two asterisks denote an alternate.

Commission on Safety Standards

Argentina: González, A.J.; *Australia*: Loy, J.; *Belgium*: Samain, J.-P.; *Brazil*: Vinhas, L.A.; *Canada*: Jammal, R.; *China*: Liu Hua; *Egypt*: Barakat, M.; *Finland*: Laaksonen, J.; *France*: Lacoste, A.-C. (Chairperson); *Germany*: Majer, D.; *India*: Sharma, S.K.; *Israel*: Levanon, I.; *Japan*: Fukushima, A.; *Korea, Republic of*: Choul-Ho Yun; *Lithuania*: Maksimovas, G.; *Pakistan*: Rahman, M.S.; *Russian Federation*: Adamchik, S.; *South Africa*: Magugumela, M.T.; *Spain*: Barceló Vernet, J.; *Sweden*: Larsson, C.M.; *Ukraine*: Mykolaichuk, O.; *United Kingdom*: Weightman, M.; *United States of America*: Virgilio, M.; *Vietnam*: Le-chi Dung; *IAEA*: Delattre, D. (Coordinator); *Advisory Group on Nuclear Security*: Hashmi, J.A.; *European Commission*: Faross, P.; *International Nuclear Safety Group*: Meserve, R.; *International Commission on Radiological Protection*: Holm, L.-E.; *OECD Nuclear Energy Agency*: Yoshimura, U.; *Safety Standards Committee Chairpersons*: Brach, E.W. (TRANSSC); Magnusson, S. (RASSC); Pather, T. (WASSC); Vaughan, G.J. (NUSSC).

Nuclear Safety Standards Committee

Algeria: Merrouche, D.; *Argentina*: Waldman, R.; *Australia*: Ward, J.; *Austria*: Sholly, S.; *Belgium*: De Boeck, B.; *Brazil*: Gromann, A.; **Bulgaria*: Vlahov, N.; *Canada*: Rzentkowski, G.; *China*: Li, Jingxi; *Croatia*: Medakovič, S.; **Cyprus*: Demetriades, P.; *Czech Republic*: Vesely, J.; *Egypt*: Ibrahim, M.; *Finland*: Järvinen, M.-L.; *France*: Feron, F. (Chairperson); *Germany*: Weidenbrück, K.; **Greece*: Nikolaou, G.; *Hungary*: Adorján, F.; *India*: Vaze, K.; **Indonesia*: Antariksawan, A.; *Iran, Islamic Republic of*: Mataji Kojouri, N.; *Israel*: Harari, R.; *Italy*: Matteocci, L.; *Japan*: Maki, S.; *Korea, Republic of*: Lee, S.; *Libya:* Abulagassem, O.; *Lithuania*: Šlepavičius, S.; *Malaysia*: Azlina Mohammed Jais; *Mexico*: Carrera, A.; *Morocco*: Soufi, I.; *Pakistan*: Mansoor, F.; *Panama*: Gibbs, E.; *Poland*: Kielbasa, W.; *Romania*: Ciurea-Ercau, C.; *Russian Federation*: Stroganov, A.; *Slovakia*: Uhrik, P.; *Slovenia*: Vojnovič, D.; *Spain*: Zarzuela, J.; *Sweden*: Hallman, A.;

Switzerland: Flury, P.; **Thailand*: Siripirom, L.; **Turkey*: Kilinc, B.; *Ukraine*: Gromov, G.; *United Arab Emirates:* Grant, I.; *United Kingdom*: Hart, A; *United States of America*: Case, M.; *European Commission*: Vigne, S.; *ENISS*: Bassing, G.; *IAEA*: Svab, M. (Coordinator); *International Electrotechnical Commission*: Bouard, J.-P.; *International Organization for Standardization*: Sevestre, B.; *OECD Nuclear Energy Agency*: Reig, J.; *World Nuclear Association*: Fröhmel, T.

Radiation Safety Standards Committee

**Algeria*: Chelbani, S.; *Argentina*: Massera, G. (Chairperson), **Gregory, B.; *Australia*: Topfer, H.; **Austria*: Karg, V.; *Belgium*: van Bladel, L.; *Brazil*: Da Hora Marechal, M.H.; **Bulgaria*: Katzarska, L.; *Canada*: Thompson, P.; *China*: Yang, H.; *Croatia*: Kralik, I.; **Cyprus*: Demetriades, P.; *Czech Republic*: Petrova, K.; *Denmark*: Øhlenschlæger, M.; *Egypt*: Hamed Osman, A.; *Finland*: Markkanen, M.; *France*: Godet, J.-L.; *Germany*: Helming, M.; **Greece*: Kamenopoulou, V.; *Hungary*: Koblinger, L.; *India*: Sharma, D.N.; **Indonesia*: Rusdian, Y.; *Iran, Islamic Republic of*: Kardan, M.R.; *Ireland*: Pollard, D.; *Israel*: Koch, J.; *Italy*: Bologna, L.; *Japan*: Nagata, M.; *Korea, Republic of*: Rho, S.; *Libya*: El-Fawaris, B.; *Lithuania*: Mastauskas, A.; *Malaysia*: Mishar, M.; *Mexico*: Delgado Guardado, J.; *Netherlands*: Vermeulen, T.; *New Zealand*: Cotterill, A.; *Norway*: Saxebol, G.; *Pakistan*: Nasim, B.; *Panama*: Gibbs, E.; *Peru*: Ramirez Quijada, R.; *Poland*: Merta, A.; *Romania*: Preoteasa, A.; *Russian Federation*: Mikhenko, S.; *Slovakia*: Jurina, V.; *Slovenia*: Sutej, T.; *South Africa*: Tselane, T.J.; *Spain*: Álvarez, C.; *Sweden*: Hägg, A.; *Switzerland*: Leupin, A.; **Thailand*: Suntarapai, P.; **Turkey*: Celik, P.; *Ukraine*: Pavlenko, T.; *United Arab Emirates*: Loy, J; *United Kingdom*: Temple, C.; *United States of America*: McDermott, B.; *European Commission*: Janssens, A.; *European Nuclear Installation Safety Standards*: Lorenz, B.; *Food and Agriculture Organization of the United Nations*: Byron, D.; *IAEA*: Colgan, P.A. (Coordinator); *International Commission on Radiological Protection*: Clement, C.; *International Labour Office*: Niu, S.; *International Radiation Protection Association*: Kase, K.; *International Organization for Standardization*: Rannou, A.; *International Source Suppliers and Producers Association*: Fasten, W.; *OECD Nuclear Energy Agency*: Lazo, T.E.; *Pan American Health Organization*: Jiménez, P.; *United Nations Scientific Committee on the Effects of Atomic Radiation*: Crick, M.; *World Health Organization*: Peres, M.; *World Nuclear Association*: Saint-Pierre, S.

Transport Safety Standards Committee

Algeria: Herrati, A.; *Argentina*: López Vietri, J.; *Australia*: Sarkar, S.; *Austria*: Kirchnawy, F.; *Belgium*: Lourtie, G.; *Brazil*: Xavier, A.M.; **Bulgaria*: Bakalova, A.; *Canada*: Faille, S.; *China*: Xiaoqing, Li; *Croatia*: Ilijas, B.; **Cyprus*: Demetriades, P.; *Czech Republic*: Ducháček, V.; *Egypt*: Nada, A.; *Finland*: Lahkola, A.; *France*: Kueny, L., **Sert, G.; *Germany*: Richartz, M., **Nitsche, F.; **Greece*: Vogiatzi, S.; *Hungary*: Sáfár, J.; *India*: Singh, K.; **Indonesia*: Sinaga, D.; *Iran, Islamic Republic of*: Eshraghi, A.; *Ireland*: Duffy, J.; *Italy*: Trivelloni, S.; *Japan*: Kojima, S.; *Korea, Republic of*: Cho, D.; *Lithuania*: Statkus, V.; *Malaysia*: Mohd Sobari, M.P.; **Hussain, Z.A.; *Mexico*: Bautista Arteaga, D.M.; **Delgado Guardado, J.L.; **Morocco*: Allach, A.; *Netherlands*: Ter Morshuizen, M.; **New Zealand*: Ardouin, C.; *Norway*: Hornkjøl, S.; *Pakistan*: Muneer, M.; *Panama:* Francis, D.; **Poland*: Dziubiak, T.; *Russian Federation*: Buchelnikov, A., **Ershov, V., **Anikin, A.; *South Africa*: Mohajane, P., **Hinrichsen, P., **Mmutle, N.; *Spain*: Zamora, F.; *Sweden*: Zika, H.; *Switzerland*: Koch, F.; **Thailand*: Jerachanchai, S.; **Turkey*: Türkes Yilmas, S.; *Ukraine*: Kutuzova, T.; *United Kingdom*: Sallit, G.; *United States of America*: Boyle, R.W.; **Brach, E.W. (Chairperson); **Weaver, D.; *European Commission*: Binet, J.; *IAEA*: Stewart, J.T. (Coordinator); *International Air Transport Association*: Brennan, D.; *International Civil Aviation Organization*: Rooney, K.; *International Organization for Standardization*: Malesys, P.; *International Source Supplies and Producers Association*: Miller, J.J.; *United Nations Economic Commission for Europe*: Kervella, O.; *Universal Postal Union*: Bowers, D.G.; *World Nuclear Association*: Gorlin, S.; *World Nuclear Transport Institute*: Neau, H.J.

Waste Safety Standards Committee

**Algeria*: Ghezal, A.; *Argentina*: Lee Gonzales, H.A.; *Australia*: Williams, G. (Chairperson); **Austria*: Fischer, H.; *Belgium*: Blommaert, W.; *Brazil*: De Souza Ferreira, R.; **Bulgaria*: Alexiev, A.; *Canada*: Howard, D.; *China*: Zhimin Qu; *Croatia*: Trifunovic, D.; *Cyprus*: Demetriades, P.; *Czech Republic*: Lietava, P.; *Denmark*: Hannesson, H.; *Egypt*: Abdel-Geleel, M.; *Finland*: Hutri, K.; *France*: Evrard, L.; *Germany*: Götz, C.; **Greece*: Mitrakos, D.; *Hungary*: Molnár, B.; *India*: Rana, D.; **Indonesia*: Wisnubroto, D.; *Iran, Islamic Republic of*: Sebteahmadi, S.; *Iraq*: Al-Janabi, M.; *Israel*: Torgeman, S.; *Italy*: Dionisi, M.; *Japan*: Shiozaki, M.; *Korea, Republic of*: Park, W.-J.; *Libya*: Gremida, K.; *Lithuania*: Paulikas, V.; *Malaysia*: Hassan, H.; *Mexico*: Aguirre Gómez, J.; **Morocco*: Bouanani, A.; *Netherlands*: van der Shaaf, M.; **New Zealand*: Cotterill, A.; *Norway*: Lystad, R.; *Pakistan*: Mannan, A.; *Panama*: Fernández, M.A.; *Poland*:

Skrzeczkowska, M.; *Romania*: Rodna, A.; *Russian Federation*: Polyakov, Y.; *Slovakia*: Homola, J.; *Slovenia*: Kroselj, V.; *South Africa*: Mosoeunyane, S.; *Spain*: López de la Higuera, J.; *Sweden*: Hedberg, B.; *Switzerland*: Altorfer, F.; **Thailand*: Supaokit, P.; **Turkey*: Ünver, Ö.; *Ukraine*: Kondratyev, S.; *United Kingdom*: Chandler, S.; *United States of America*: Camper, L.; *European Nuclear Installation Safety Standards-FORATOM*: Nocture, P.; *European Commission*: Necheva, C.; *IAEA*: Siraky, G. (Coordinator); *International Organization for Standardization*: James, M.; *International Source Suppliers and Producers Association*: Fasten, W.; *OECD Nuclear Energy Agency*: Riotte, H.; *World Nuclear Association*: Saint-Pierre, S.

This publication has been superseded by SSG-15 (Rev. 1).

IAEA
International Atomic Energy Agency

No. 22

Where to order IAEA publications

In the following countries IAEA publications may be purchased from the sources listed below, or from major local booksellers. Payment may be made in local currency or with UNESCO coupons.

AUSTRALIA
DA Information Services, 648 Whitehorse Road, MITCHAM 3132
Telephone: +61 3 9210 7777 • Fax: +61 3 9210 7788
Email: service@dadirect.com.au • Web site: http://www.dadirect.com.au

BELGIUM
Jean de Lannoy, avenue du Roi 202, B-1190 Brussels
Telephone: +32 2 538 43 08 • Fax: +32 2 538 08 41
Email: jean.de.lannoy@infoboard.be • Web site: http://www.jean-de-lannoy.be

CANADA
Bernan Associates, 4501 Forbes Blvd, Suite 200, Lanham, MD 20706-4346, USA
Telephone: 1-800-865-3457 • Fax: 1-800-865-3450
Email: customercare@bernan.com • Web site: http://www.bernan.com

Renouf Publishing Company Ltd., 1-5369 Canotek Rd., Ottawa, Ontario, K1J 9J3
Telephone: +613 745 2665 • Fax: +613 745 7660
Email: order.dept@renoufbooks.com • Web site: http://www.renoufbooks.com

CHINA
IAEA Publications in Chinese: China Nuclear Energy Industry Corporation, Translation Section, P.O. Box 2103, Beijing

CZECH REPUBLIC
Suweco CZ, S.R.O., Klecakova 347, 180 21 Praha 9
Telephone: +420 26603 5364 • Fax: +420 28482 1646
Email: nakup@suweco.cz • Web site: http://www.suweco.cz

FINLAND
Akateeminen Kirjakauppa, PO BOX 128 (Keskuskatu 1), FIN-00101 Helsinki
Telephone: +358 9 121 41 • Fax: +358 9 121 4450
Email: akatilaus@akateeminen.com • Web site: http://www.akateeminen.com

FRANCE
Form-Edit, 5, rue Janssen, P.O. Box 25, F-75921 Paris Cedex 19
Telephone: +33 1 42 01 49 49 • Fax: +33 1 42 01 90 90
Email: formedit@formedit.fr • Web site: http://www. formedit.fr

Lavoisier SAS, 145 rue de Provigny, 94236 Cachan Cedex
Telephone: + 33 1 47 40 67 02 • Fax +33 1 47 40 67 02
Email: romuald.verrier@lavoisier.fr • Web site: http://www.lavoisier.fr

GERMANY
UNO-Verlag, Vertriebs- und Verlags GmbH, Am Hofgarten 10, D-53113 Bonn
Telephone: + 49 228 94 90 20 • Fax: +49 228 94 90 20 or +49 228 94 90 222
Email: bestellung@uno-verlag.de • Web site: http://www.uno-verlag.de

HUNGARY
Librotrade Ltd., Book Import, P.O. Box 126, H-1656 Budapest
Telephone: +36 1 257 7777 • Fax: +36 1 257 7472 • Email: books@librotrade.hu

INDIA
Allied Publishers Group, 1st Floor, Dubash House, 15, J. N. Heredia Marg, Ballard Estate, Mumbai 400 001,
Telephone: +91 22 22617926/27 • Fax: +91 22 22617928
Email: alliedpl@vsnl.com • Web site: http://www.alliedpublishers.com

Bookwell, 2/72, Nirankari Colony, Delhi 110009
Telephone: +91 11 23268786, +91 11 23257264 • Fax: +91 11 23281315
Email: bookwell@vsnl.net

ITALY
Libreria Scientifica Dott. Lucio di Biasio “AEIOU”, Via Coronelli 6, I-20146 Milan
Telephone: +39 02 48 95 45 52 or 48 95 45 62 • Fax: +39 02 48 95 45 48
Email: info@libreriaaeiou.eu • Website: www.libreriaaeiou.eu

JAPAN
Maruzen Company, Ltd., 13-6 Nihonbashi, 3 chome, Chuo-ku, Tokyo 103-0027
Telephone: +81 3 3275 8582 • Fax: +81 3 3275 9072
Email: journal@maruzen.co.jp • Web site: http://www.maruzen.co.jp

REPUBLIC OF KOREA
KINS Inc., Information Business Dept. Samho Bldg. 2nd Floor, 275-1 Yang Jae-dong SeoCho-G, Seoul 137-130
Telephone: +02 589 1740 • Fax: +02 589 1746 • Web site: http://www.kins.re.kr

NETHERLANDS
De Lindeboom Internationale Publicaties B.V., M.A. de Ruyterstraat 20A, NL-7482 BZ Haaksbergen
Telephone: +31 (0) 53 5740004 • Fax: +31 (0) 53 5729296
Email: books@delindeboom.com • Web site: http://www.delindeboom.com

Martinus Nijhoff International, Koraalrood 50, P.O. Box 1853, 2700 CZ Zoetermeer
Telephone: +31 793 684 400 • Fax: +31 793 615 698
Email: info@nijhoff.nl • Web site: http://www.nijhoff.nl

Swets and Zeitlinger b.v., P.O. Box 830, 2160 SZ Lisse
Telephone: +31 252 435 111 • Fax: +31 252 415 888
Email: infoho@swets.nl • Web site: http://www.swets.nl

NEW ZEALAND
DA Information Services, 648 Whitehorse Road, MITCHAM 3132, Australia
Telephone: +61 3 9210 7777 • Fax: +61 3 9210 7788
Email: service@dadirect.com.au • Web site: http://www.dadirect.com.au

SLOVENIA
Cankarjeva Zalozba d.d., Kopitarjeva 2, SI-1512 Ljubljana
Telephone: +386 1 432 31 44 • Fax: +386 1 230 14 35
Email: import.books@cankarjeva-z.si • Web site: http://www.cankarjeva-z.si/uvoz

SPAIN
Díaz de Santos, S.A., c/ Juan Bravo, 3A, E-28006 Madrid
Telephone: +34 91 781 94 80 • Fax: +34 91 575 55 63
Email: compras@diazdesantos.es, carmela@diazdesantos.es, barcelona@diazdesantos.es, julio@diazdesantos.es
Web site: http://www.diazdesantos.es

UNITED KINGDOM
The Stationery Office Ltd, International Sales Agency, PO Box 29, Norwich, NR3 1 GN
Telephone (orders): +44 870 600 5552 • (enquiries): +44 207 873 8372 • Fax: +44 207 873 8203
Email (orders): book.orders@tso.co.uk • (enquiries): book.enquiries@tso.co.uk • Web site: http://www.tso.co.uk

On-line orders
DELTA Int. Book Wholesalers Ltd., 39 Alexandra Road, Addlestone, Surrey, KT15 2PQ
Email: info@profbooks.com • Web site: http://www.profbooks.com

Books on the Environment
Earthprint Ltd., P.O. Box 119, Stevenage SG1 4TP
Telephone: +44 1438748111 • Fax: +44 1438748844
Email: orders@earthprint.com • Web site: http://www.earthprint.com

UNITED NATIONS
Dept. I004, Room DC2-0853, First Avenue at 46th Street, New York, N.Y. 10017, USA
(UN) Telephone: +800 253-9646 or +212 963-8302 • Fax: +212 963-3489
Email: publications@un.org • Web site: http://www.un.org

UNITED STATES OF AMERICA
Bernan Associates, 4501 Forbes Blvd., Suite 200, Lanham, MD 20706-4346
Telephone: 1-800-865-3457 • Fax: 1-800-865-3450
Email: customercare@bernan.com · Web site: http://www.bernan.com

Renouf Publishing Company Ltd., 812 Proctor Ave., Ogdensburg, NY, 13669
Telephone: +888 551 7470 (toll-free) • Fax: +888 568 8546 (toll-free)
Email: order.dept@renoufbooks.com • Web site: http://www.renoufbooks.com

Orders and requests for information may also be addressed directly to:

Marketing and Sales Unit, International Atomic Energy Agency
Vienna International Centre, PO Box 100, 1400 Vienna, Austria
Telephone: +43 1 2600 22529 (or 22530) • Fax: +43 1 2600 29302
Email: sales.publications@iaea.org • Web site: http://www.iaea.org/books

11-27601

RELATED PUBLICATIONS

FUNDAMENTAL SAFETY PRINCIPLES
IAEA Safety Standards Series No. SF-1
STI/PUB/1273 (37 pp.; 2006)
ISBN 92–0–110706–4 Price: €25.00

GOVERNMENTAL, LEGAL AND REGULATORY FRAMEWORK FOR SAFETY
IAEA Safety Standards Series No. GSR Part 1
STI/PUB/1465 (63 pp.; 2010)
ISBN 978–92–0–106410–3 Price: €45.00

THE MANAGEMENT SYSTEM FOR FACILITIES AND ACTIVITIES
IAEA Safety Standards Series No. GS-R-3
STI/PUB/1252 (39 pp.; 2006)
ISBN 92–0–106506–X Price: €25.00

RADIATION PROTECTION AND SAFETY OF RADIATION SOURCES: INTERNATIONAL BASIC SAFETY STANDARDS: INTERIM EDITION
IAEA Safety Standards Series No. GSR Part 3 (Interim)
STI/PUB/1531 (142 pp.; 2011)
ISBN 978–92–0–120910–8 Price: €65.00

SAFETY ASSESSMENT FOR FACILITIES AND ACTIVITIES
IAEA Safety Standards Series No. GSR Part 4
STI/PUB/1375 (56 pp.; 2009)
ISBN 978–92–0–112808–9 Price: €48.00

PREDISPOSAL MANAGEMENT OF RADIOACTIVE WASTE
IAEA Safety Standards Series No. GSR Part 5
STI/PUB/1368 (38 pp.; 2009)
ISBN 978–92–0–111508–9 Price: €45.00

DECOMMISSIONING OF FACILITIES USING RADIOACTIVE MATERIAL
IAEA Safety Standards Series No. WS-R-5
STI/PUB/1274 (25 pp.; 2006)
ISBN 92–0–110906–7 Price: €25.00

REMEDIATION OF AREAS CONTAMINATED BY PAST ACTIVITIES AND ACCIDENTS
IAEA Safety Standards Series No. WS-R-3
STI/PUB/1176 (21 pp.; 2003)
ISBN 92–0–112303–5 Price: €15.00

PREPAREDNESS AND RESPONSE FOR A NUCLEAR OR RADIOLOGICAL EMERGENCY
IAEA Safety Standards Series No. GS-R-2
STI/PUB/1133 (72 pp.; 2002)
ISBN 92–0–116702–4 Price: €20.50

Safety through international standards

"Governments, regulatory bodies and operators everywhere must ensure that nuclear material and radiation sources are used beneficially, safely and ethically. The IAEA safety standards are designed to facilitate this, and I encourage all Member States to make use of them."

Yukiya Amano
Director General

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA
ISBN 978–92–0–115110–0
ISSN 1020–525X