This publication has been superseded by SSR-4

IAEA Safety Standards

for protecting people and the environment

Safety of Nuclear Fuel Cycle Facilities

Safety Requirements

No. NS-R-5 (Rev. 1)

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 on 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: Vienna International Centre, 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 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 **Emergency Preparedness and Response** publications, **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** comprises informational publications to encourage and assist research on, and the development and practical application of, nuclear energy for peaceful purposes. It includes reports and guides on the status of and advances in technology, and on experience, good practices and practical examples in the areas of nuclear power, the nuclear fuel cycle, radioactive waste management and decommissioning.

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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".

This publication has been superseded by SSR-4

IAEA SAFETY STANDARDS SERIES No. NS-R-5 (Rev. 1)

SAFETY OF NUCLEAR FUEL CYCLE FACILITIES

SAFETY REQUIREMENTS

This Safety Requirements publication includes
a CD-ROM containing the IAEA Safety Glossary:
2007 Edition (2007) and the Fundamental Safety Principles (2006),
each in English, Arabic, Chinese, French, Russian and Spanish versions.
The CD-ROM is also available for purchase separately.
See: http://www-pub.iaea.org/MTCD/publications/publications.asp

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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 specialized 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.

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

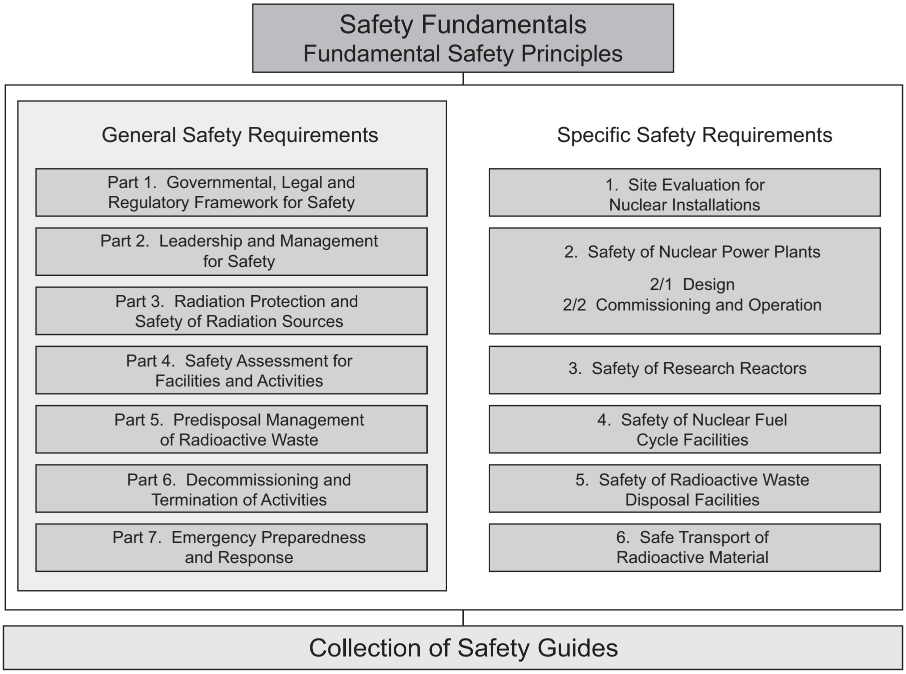

FIG. 1. The long term structure of the IAEA Safety Standards Series.

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 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

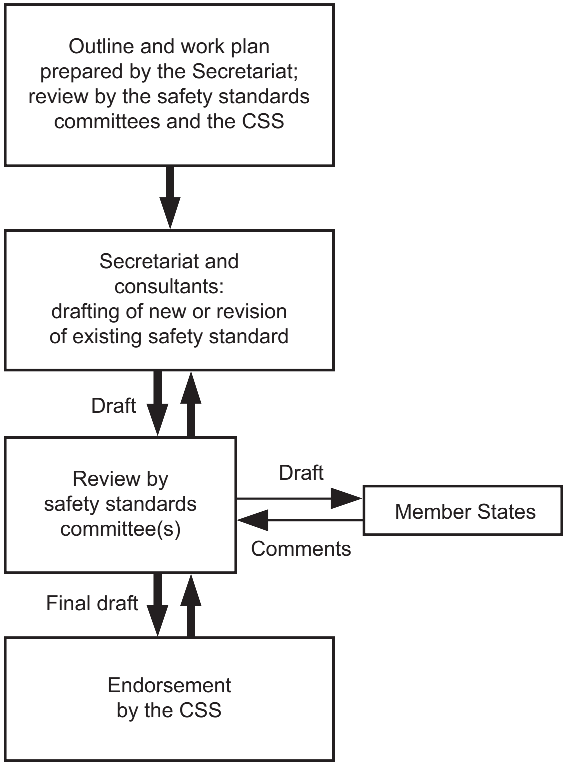

FIG. 2. The process for developing a new safety standard or revising an existing standard.

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 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. In nuclear fuel cycle facilities, nuclear material and radioactive material are used, stored and disposed of, in quantities or concentrations that pose potential hazards to workers, the public and the environment. Facilities in the nuclear fuel cycle include reactors, and facilities for mining, processing, refining, conversion, enrichment and fabrication of fuel (including mixed oxide (MOX) fuel), spent fuel storage, reprocessing, associated waste conditioning and storage, related research and development, and waste disposal. Reactors, mining facilities and waste disposal facilities are not considered here, and for the purposes of this publication the term ‘fuel cycle facility’ or ‘facility’ includes only facilities for processing, refining, conversion, enrichment and fabrication of fuel (including MOX fuel), spent fuel storage, reprocessing and associated waste conditioning and storage, and research and development.

1.2. Fuel cycle facilities employ many diverse technologies and processes. Radioactive material is often processed through a series of interconnected units and consequently can be found throughout the entire facility. The physical and chemical forms of the processed material may also vary within a single facility. Some of the processes use large quantities of hazardous chemical substances and gases, which may be toxic, corrosive, combustible, reactive (i.e. give rise to exothermic reactions) or explosive, and consequently may give rise to the need for specific safety requirements in addition to requirements for nuclear safety. A further specific feature of fuel cycle facilities is that they are often characterized by frequent changes in the mode of operation, and in equipment and processes. This can be necessitated by new production campaigns or product development, ongoing research and development, and continuous improvement. Operations at large fuel cycle facilities generally require more operator intervention than those at nuclear power plants or research reactors. This may result in specific hazards to the workforce. In addition, the nature and diversity of the processes associated with the facilities result in a broad range of hazardous conditions and possible events that need to be considered in the safety analysis.

1.3. The principles that must be met to ensure safety in nuclear installations are presented in the Fundamental Safety Principles [1]. The safety requirements for fuel cycle facilities, as presented in this publication, are based on, and are established to apply, these principles.

OBJECTIVE

1.4. The objective of this publication is to establish requirements that, in the light of experience and the present state of technology, must be satisfied to ensure safety, for all stages in the lifetime of a nuclear fuel cycle facility, i.e. its siting, design, construction, commissioning, operation and decommissioning. This publication is intended to be used by designers, operating organizations and regulators for ensuring the safety of fuel cycle facilities.

1.5. A number of the safety requirements for fuel cycle facilities are similar to those that have been established for nuclear power plants. In view of the specificities addressed in para. 1.2, and the broad diversity of installations and operations covered, the requirements established in this publication are to be applied in a manner that is commensurate with the potential hazards for each facility, i.e. using a graded approach to ensure that the safety of the facility is adequate throughout its entire lifetime.

1.6. This Safety Requirements publication establishes the safety requirements to be met for ensuring safety. It must be used in conjunction with the IAEA Safety Guides that provide recommendations on ways of meeting the safety requirements for processing and refining, conversion and enrichment, uranium fuel fabrication, MOX fuel fabrication, spent fuel storage, reprocessing, waste conditioning and storage, and research and development facilities. In addition, some requirements that are specific to these different types of fuel cycle facility are established in the appendices to this publication (see para. 1.15).

SCOPE

1.7. This Safety Requirements publication applies to processing, refining, conversion, enrichment, fabrication of fuel (including MOX fuel), spent fuel storage, spent fuel reprocessing, waste conditioning and storage, and fuel cycle research and development facilities.

1.8. The requirements established in this publication are applicable to new fuel cycle facilities and may be applied to existing fuel cycle facilities, as appropriate. The requirements might not be fully met at some facilities built to earlier standards. The way in which the requirements are to be applied to such facilities is a matter for the individual States.

1.9. The safety of fuel cycle facilities is ensured by means of their proper siting, design, construction, commissioning, operation and decommissioning. In this publication, emphasis is placed on the safety aspects of design and operation.

1.10. Fuel cycle facilities generate radioactive waste that requires appropriate and systematic management arrangements. The corresponding safety principles are stated in Ref. [1], and the requirements for predisposal management are established in Ref. [2].

1.11. The safety requirements for installations for the predisposal management of radioactive waste (i.e. waste treatment and storage facilities) are addressed in Ref. [2]. More detailed safety requirements are presented in this publication.

1.12. The detailed requirements for emergency response are established in Ref. [3].

1.13. The requirements for the safe transport of radioactive material or fissile material arriving at, or leaving from, fuel cycle facilities are established in Ref. [4].

1.14. The implementation of the safety requirements for any fuel cycle facility shall be commensurate with its potential hazards (the ‘graded approach’). The facility type and the following facility specific attributes shall be taken into account:

(a) The nature and the physical and chemical forms of the radioactive materials that are used, processed and stored at the facility;
(b) The scale of operations undertaken at the facility (i.e. the ‘throughput’ of the facility) and the inventory of hazardous material, including products and waste in storage;
(c) The processes, technologies and hazardous chemicals that are used;
(d) The available routes for the disposal of effluents and the storage of radioactive waste.

STRUCTURE

1.15. This publication consists of ten sections, five appendices and three annexes. Section 2 covers the general safety objective and safety principles for fuel cycle facilities, with emphasis on the radiological and nuclear safety aspects. Section 3 addresses the regulatory supervision aspects. Section 4 deals with the management and verification of safety by the operating organization. Sections 5–10 contain specific requirements applicable to the stages of a fuel cycle facility, considering in turn siting, design, construction, commissioning, operation and decommissioning. Appendices I–V establish additional safety requirements specific to uranium fuel fabrication facilities, MOX fuel fabrication facilities, conversion facilities and uranium enrichment facilities, reprocessing facilities, and fuel cycle research and development facilities, respectively. Annex I provides a list of postulated initiating events. Annex II deals with the availability and reliability principles to be applied in fuel cycle facilities. Finally, Annex III addresses the safety approach to be applied in the design of fuel cycle facilities.

2. THE SAFETY OBJECTIVE, CONCEPTS AND SAFETY PRINCIPLES

SAFETY OBJECTIVE

2.1. The Fundamental Safety Principles [1] state that "the fundamental safety objective is to protect people and the environment from harmful effects of ionizing radiation."

2.2. To achieve this safety objective:

> "measures have to be taken:
>
> (a) To control the radiation exposure of people and the release of radioactive material to the environment;
> (b) To restrict the likelihood of events that might lead to a loss of control over … source[s] of radiation;
> (c) To mitigate the consequences of such events if they were to occur" [1].

In the context of fuel cycle facilities, the control of events initiated by chemical hazards can have a significant bearing on achieving the fundamental safety objective. Events initiated by chemical hazards shall be considered in the design, commissioning and operation of the facility. Activities at fuel cycle facilities may also include industrial processes that pose additional hazards to site personnel and the environment. Purely industrial hazards are outside the scope of this publication, but they shall be considered by the operating organization. Guidance relating to the management of specific chemical hazards may be found in the

IAEA Safety Guides associated with this publication or in chemical industry standards.

SAFETY PRINCIPLES

2.3. The ten safety principles established in Ref. [1] apply to fuel cycle facilities, existing and new, throughout their entire lifetime. These principles provide the basis for the requirements for the safety of these facilities.

DEFENCE IN DEPTH

2.4. The concept of defence in depth shall be applied at the facility for the prevention and mitigation of accidents (Principle 8 of Ref. [1]). Defence in depth is the application of multiple levels of protection for all relevant safety activities, whether organizational, behavioural or equipment related [5, 6]. Application of the concept of defence in depth throughout the design and operation of a fuel cycle facility provides multilayer protection against a wide range of anticipated operational occurrences[1] and accident conditions, including those resulting from equipment failure or human error within the facility, and from events that originate outside the facility.

2.5. The strategy for defence in depth shall be twofold: first, to prevent accidents, and second, if prevention fails, to limit the potential radiological and associated chemical consequences and to prevent any evolution to more serious conditions. Defence in depth is generally structured in five different levels, as set out in Table 1, which is adapted from Ref. [5]. If one level fails, the subsequent level comes into play.

2.6. The design features, controls and arrangements necessary to implement the defence in depth concept shall be identified mainly by means of a deterministic analysis (which may be complemented by probabilistic studies) of the design and operational regime. The analysis shall be justified by the application of sound engineering practices based on research and operational experience. This analysis, which is usually called a safety analysis, shall be carried out during the design stage to ensure that the regulatory requirements can be met.

[1] Anticipated operational occurrences: see Annex III, para. III–12.

TABLE 1. LEVELS OF DEFENCE IN DEPTH

Level	Objective	Essential means
Level 1	Prevention of abnormal operation and failures	Conservative design and high quality in construction, commissioning[a] and operation (including management aspects)
Level 2	Control of abnormal operation and detection of failures	Control, limiting and protective barriers and systems, and other surveillance features
Level 3	Control of accidents within the design basis	Engineered safety features and accident procedures
Level 4	Control of accident conditions beyond the design basis, including prevention of accident progression and mitigation of the consequences of such accident conditions	Complementary measures and accident management[b]
Level 5	Mitigation of radiological consequences of significant releases of radioactive materials	On-site and off-site emergency response

[a] In the context of fuel cycle facilities, commissioning is the process by means of which systems and components, having been constructed, are made operational and verified to be in accordance with the design and to have met the required performance criteria. Commissioning may include both non-nuclear and/or non-radioactive and nuclear and/or radioactive testing.

[b] In the context of fuel cycle facilities, accident management is the taking of a set of actions during the evolution of a beyond design basis accident: to prevent the escalation of the event into a more severe accident; to mitigate the consequences of such beyond design basis accidents; and to achieve a long term safe and stable state.

2.7. Defence in depth shall be implemented by taking into account the graded approach as described in Section 1. The amount and type of radioactive material present, the potential for dispersion, the potential for nuclear, chemical or thermal reactions, and the kinetics of such events shall all be considered in determining the required number and strength of lines of defence.

2.8. The degree of application of each level of defence in depth shall be commensurate with the potential hazards of the facility and shall be established in the facility's licensing documentation.

LICENSING DOCUMENTATION

2.9. The operating organization shall establish and justify the safety of its facility through a set of documents known as the 'licensing documentation' (or 'safety case').[2] The licensing documentation shall provide the basis for the safe siting, construction, commissioning, operation and decommissioning of the facility, including the justification for changes. The licensing documentation shall be considered in determining whether the authorizations necessary under national legislative requirements are to be granted, and thus it forms an important link between the operating organization and the regulatory body.

2.10. The content of the licensing documentation for a facility may vary between States but at least the safety analysis report and the operational limits and conditions or equivalent shall be included. Consideration of the application of the principle of optimization of protection (Principle 5 of Ref. [1]) in the design and operation of the facility shall be included in the licensing documentation.

2.11. The safety analysis report shall provide a detailed demonstration of the safety of the facility. It shall give a detailed description of those aspects having safety significance, such as information on the input feed and the products of the facility and the corresponding limits (e.g. limits on burnup and enrichment), and it shall discuss the application of the safety principles and criteria in the design for the protection of operating personnel, the public and the environment. The safety analysis report shall contain an analysis of the hazards associated with the operation of the facility and shall demonstrate compliance with the regulatory requirements and criteria. It shall also contain safety analyses of accident sequences and of the safety features incorporated in the design for preventing accidents or minimizing the likelihood of their occurrence and for mitigating their consequences.

2.12. The safety functions and the structures, systems and components (SSCs) important to safety shall be identified in the safety analysis report to the extent appropriate and in accordance with a graded approach. The SSCs important to safety provide means for the prevention of the occurrence of postulated initiating events, the control and limitation of accident sequences, and mitigation of the consequences.

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[2] In the context of fuel cycle facilities, the licensing documentation (or safety case) is a collection of arguments and evidence in support of the safety of a facility or activity. This will normally include the findings of a safety assessment and a statement of confidence in these findings.

2.13. The operational limits and conditions are the set of rules that establish parameter limits, the functional capability and the performance levels of equipment and personnel for the safe operation of a facility.

2.14. The licensing documentation shall also define the required intervals for periodic testing and inspection of SSCs important to safety.

2.15. The licensing documentation shall be maintained and updated during the operational lifetime of the facility on the basis of the experience and knowledge gained and in accordance with the regulatory requirements, with account taken of modifications[3] to the facility.

3. LEGAL FRAMEWORK AND REGULATORY SUPERVISION

GENERAL

3.1. This section outlines requirements relating to general aspects of the legal and governmental infrastructure for the safety of fuel cycle facilities. Further general requirements are established in Ref. [7]. Guidance on the application of the requirements in Ref. [7] is provided in the IAEA Safety Guides associated with that publication (Refs [8–11]).

LEGAL FRAMEWORK

3.2. The government shall ensure that an adequate legal framework and regulatory basis are available for ensuring the safety of a facility and assessing its safety implications. The government shall adopt legislation that assigns the prime responsibility for safety to the operating organization. Legislation shall be enacted to provide for the establishment of a regulatory body that is effectively independent of organizations or bodies charged with the promotion of nuclear technologies or responsible for facilities or activities. The regulatory body

[3] In the context of this publication, a modification is a deliberate change in or an addition to the existing facility configuration, with potential safety implications, intended for continuation of the facility's operation. It may involve safety systems, safety related items or systems, procedures, documentation or operating conditions.

shall be structured and resourced in a manner commensurate with the potential magnitude and nature of the hazard to be controlled. The government shall make arrangements to ensure that the regulatory body is adequately funded to fulfil the national safety requirements and legislative requirements assigned to it.

3.3. Safety, health and environment related regulatory requirements are influenced by industrial, chemical and toxic hazards in addition to the radiological hazards. The government shall ensure cooperation with and between the relevant authorities where nuclear, environmental, industrial safety and occupational health aspects are separately regulated. The construction, adjacent to a facility site, of installations that could prejudice the safety of the facility shall be monitored and controlled by means of planning requirements for land use.

REGULATORY BODY

3.4. To be effective, the regulatory body shall be provided with the legal powers and statutory authority necessary to ensure that it can discharge its responsibilities and perform its functions. Such powers normally include the authority to review and assess safety information submitted by the operating organization in the authorization process and to administer the relevant regulations, including carrying out regulatory inspections and audits for compliance with the regulations, taking enforcement actions, and providing information to other competent authorities and to the public, as appropriate.

3.5. **“The regulatory body shall establish or adopt regulations and guides to specify the principles, requirements and associated criteria for safety upon which its regulatory judgements are based”** (Ref. [7], Requirement 32). These principles, requirements and criteria shall set targets and limits on the radiological consequences for the workforce, members of the public and the environment.

AUTHORIZATION PROCESS

3.6. Every project for a new fuel cycle facility shall follow an authorization process that comprehensively addresses all safety aspects.

3.7. The authorization steps and procedures may vary among States. This authorization can be a step by step process starting at the site planning and feasibility study stage and continuing up to and including the decommissioning of the facility. Alternatively, the authorization can be granted for the entire project, but conditions may need to be attached in order to apply control in subsequent stages.

3.8. An authorization from the regulatory body, which shall take the form of a licence, is required by the operating organization of any fuel cycle facility before taking into its possession or processing any radioactive substances (Ref. [12], Requirement 7).

3.9. Irrespective of the differences between national practices, a detailed demonstration of safety in the form of licensing documentation (see paras 2.9–2.15 of this publication) shall be submitted by the operating organization, and shall be reviewed and assessed by the regulatory body before progress of the project to the next stage is authorized. The degree of scrutiny and assessment maintained by the regulatory body shall be commensurate with its judgement of the degree of potential hazards posed by the facility.

3.10. The regulatory body shall ensure that the operating organization has made adequate arrangements for keeping the licensing documentation up to date throughout the lifetime of the facility so as to reflect the current status of the experience and knowledge gained of the facility and in accordance with the regulatory requirements. The regulatory body shall also ensure that the licensing documentation includes adequate references to supporting documents and that the operating organization maintains the reference material readily available for presentation upon request. In addition, the operating organization shall not limit or prevent adequate review and assessment by classifying the reference material.

REGULATORY INSPECTION AND ENFORCEMENT

3.11. The regulatory body shall establish a planned and systematic programme of regulatory inspection (including provisions for unannounced regulatory inspections as necessary). The scope and frequency of the regulatory inspections under this programme shall be commensurate with the potential hazards posed by the facility.

3.12. In addition to ensuring compliance with safety requirements, the programme shall take into account issues such as the safety culture of the operating organization, the adequacy of its resources (including the size of the workforce), the use of contractors and the arrangements put in place to ensure that workers are suitably qualified and experienced to perform their safety related tasks.

4. THE MANAGEMENT SYSTEM AND VERIFICATION OF SAFETY

GENERAL

4.1. To fulfil its prime responsibility for safety throughout the lifetime of a fuel cycle facility, the operating organization shall establish, implement, assess and continually improve a management system that integrates safety, health, environmental, security, quality and economic elements to ensure that safety is properly taken into account in all the activities of an organization. Requirements for the management system are established in Ref. [13].

4.2. The operating organization:

(a) Shall establish and implement safety, health and environmental policies in accordance with national and international standards and shall ensure that these matters are given the highest priority;
(b) Shall establish an organizational structure to enable these policies to be carried out with a clear definition of responsibilities and accountabilities, lines of authority and lines of communication;
(c) Shall specify and implement a management system covering all stages of the facility's lifetime;
(d) Shall develop and maintain an effective safety culture;
(e) Shall prepare accident management procedures and on-site emergency plans (in accordance with the hazard potential);
(f) Shall perform a safety assessment of the facility;
(g) Shall design and implement the physical protection of the facility.

4.3. The key aspects of each of these safety requirements are discussed in the following subsections. They are considered in terms of the main arrangements and procedures necessary for achieving and maintaining an effective organization. Arrangements specific to siting, construction, commissioning, operation and decommissioning are addressed in the corresponding sections of this publication.

4.4. The operating organization shall allocate suitable financial resources to fulfil its prime responsibility for safety and to implement these foregoing safety requirements.

4.5. The operating organization may delegate to other organizations work necessary for discharging its responsibilities, in accordance with the regulatory requirements, but the overall responsibility and control shall be retained by the operating organization.

SAFETY, HEALTH AND ENVIRONMENTAL POLICIES

4.6. An essential step in setting the necessary standards for the health and safety of operating personnel and the public and for the protection of the environment are the statements by the operating organization of its safety, health and environmental policies. These policy statements shall be provided to staff as a declaration of the organization's objectives and the public commitment of corporate management. To put these policies into effect, the operating organization shall also specify and put in place organizational structures, standards and management arrangements capable of meeting the organization's objectives and public commitments under the policy.

ORGANIZATIONAL PROVISIONS

4.7. The operating organization shall clearly specify the responsibilities and accountabilities of all staff involved in conducting or controlling operations that affect safety. The person with the responsibility for direct supervision shall be clearly identified at all times. This applies throughout the lifetime of the facility, from its siting to its decommissioning.

4.8. The management structure shall define clear lines of communication and shall provide the necessary infrastructure for facility operations to be conducted safely.

4.9. The operating organization shall maintain the capability in terms of staffing, skills, experience and knowledge to undertake competently all activities throughout the lifetime of the facility, from its siting to decommissioning. Where the resources and skills necessary to fulfil any part of these undertakings are provided by an external organization, the operating organization shall nevertheless retain within its organization the capability to assess the adequacy of the external organization's capabilities for ensuring safety.

4.10. The operating organization shall specify the necessary qualifications and experience for all staff involved in activities that may affect safety. It shall also specify appropriate requirements on training and its assessment and approval. The operating organization shall additionally ensure that the qualifications and training of contractors are adequate for the activities to be performed and that adequate control and supervision are in place. Records of the training provided to staff or to contractors shall be maintained.

MANAGEMENT SYSTEM PROCESSES[4]

4.11. The operating organization shall establish and implement generic processes in a management system [13, 14] aligned with internationally recognized standards, for ensuring facility safety by providing necessary assurance that the siting, design, construction, commissioning, operational and decommissioning requirements are defined and executed in accordance with the necessary standards and degree of rigour.

4.12. From the outset, the design process shall be developed, managed and, as necessary, modified to achieve a safe design of the facility.

4.13. Throughout all stages in the lifetime of the fuel cycle facility, safety related work (including that of contractors) shall be planned and performed in accordance with established codes, standards, specifications, practices and administrative controls. Items and services important to safety shall be identified and controlled to ensure their proper use.

4.14. To ensure that all items and services important to safety under procurement meet established requirements and perform as specified, such items and services shall be subject to an appropriate management system. Suppliers shall be evaluated and selected by the operating organization on the basis of specified criteria. Requirements on reporting deviations from procurement specifications and on corrective actions shall be specified in the procurement documents. Evidence that purchased items and services meet procurement specifications shall be available before they are used.

4.15. The use of computer codes for the safety justification of the facility, and their verification and validation (e.g. tests and experiments), shall be subject to the management system.

[4] The term ‘management system’ has been adopted in Refs [13, 14] instead of the term ‘quality assurance’. The term ‘management system’ includes all aspects of the management of a nuclear facility, such as a fuel cycle facility, and brings the safety, health, environment and quality assurance related requirements together in one integrated system.

4.16. Where the facility generates products, including waste products, any safety implications of these products shall also be covered by the management system.

SAFETY CULTURE[5]

4.17. Fuel cycle facilities may require special considerations to achieve high safety, health and environmental standards by virtue of their size and the number of their staff, the distribution and the movement of radioactive material and other hazardous material throughout the installation, the frequent changes in operations, and the reliance on operator action in normal operation. The awareness by individuals of safety matters and the commitment of individuals to safety are therefore essential. The operating organization shall adopt and implement the necessary principles and processes to achieve an effective safety culture [15].

4.18. The operating organization shall address the major components of safety culture as illustrated in Fig. 1 [15].

4.19. The operating organization shall report incidents significant to safety to the regulatory body in a timely manner.

ACCIDENT MANAGEMENT AND EMERGENCY PREPAREDNESS

4.20. The prevention of accidents is the first priority for safety of the operating organization. Nevertheless, as there can be no guarantee that measures to prevent accidents will always be totally successful, the operating organization and the regulatory body have to make preparations to deal with accidents. Requirements for emergency preparedness and response are established in Ref. [3].

4.21. The operating organization shall prepare accident management procedures and on-site emergency procedures, taking into account the potential hazards of the facility, before the introduction of hazardous material. Where necessary, in accordance with the degree of the hazards, the operating organization shall prepare off-site procedures in coordination with the relevant off-site organizations

[5] "The attitudes of individuals are greatly influenced by their working environment. The key to an effective Safety Culture in individuals is found in the practices moulding the environment and fostering attitudes conducive to safety. It is the responsibility of managers to institute such practices in accordance with their organization's safety policy and objectives" (Ref. [15], para. 35).

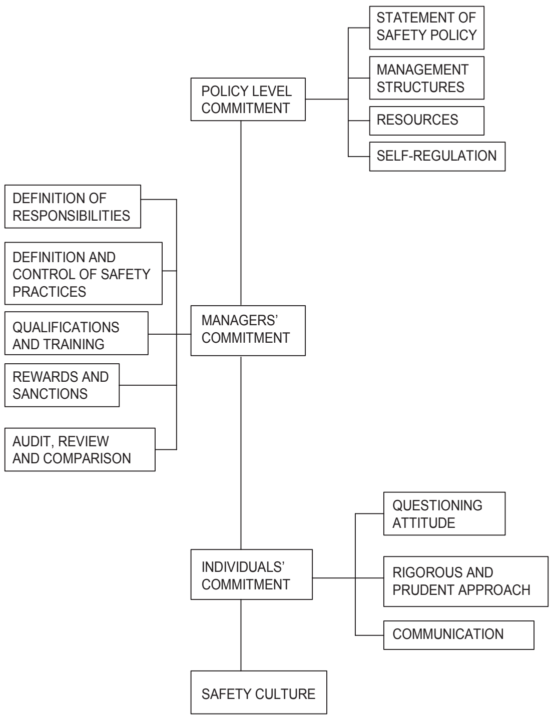

FIG. 1. Illustration of the presentation of safety culture (see Ref. [15], fig. 1; explanatory text in Ref. [14]).

and competent authorities. The off-site procedures shall be consistent with national and international practices.

4.22. Periodic exercises for on-site and off-site emergencies shall be carried out to the extent necessary to ensure the preparedness of the responsible organizations.

4.23. When necessary, the emergency procedures shall be updated on the basis of the lessons learned from these exercises.

VERIFICATION OF SAFETY

4.24. The operating organization shall be responsible for verifying the safety of the facility at all times. It shall establish or shall have access to an appropriate capability for safety analysis for ensuring that the necessary justifications are generated and maintained throughout the lifetime of the facility. It shall ensure that events that are significant to safety are reviewed in depth and that, when necessary to prevent the recurrence of accidents, equipment is modified, procedures are revised, qualifications of personnel are reassessed and training is updated and provided.

4.25. When available, information about incidents and events at other installations of the same type as the facility shall also be investigated and the lessons learned shall be considered.

4.26. In accordance with the national regulatory requirements, the operating organization shall carry out periodic safety reviews to confirm that the licensing documentation remains valid and that modifications made to the facility, as well as changes in its operating arrangements or utilization, have been accurately reflected in the licensing documentation. In conducting these reviews, the operating organization shall expressly consider the cumulative effects of changes to procedures, modifications to the facility and the operating organization, technical developments, operating experience and ageing.

PHYSICAL PROTECTION

4.27. Appropriate measures shall be taken, in accordance with national laws and regulations, to prevent unauthorized actions, including acts of sabotage, that could jeopardize safety at the fuel cycle facility, and to respond to such actions if they do occur.

4.28. International recommendations on the physical protection of nuclear facilities and nuclear material are provided in Ref. [16].

4.29. The physical protection of the facility shall take account of the safety requirements and shall be in accordance with the facility's emergency plan.

5. SITING OF THE FACILITY

INITIAL SITE EVALUATION AND SITE SELECTION

5.1. The main safety objective in the siting of a facility shall be the consideration of external hazards and the protection of the public and the environment from the impacts of authorized discharges and accidental releases of radioactive and chemically hazardous materials.

5.2. The basis for the selection of a site for a facility will depend on a number of factors, including public acceptance.

5.3. In particular, the design of the facility and its intended purpose will have a bearing upon its siting. Certain facilities may require minimal siting constraints because they inherently pose a limited potential hazard to the public and would be relatively unaffected by site related, external initiating events. Other facilities may pose a greater potential hazard to the public or may be more vulnerable to external events.

5.4. The operating organization shall carry out a site evaluation, to the extent that it is appropriate for the potential hazards presented by the facility, on the basis of the requirements established in Ref. [17]. In particular in this site evaluation, consideration shall be given to the suitability of a particular site for such a facility, the site characteristics that may affect safety aspects of the facility, and the ways in which these site characteristics will influence the design and operating criteria for the facility.

5.5. The site evaluation, with due consideration of the potential hazards posed by the facility, shall constitute the first part of the development of the licensing documentation for a new facility. For the site evaluation, the following requirements apply:

(a) Appropriate radiological monitoring of the site shall be conducted prior to carrying out any site activities in order to establish baseline levels of radiological parameters for assessing the future impact of the facility at the site. Natural and artificial radioactivity at the site in the air, the water and the ground and in flora and fauna shall be investigated and recorded.
(b) Environmental characteristics of the area that may potentially be affected by the radiological impacts and the associated chemical impacts of the facility

in operational states and in accident conditions[6] shall be investigated. An appropriate monitoring system shall be designed to verify the results obtained using the mathematical models of the radiological impacts and the associated chemical impacts.

(c) The possible locations near the facility where radioactive material and other hazardous material could be discharged or could pass to the environment shall be investigated. Hydrological and hydrogeological investigations shall be carried out to assess, to the extent necessary, the dilution and dispersion characteristics of water bodies. The models used to evaluate the possible impacts of the contamination of surface water and groundwater on the public and the environment shall be described.

(d) Models used to assess the dispersion of radioactive material and other hazardous material released to the environment in operational states and in accident conditions shall be in accordance with the requirements of the operating organization and of the regulatory body.

(e) Information shall be collected which, together with the anticipated discharges of radioactive material and other hazardous material from the facility and with the transfer behaviour of the radioactive material, permits an assessment of doses to the public and of the contamination of biological systems and food chains.

(f) Site characteristics (e.g. soil properties, geology, hydrogeology) that may affect safety aspects of the facility shall be assessed, in particular the likelihood and the potential severity of natural phenomena (e.g. earthquakes, tsunamis, flooding, high winds, extreme temperatures, lightning) or external human induced events such as accidental aircraft crashes, impacts, fires (e.g. forest fires) and explosions (e.g. at a nearby gas terminal). Such events shall be considered in the design basis of the facility.

(g) For a new facility, geological, hydrogeological and meteorological data concerning the site shall be collected and incorporated in the facility licensing documentation. The choice of the site can eliminate or reduce the risk due to the above events.

(h) The potential for accidental aircraft crashes, including impacts, fires and explosions on the site, shall be evaluated, with account taken of the foreseeable characteristics of air traffic, the locations and types of airports, and the characteristics of aircraft, including those with special permission to fly over or near the facility such as firefighting aircraft and helicopters.

(i) In the analysis of the suitability of the site, consideration shall be given to the storage and transport of radioactive material, processing chemicals,

[6] Accident conditions: see Annex III, para. III–12.

radioactive waste and chemical wastes, and to the existing site infrastructure (e.g. the power supply and its reliability).

(j) Foreseeable natural and human-made changes in the area that may have a bearing on safety shall be evaluated over a period that encompasses the projected lifetime of the facility.

(k) The influence of the siting decision on the need for, or the extent of, mitigatory actions such as accident management measures or emergency measures (e.g. the use of the firefighting service) that may be required in the event of an accident at the facility shall be considered.

5.6. The operating organization shall collect information in sufficient detail to support the safety analysis to demonstrate that the facility can be safely operated at the proposed site. For facilities that present a very limited hazard potential, the amount of detail necessary could be substantially less than is required for a facility of medium or high hazard potential.

5.7. A site shall be deemed suitable only if the evaluation results lead to the conclusion that radioactive releases in operational states are within authorized limits and that the radiological consequences for the public of releases in accident conditions, including conditions that may lead to mitigatory actions being taken, are within acceptable limits and in accordance with national requirements. The investigations and assessments shall be such as to provide adequate results to allow for a discussion and for conclusions to be drawn on the suitability of the site for the proposed facility.

5.8. The evaluation results shall be documented and shall be presented in sufficient detail in the licensing documentation.

ONGOING SITE EVALUATION

5.9. The operating organization shall establish a programme of monitoring throughout the lifetime of the facility (including the decommissioning stage) to evaluate natural and human-made changes in the area and their impacts on the site characteristics and to compare them with the original predictions of such possible changes.

5.10. If the ongoing site evaluation identifies new information with regard to site characteristics, safety precautions, such as engineering controls and emergency preparedness arrangements, may need to be reviewed and changed.

6. DESIGN OF THE FACILITY

GENERAL

6.1. A fuel cycle facility shall be designed in such a way that the fundamental safety objective quoted in Section 2 of this publication is achieved.

6.2. The design requirements established in this section shall be applied commensurate with the potential hazards of the facility. These requirements shall be implemented in all stages of design, with account taken of the feedback from the results of the accompanying safety analysis (see also Section 4).

6.3. In the design and safety justification for the facility, not only the facility itself but also the interfaces with other facilities and installations that may affect its safety shall be considered.

DESIGN BASIS

6.4. Within these requirements and the general framework presented in Section 2, the operating organization shall establish explicit criteria for the level of safety to be achieved. The operating organization shall set limits on the radiological consequences and associated chemical consequences for the workforce and the public of direct exposures to radiation or authorized discharges of radionuclides to the environment. These limits shall apply to the consequences of operational states and the possible consequences of accident conditions at the facility and shall be set equal to, or below, international and national standards to ensure compliance across the full range of operating conditions and throughput. For new designs, targets shall be considered that are below these limits, since it is generally more effective to incorporate enhanced safety provisions at the design stage.

6.5. Limits and acceptance criteria shall be defined. As an example, in setting limits related to accident conditions, the risks from adverse events could be characterized as tolerable risks or unacceptable risks such that if the consequences for the public and the workforce increase, the acceptability in terms of the frequency or probability of occurrence has to decrease. Such limits may be represented in the form of an acceptability diagram (Fig. 2). Additional provisions can be made in accordance with the defence in depth principle.

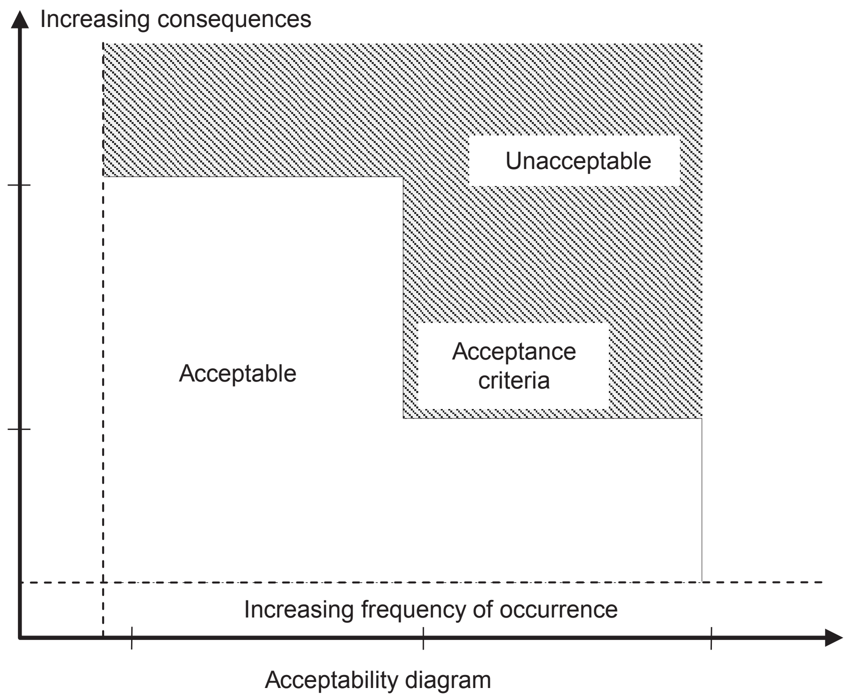

FIG. 2. Example of an acceptability diagram.

6.6. The following hierarchy of design measures shall be used to the extent practicable in protecting against potential hazards:

(1) Selection of the process (to eliminate the hazard);
(2) Passive design features;
(3) Active design features;
(4) Administrative controls.

6.7. The availability and reliability of the design measures and the administrative controls shall be commensurate with the significance of the potential hazards to be managed.

6.8. The operating organization shall identify postulated initiating events that could lead to a release of radiation and/or significant amounts of radioactive material and associated chemical substances. The resulting set of identified postulated initiating events shall be confirmed to be comprehensive and shall be defined in such a way that the events cover credible failures of the SSCs of the facility and human errors that could occur in any of the operating conditions of the facility. The set of postulated initiating events shall include both internally and externally initiated events. Examples of postulated initiating events are provided in Annex I.

6.9. A design basis accident approach (see Annex III), or an equivalent methodology, shall be used to identify significant accident sequences. For each accident sequence identified, the safety functions, the corresponding SSCs important to safety and the administrative safety requirements that are used to implement the defence in depth concept shall be identified.

DESIGN ASSESSMENT

6.10. The responsibility for the production of a safe facility design shall lie with the operating organization. The operating organization may be supported by a facility designer; if so, the facility designer shall demonstrate that the established safety requirements can be met. A close liaison shall be maintained between the facility designer and the operating organization for achieving the safe design of the facility; however, the operating organization shall implement an internal safety review of the facility design, as independently as possible from the designer. The designer shall arrange for the orderly preparation, presentation and submission of design documents to the operating organization for its use in the preparation of the licensing documentation. The evolution of the design may proceed concurrently with the development of the licensing documentation. (For further details, see Annex III.)

GENERAL SAFETY REQUIREMENTS

Criteria and rules

6.11. Design criteria for all relevant parameters shall be specified for each operational state of the facility and for each design basis accident or equivalent. Design criteria for SSCs important to safety may be in the form of engineering design rules. Engineering design rules include requirements in relevant codes and standards, and may be set and required explicitly by the regulatory body by requiring the use of applicable standard engineering practices already established in the State or used internationally. Design rules shall provide for safety margins[7]

[7] A safety margin is the difference between a safety limit and an operational limit.

over and above those foreseen for operations to provide reasonable assurance that no significant consequences would occur even if the operational limits were exceeded within the safety margin.

Codes and standards

6.12. The operating organization shall identify the codes and standards applicable to SSCs important to safety and shall justify their use. In particular, if different codes and standards are used for different aspects of the same item or system, consistency between them shall be demonstrated. Typical areas covered by codes and standards are:

(a) Mechanical design, including design of pressure retaining components;
(b) Structural design;
(c) Selection of materials;
(d) Thermohydraulic design;
(e) Electrical design;
(f) Design of instrumentation and control systems;
(g) Software design and control;
(h) Inspection, testing and maintenance as related to design;
(i) Criticality;
(j) Shielding and radiation protection;
(k) Fire protection;
(l) Chemical hazard protection;
(m) Seismically qualified design;
(n) Other designs for protection against natural phenomena.

Availability and reliability

6.13. The operating organization shall ensure that the necessary levels of availability and reliability of SSCs important to safety, as established in the licensing documentation, are attained. The design principles stated in Annex II shall be applied, as appropriate, to achieve the required availability and reliability of SSCs important to safety in operational states and in accident conditions.

6.14. For SSCs important to safety for which no appropriate established codes or standards exist, an approach derived from existing codes or standards for similar equipment may be applied. In the absence of such codes or standards, lessons learned from experience, tests including tests at pilot plants, analyses and expert committee recommendations or a combination thereof may be applied. Such application shall be justified.

Ergonomics and human factors

6.15. Human factors and human–machine interfaces shall be considered throughout the design process. Human factors are an important aspect of the safety of fuel cycle facilities, as the state of the process changes frequently and operators have relatively greater access to the process operations. Ergonomic principles shall be applied in the design of control rooms and panels. Operators shall be provided with clear displays and audible signals for those parameters that are important to safety.

6.16. The design shall minimize the demands on operators in normal operations and in anticipated operational occurrences and accident conditions, e.g. through automating appropriate actions to promote the success of the operation. The need for appropriate control devices (e.g. interlocks, keys, passwords) to anticipate foreseeable human errors shall be taken into account in the design.

Material selection and ageing

6.17. In the design stage, design safety margins shall be adopted so as to accommodate the anticipated properties of materials at the end of their useful life. This is particularly important for fuel cycle facilities because of the range and characteristics of chemical and radiation conditions experienced in operational states and in accident conditions. Where details of the characteristics of materials are unavailable, a suitable material surveillance programme shall be implemented by the operating organization. Results derived from this programme shall be used to review the adequacy of the design at appropriate intervals. This may require provisions in the design for the monitoring of materials whose mechanical properties may change in service owing to factors such as fatigue (e.g. from cyclic mechanical or thermal loadings), stress corrosion, erosion, chemical corrosion or the induction of changes by irradiation.

Provision for maintenance, inspection and testing

6.18. SSCs important to safety shall be designed to facilitate maintenance, inspection and testing for their functional capability over the lifetime of the facility.

6.19. The design and layout of SSCs important to safety shall include provision to minimize exposures arising from maintenance, inspection and testing activities. The term ‘maintenance’ includes both preventive and corrective actions.

Use of computer based systems as SSCs important to safety

6.20. If a computer based system is important to safety or forms part of a system important to safety, appropriate standards and practices for the development and testing of computer hardware and software shall be established and shall be implemented throughout the lifetime of the system, in particular at the software development stage. The entire development shall be subject to an appropriate management system. The level of reliability necessary shall be commensurate with the importance of the system to safety [18].

Design for accident conditions

6.21. SSCs important to safety shall be designed to withstand the effects of extreme loadings and environmental conditions (e.g. extremes of temperature, humidity, pressure, radiation levels) arising in operational states and in relevant design basis accident (or equivalent) conditions.

6.22. If an emergency shutdown of the facility or part(s) thereof is necessary, the interdependences between different processes shall be considered. In cases where it is impractical to stop the process immediately (e.g. in a gaseous diffusion enrichment facility), the design shall provide for the means to attain a safe and stable operational state.

6.23. The design and arrangements for process control shall incorporate provisions for bringing the process operations to a safe and stable state.

6.24. Where prompt, reliable action would be required in response to postulated initiating events, the design of the facility shall include the means to actuate automatically the necessary safety systems.[8] In some cases, in accident conditions, it may be necessary for the operator to take further action to place the facility in a safe and stable long term state.

6.25. Manual operator action shall be sufficiently reliable to bring the process to a safe state provided that:

(a) Adequate time is available for the operator to take actions for safety.
(b) The information available has been suitably processed and presented.

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[8] A safety system is a system important to safety, provided to ensure the safe shutdown of a facility or to limit the consequences of anticipated operational occurrences and design basis accidents.

(c) The diagnosis is simple and the necessary action is clearly specified.
(d) The demands imposed on the operator are not excessive.

If any of these conditions may not be met, the safety systems shall be such as to ensure that the facility attains a safe state.

6.26. A capability shall be provided for monitoring all essential processes and equipment during and following an accident. If necessary, a remote monitoring and shutdown capability shall be provided.

6.27. The principle of independence (see Annex II) shall be specifically addressed with respect to the segregation for purposes of operational control between SSCs important to safety and also within SSCs important to safety, as appropriate.

6.28. SSCs important to safety either shall be capable of performing their safety functions in spite of a loss of support systems, e.g. electrical power systems, compressed air systems or systems for the supply of cooling or heating fluids, or, if not, shall be designed to fail to a safe configuration.

6.29. The loss or excess of process reagents and diluent gases shall be considered during the safety assessment.

Design for emergency planning

6.30. Specific design features for emergency planning purposes shall be considered, in accordance with the potential hazards presented by the facility. Such features may include simple escape routes with reliable emergency lighting, reliable means of communication and dedicated instrumentation for monitoring radiation levels and hazardous chemicals. Depending on the potential hazards posed by the facility, consideration shall also be given to providing an on-site emergency control centre in a location separate from the operations area to maintain the chain of command and communication.

Design for radioactive waste management

6.31. To the extent that is practicable at the design stage, the operating organization shall take measures to avoid or to optimize the generation of radioactive waste with the aim of minimizing the overall environmental impact. The predisposal and disposal routes for waste shall be considered with the same aim of minimizing the overall environmental impact.

6.32. Requirements on the generation, processing and storage of radioactive waste are established in Ref. [2].

Design for the management of aerial and liquid radioactive discharges

6.33. Design provisions shall be established for ensuring that aerial and liquid radioactive discharges to the environment are in compliance with authorized limits and to reduce doses to the public and effects on the environment to levels that are as low as reasonably achievable.

6.34. Design provisions shall be established for monitoring aerial and liquid radioactive discharges to the environment.

Design for decommissioning

6.35. In the design of a fuel cycle facility, consideration shall be given to facilitating its ultimate decommissioning, so as to keep the exposure of personnel and the public, arising from decommissioning, as low as reasonably achievable and to ensure adequate protection of the environment, as well as to minimize the amount of radioactive waste generated.

6.36. While ensuring the safe operation of the facility, to the extent practicable, the designer:

(a) Shall minimize the number and size of contaminated areas to facilitate cleanup in the decommissioning stage;
(b) Shall choose materials that can be stored in the facility, that are resistant to all chemicals in use and that have sufficient wear resistance, to facilitate their decontamination at the end of their lifetime;
(c) Shall design the facility to avoid undesired accumulations of chemical or radioactive materials;
(d) Shall design the facility to allow remote decontamination where necessary;
(e) Shall consider the amenability to treatment, interim storage, transport and disposal of the waste to be generated during the decommissioning stage;
(f) Shall pay specific attention to keeping the design documentation and records available throughout the lifetime of the facility.

DESIGN FOR PROTECTION AGAINST RADIOLOGICAL HAZARDS

Contamination control and protection against internal exposure

6.37. Consideration shall be given to protecting workers, the public and the environment against releases of hazardous material in both operational states and accident conditions.

6.38. The main design features for the control of contamination are confinement and leak detection. Confinement is achieved by means of physical barriers (static containment) and/or dynamic containment (e.g. by ventilation). The nature and number of the barriers and their performance, as well as the performance of air purification systems, shall be commensurate with the degree of the potential hazards, with special attention paid to the potential dispersion of alpha emitters.

6.39. Areas shall be classified according to foreseeable levels of surface contamination and atmospheric contamination, and equipment shall be installed in accordance with this classification (see Ref. [12]). Means of monitoring and appropriate alarm systems for atmospheric contamination shall be installed. The need for appropriate provisions for specific operations in contaminated areas shall be taken into account in the design.

Protection against external exposure

6.40. Protection against radiation exposure shall be achieved by means of engineered provisions such as adequate shielding and the use of remote handling equipment.

6.41. The designer shall classify areas by taking into consideration the magnitude of the expected normal exposures, the likelihood and magnitude of potential exposures, and the nature and extent of the required protection and safety procedures. Access to areas where radiation levels may cause exposures that give rise to high doses for workers shall be restricted and the level of control applied shall be commensurate with the hazards (see Ref. [12]).

6.42. Radiation levels shall be monitored so that any abnormal conditions would be detected and workers may be evacuated. Areas of potential exposure for workers shall be appropriately identified and marked.

Criticality

6.43. Criticality accidents can result in high radiation doses to nearby personnel and widespread contamination. As far as practicable, criticality hazards shall be controlled by means of design.

6.44. The achievement of criticality depends upon:

(a) The properties of the fissile material;
(b) The mass of fissile material present and its distribution among the components of the system in which it is present;
(c) The mass, properties and distribution of all other materials associated with or surrounding the fissile material.

6.45. For the prevention of criticality by means of design, the double contingency principle (see Annex II) shall be the preferred approach.

6.46. The most important factors in preventing criticality are mass, geometry, moderation, reflection, interaction, neutron absorption and concentration. These factors shall be considered both alone and in combination for a proper design.

6.47. Criticality evaluations and calculations shall be performed on the basis of making conservative assumptions.

6.48. Specific attention shall be paid to those system interfaces for which there is a change in the method of criticality control.

6.49. Methods of ensuring criticality safety in any process shall include, but shall not be limited to, any one of or a combination of the following:

(a) Passive engineered control involving equipment design;
(b) Active engineered control involving the use of process control instrumentation;
(c) Chemical means, such as the prevention of conditions that allow precipitation;
(d) Reliance on a natural or credible course of events, such as a process the nature of which is to keep the density of fissile material lower than the theoretical minimum necessary for a criticality event to occur;
(e) Administrative controls to ensure compliance with operating procedures.

6.50. States have adopted various approaches to mitigatory measures for, and consequence assessments of, criticality accidents. The following measures shall be assessed for their suitability:

(a) The installation of a criticality detection and alarm system to initiate immediate evacuation;
(b) The identification and marking of appropriate evacuation routes and regrouping areas;
(c) The provision of appropriate emergency equipment and the adoption of emergency procedures.

6.51. Further guidance on criticality control is provided in Ref. [19].

Radioactive decay heat

6.52. The generation of heat by radioactive decay, if not adequately controlled, may result in the release of radioactive material. Heat generation shall be taken into account, as appropriate, in the facility design.

Radiolysis

6.53. Radiolysis, if not adequately controlled, may result in the release of hydrogen, with the risk of explosions. Radiolysis shall be taken into account, as appropriate, in the facility design.

NON-RADIOLOGICAL HAZARDS

6.54. Chemical, toxic, flammable or explosive substances can affect nuclear safety. To prevent this from occurring, the following shall be considered in the design:

(a) Design requirements and guidance contained in international and national standards and guidance on chemical safety;
(b) The chemical compatibility of materials that are likely to come into contact;
(c) The safe storage of hazardous process materials;
(d) The initial process configuration and/or credible changes to it that may lead to the release of chemical compounds or toxic materials (e.g. hydrogen, solvents), fires or explosions;
(e) The detection and alarm capability for chemical or toxic releases;

(f) The minimization of inventories;
(g) Personnel protective equipment to protect against exposures to chemical compounds or toxic materials.

6.55. The operating organization shall make design provisions for fire safety on the basis of a fire safety analysis and the implementation of the concept of defence in depth (i.e. for prevention, detection, control and mitigation).

7. CONSTRUCTION OF THE FACILITY

7.1. Before the construction of a fuel cycle facility begins, the operating organization shall satisfy the regulatory requirements regarding the safety of the facility design.

7.2. For large or complex facilities, authorization by the regulatory body may be granted in several stages. Each stage may have a hold point and regulatory agreement may be necessary to proceed to the next stage. The extent of involvement by the regulatory body during construction shall be commensurate with the potential hazards of the facility.

7.3. Before construction begins, the operating organization shall make adequate arrangements with the selected contractor(s) concerning the responsibility for ensuring safety during construction and for the identification and control of any adverse impacts of the construction activities on facility operations and vice versa. The impact of construction of the facility on the local population and the environment and on any adjacent operating plants and services shall be considered. In particular, hazards associated with vibration, movements of heavy loads and dust generation shall be assessed.

7.4. The operating organization shall implement a management system, as described in Section 4, in the construction stage to ensure that the design requirements and intent are properly met in the construction stage since, for certain SSCs important to safety, the verification of compliance after construction and installation may be more difficult.

7.5. Records shall be maintained in accordance with the management system to demonstrate that the facility and its equipment have been constructed in accordance with the design specifications.

7.6. The operating organization shall specify a formal procedure for design changes such that those made to the facility during construction are accurately recorded and their impacts are assessed.

7.7. 'As built' drawings of the facility shall be provided to the operating organization. Following construction of the facility, the operating organization shall review the as built drawings to confirm that, as far as can be assessed, the design intent has been met and the safety functions specified will be fulfilled. The operating organization shall, as required, seek agreement by the regulatory body to proceed to the commissioning stage.

8. COMMISSIONING OF THE FACILITY

COMMISSIONING PROGRAMME

8.1. Before the commencement of commissioning, an adequate commissioning programme shall be prepared for the testing of a facility to demonstrate that it meets the design objectives and the performance criteria. The commissioning programme, agreed as required with the regulatory body, shall cover the organization for and responsibilities for commissioning, the stages of commissioning, the suitable testing of SSCs on the basis of their importance to safety, the test schedule, the commissioning procedures and reports, the methods of reviewing and verification, the treatment of deviations and deficiencies, and the requirements for documentation.

8.2. The requirements in this section shall also apply to the restart of existing processes after a lengthy shutdown period.

ORGANIZATION AND RESPONSIBILITIES

8.3. The involvement of the operating organization, designers and manufacturers in the preparation of the commissioning programme shall be established by the operating organization to familiarize the future operating personnel with the particular characteristics of the facility and its process operations, and to ensure the adequate transfer of knowledge and the feedback of lessons learned from experience to the facility staff.

8.4. The commissioning period shall be used to train the operators in all aspects of operation and maintenance of the facility. Integral to this training process shall be the verification of the operational documentation, including operating procedures, maintenance procedures, emergency procedures, administrative procedures and operational limits and conditions.

8.5. The handover from the commissioning workforce to the operating workforce shall be carefully managed to ensure that knowledge and experience are not lost. Commissioning is also an opportunity for the operating organization to become familiar with the facility and for the management to develop a safety culture, including positive behaviour and attitudes.

8.6. At all stages of commissioning, the operating organization shall ensure that the person or organization responsible for safety is clearly identified. When the responsibility for safety is transferred, the arrangements for the transfer of responsibility shall be clearly specified.

8.7. The operating organization shall establish a safety committee (see para. 9.15) to review the commissioning programme and the results of commissioning tests and to provide technical advice to the operating organization.

8.8. Close liaison shall be maintained between the regulatory body and the operating organization throughout the commissioning process. In particular, the operating organization shall ensure that the results of tests directly concerning safety and their analyses are made available to the regulatory body for review and approval, as appropriate.

COMMISSIONING TESTS AND STAGES

8.9. The commissioning programme shall be divided into stages. These stages shall include, as necessary, individual equipment tests, integrated facility tests and system tests relating to cold processing (i.e. without radioactive material) and hot processing (i.e. with radioactive material).

8.10. Commissioning tests shall be arranged in functional groups and in a logical sequence, and, as far as is practicable, shall cover all planned operating aspects.

8.11. The operating organization shall specify a formal procedure for design change so that all modifications made to the facility are accurately recorded and their possible impacts are assessed.

8.12. At the commissioning stage, the operating organization shall specify the point at which the safety evaluation of modifications is transferred from a design stage evaluation process to an operation stage evaluation process.

COMMISSIONING PROCEDURES AND REPORTS

8.13. The commissioning programme shall include provisions and procedures for audits, reviews and verifications to confirm that the tests have been conducted as planned and that the programme objectives have been fully achieved. Provision shall also be made for remedying any deviation or deficiency that is discovered in the commissioning tests.

8.14. The effective testing of facilities and their equipment and systems without introducing the full chemical or radiological challenge to the facility may require the introduction of temporary commissioning aids into the software or hardware systems. The operating organization shall ensure that formal records of such aids are kept. The records shall be used to ensure that all the aids are removed on completion of the tests before the facility or system is brought into operation.

8.15. Commissioning activities shall be performed in accordance with written procedures. The procedures shall cover the purpose of the tests, the expected results and the criteria for success, the safety provisions required during the tests, the necessary precautions and prerequisites, and the test instructions.

8.16. If necessary, procedures shall include hold points for the notification and involvement of the safety committee (see para. 9.15), outside agencies, manufacturers and the regulatory body.

8.17. Reports covering the scope, sequence, expected results and criteria for the success of these tests shall be prepared in accordance with the management system and in appropriate detail. The test report shall include: a description of the test programme and the test results; a summary of the data collected and their analyses; an evaluation of the results with a comparison with acceptance criteria and a statement on the success of the test; the identification of deviations and deficiencies; and any corrective actions and the justifications for the corrective actions.

8.18. All commissioning test results, whether obtained by a member of the operating organization or a manufacturer, shall be available to the operating organization and the regulatory body and shall be retained for the lifetime of the facility.

9. OPERATION OF THE FACILITY

BACKGROUND

9.1. Section 4 establishes requirements that are common from the design stage to the decommissioning stage. These requirements also apply to operation, in particular the requirements on organizational matters and safety culture.

9.2. Section 9 concerns organizational matters and safety culture, and establishes specific requirements for operation.

GENERAL REQUIREMENTS DURING OPERATION

Structure and responsibilities of the operating organization

9.3. The operating organization shall have the overall responsibility for the safety of the facility during operation. The operating organization shall establish an appropriate management structure for the facility and shall provide the necessary infrastructure for operations to be conducted safely.

9.4. The operating organization shall ensure that relevant functions relating to the safe operation and utilization of the facility, such as maintenance, radiation protection, criticality safety, the application of the management system and other relevant supporting activities, are adequately covered, and shall take into account industrial and chemical safety.

9.5. The operating organization shall be responsible for all safety aspects of any change in the facility design or any change in control, arrangements made, utilization or management of the facility. This responsibility shall not be delegated.

Interface arrangements

9.6. The operating organization shall ensure that safety related interdependences between facilities on the same site are considered. Boundary responsibilities shall be clearly specified and effective communication routes shall be established.

9.7. As necessary, and in accordance with national regulations and international standards, a dedicated organization and specific rules for on-site transports shall be established.

Qualification and training of personnel

9.8. Minimum qualifications for personnel shall be specified, and these minimum qualifications shall be commensurate with the assigned functional responsibility and authority. The training of personnel working at the facility shall be commensurate with their assigned functional responsibilities, their authorities and their safety related activities. A training programme for personnel working at the facility shall be organized, staffed and managed to facilitate planning, direction, evaluation and control for fulfilling the training objectives. The training given shall be graded and shall be based on a competency framework.

9.9. Training shall include the retraining of previously trained and qualified personnel. The training programme shall include the following aspects: analysis and identification of functional areas for which training is required; position training requirements; development of the basis for training, including objectives; evaluation of trainee learning; on the job training; and systematic evaluation of the effectiveness of the training.

9.10. Training shall cover the operational states of the facility, including emergency procedures (see paras 9.62–9.67 of this publication), and it shall be ensured that operators have sufficient understanding of the facility and its safety features. The primary importance of safety in all aspects of facility operation shall be emphasized.

9.11. As the response time is crucial for firefighting in the event of a fire or an explosion, the operating team shall be properly and regularly trained in firefighting, and drills and exercises shall be carried out on a regular basis.

9.12. With respect to training, special attention shall be paid to radiological hazards that may involve manual intervention. Workers shall be made aware of the hazards associated with the activities they are performing.

9.13. Facility modifications shall be reflected in the training programme in a timely manner.

Minimum staffing

9.14. The operating organization shall define the minimum staffing levels for the various technical and functional areas necessary to ensure the safety of the facility in operational states, including inter-campaign periods, and in accident conditions, for persons and organizations involved in the implementation of the emergency plan.

Safety committee

9.15. The operating organization shall establish one or more internal safety committees to advise the management of the operating organization on safety issues related to the commissioning, operation and modification of the facility. Such committees shall have among their membership the necessary breadth of knowledge and experience to provide appropriate advice. The membership shall, to the extent necessary, be independent of the operations management raising the safety matter.

Feedback of operating experience

9.16. Arrangements shall be made so that available technical information on abnormal occurrences, incidents and accidents that have occurred at the facility or at similar facilities is analysed for the feedback of lessons learned from experience and for preventive actions if necessary.

Document management

9.17. The operating organization shall maintain, and shall ensure that the personnel use, a complete and up to date set of safety documentation, including the licensing documentation and procedures. Duplicates of essential documents shall be stored separately and shall be maintained, as appropriate.

9.18. The operating organization shall make arrangements for generating and controlling records and reports that have safety significance for the operation and decommissioning stages, including:

(a) The complete collection of revisions to the licensing documentation;
(b) Periodic safety reviews;

(c) Commissioning documents;
(d) Procedures and operating instructions;
(e) History of and data on modifications;
(f) Operational data for the facility;
(g) Data from maintenance, testing, surveillance and inspection;
(h) Reports on events and incidents;
(i) Radiation protection data, including personal monitoring data;
(j) Data on amounts and movements of nuclear and other radioactive material;
(k) Records of the discharges of effluents;
(l) Records of the storage and transport of radioactive waste;
(m) Results of environmental monitoring;
(n) Records of the main work activities performed in each location of the facility.

Control of organizational changes

9.19. The operating organization shall put in place arrangements to ensure that changes to the organizational structure are considered in terms of their potential impacts on safety and on any actions necessary to mitigate consequences, as appropriate.

Communication with the regulatory body

9.20. In accordance with national requirements and practices, the operating organization shall develop and implement procedures for informing the regulatory body of proposals for modifications having major safety significance, and in case of anticipated operational occurrences or accident conditions (see para. 9.16).

SPECIFIC REQUIREMENTS FOR OPERATION

Operating instructions

9.21. Operational limits and conditions shall be prepared before operation of the facility commences.

9.22. Operating instructions shall be developed by the operating organization, in cooperation with the designer and manufacturer if necessary. Safety related operating instructions shall be prepared before operations commence. Operating instructions shall clearly describe the methods of operating, including all checks, tests, calibrations and inspections necessary to ensure compliance with the operational limits and conditions (see paras 2.9–2.15).

9.23. Operators shall be made aware of the special safety significance of the instructions and procedures necessary to ensure compliance with the operational limits and conditions, and of the requirements for strict compliance with them.

9.24. Operating instructions and procedures shall be reviewed and updated periodically and shall be made accessible to users as necessary.

9.25. Arrangements shall be made to ensure that significant deviations from operating instructions are identified, and, where appropriate, an investigation is carried out into the cause and appropriate actions are taken to prevent recurrence. Such arrangements shall include notification to the regulatory body if the deviations result in the breach of an operational limit or condition.

9.26. The operating instructions shall provide for the facility to be brought into a safe operational state after an anticipated operational occurrence, which could necessitate shutting down the facility.

9.27. When an activity not covered by existing instructions is planned, appropriate instructions shall be prepared and reviewed, and shall be subject to appropriate approval before the activity is started. Additional training of relevant operating personnel on the instructions shall be provided.

MAINTENANCE, CALIBRATION, PERIODIC TESTING AND INSPECTION

9.28. Maintenance, calibration, periodic testing and inspection shall be performed to ensure that SSCs important to safety are able to function in accordance with the design intent and with safety requirements. In this context, the term ‘maintenance’ includes both preventive and corrective actions. Maintenance, calibration and periodic testing shall also be carried out on the equipment necessary for implementation of the on-site emergency plan.

9.29. All maintenance, calibration, periodic testing and inspection shall be performed in accordance with a programme based on approved, written procedures. Before operation of the facility commences, the operating organization shall prepare and obtain approval for the programmes for maintenance, calibration, periodic testing and inspection of SSCs important to safety. These procedures shall specify any changes from the normal operational status of the facility and shall make provision for restoration of the normal configuration upon completion of the activity. A system of work permits in accordance with the management system shall be used for maintenance, calibration, periodic testing and inspection. Resumption of normal operation shall be permitted only after the person responsible for coordinating the maintenance work has approved the results of the maintenance assessment.

9.30. The frequency of maintenance, calibration, periodic testing and inspection of SSCs important to safety shall be in accordance with the facility licensing documentation.

9.31. Equipment and items used for maintenance, calibration, periodic testing and inspection shall be identified and controlled to ensure their proper use.

9.32. The results of maintenance, testing and inspection shall be recorded and assessed.

9.33. The maintenance, calibration, periodic testing and inspection programmes shall be reviewed at regular intervals to incorporate the lessons learned from experience.

9.34. Special attention shall be paid to subordinate operations such as decontamination, washing and preparation for maintenance or testing, as there are many occurrences at facilities while such operations are taking place.

CONTROL OF MODIFICATIONS

9.35. The operating organization shall establish a process whereby its proposals for changes to the design, equipment, feed material characteristics, control or management are subject to a degree of assessment and scrutiny appropriate to the safety significance of the change, so that the direct and wider consequences of the modification are adequately assessed (by the safety committee; see para. 9.15). The process shall include a review of possible consequences to ensure that a foreseen modification or change in one facility will not adversely affect the operability or safety of associated or adjacent facilities.

RADIATION PROTECTION DURING OPERATION

9.36. The measures for protection against radiation exposure of operating personnel, including contractors, and members of the public shall comply with the requirements of the regulatory body and with the requirements established in Ref. [12].

9.37. For all operational states the radiation protection measures shall be such as:

(a) To ensure that exposures are kept below regulatory limits;
(b) To optimize radiation protection.

Radiation protection programme

9.38. The operating organization shall establish and implement a radiation protection programme to ensure that all activities involving potential radiation exposure are planned, supervised, executed and monitored. All documentation and activities relating to radiation protection shall conform to the integrated management system of the organization (see Section 4).

9.39. The radiation protection programme shall specify responsibilities and arrangements for:

(a) Monitoring of radiation and contamination levels on and off the site, and alerting operators to any abnormalities;
(b) Control of radiation exposures, due to the operations of the facility, of persons present on the site;
(c) Control of off-site radiation exposures;
(d) Preparation, in accordance with the hazards posed by the facility, for the management of site emergencies;
(e) Control of the on-site and off-site transport of radioactive material.

9.40. All operating personnel shall be individually responsible for putting into practice the measures for exposure control in the course of their work, as specified under the radiation protection programme.

9.41. The operating organization shall run the facility in such a manner as to optimize protection against external and internal exposures of the workforce. During operation, external and internal exposures shall be managed in accordance with the principle of optimization of protection, with an appropriate balance of rules and practices on:

(a) Housekeeping and decontamination of equipment and areas;
(b) Maintenance and modifications;
(c) Operation.

9.42. For potential accident conditions, the radiological consequences shall be kept low by means of engineered safety features, accident management procedures and measures provided in the emergency plan.

9.43. The monitoring results from the radiation protection programme shall be compared with the operational limits and conditions, and corrective actions shall be taken if necessary. In addition, goals for annual doses shall be determined annually. Results shall be compared with these goals, and any divergences shall be investigated.

Radiation protection personnel

9.44. The radiation protection programme shall include the establishment within the operating organization of a radiation protection group with the appointment of qualified radiation protection officers who are technically competent in radiation protection matters and knowledgeable about the radiological aspects of the design, operation and hazards of the facility.

9.45. The radiation protection personnel shall provide advice to the operating personnel and shall have access to the levels of management within the operating organization with the authority to establish and enforce operational procedures.

Control of occupational exposures

9.46. All operating personnel who may be occupationally exposed to radiation at levels that are significant for the purposes of radiation protection shall have their doses measured, recorded and assessed, as required by the regulatory body and in accordance with Ref. [12]. These records shall be made available to those exposed and to the regulatory body or any other body designated by the regulatory body. Arrangements shall be put in place to retain these records for the period required under national legislation.

Contamination control

9.47. The spread of radioactive contamination shall be controlled and minimized as far as practicable. Access to areas where contamination levels may lead to high doses for workers shall be restricted, and the level of control applied shall be commensurate with the hazard (see Ref. [12]).

9.48. In particular, where there is a likelihood of exposure, the workforce shall be provided with personal protective equipment to protect against the hazards likely to be encountered.

CRITICALITY CONTROL DURING OPERATION

9.49. All operations with fissile material shall be performed in such a way as to prevent a criticality accident.

9.50. All operations to which nuclear criticality safety is pertinent shall be governed by written procedures. The procedures shall specify all the parameters that they are intended to control and the criteria to be fulfilled.

9.51. Deviations from procedures and unforeseen changes in process conditions that affect nuclear criticality safety shall be reported to the management and shall be investigated promptly. The regulatory body shall also be informed. Action shall be taken to prevent their recurrence.

Criticality staff

9.52. Where relevant, the operating organization shall appoint qualified nuclear criticality staff who are knowledgeable about the physics of nuclear criticality and the associated safety standards, codes and best practices, and who are familiar with the facility operations. This function shall, to the extent necessary, be independent of the operations management.

9.53. The nuclear criticality staff shall give assistance for the training of personnel; shall provide technical guidance and expertise for the development of operating procedures; and shall check and validate all operations that may require criticality control (see Refs [20, 21]).

MANAGEMENT OF RADIOACTIVE WASTE AND EFFLUENTS IN OPERATION

9.54. A facility shall be operated so as to control and minimize, as far as practicable, the generation of radioactive waste of all kinds, to ensure that radioactive releases to the environment are as low as reasonably achievable, to facilitate the handling and disposal of waste, and to facilitate the decommissioning of the facility.

9.55. The management of solid, liquid and gaseous waste within, and its ultimate removal from, the facility shall fulfil the requirements established in Ref. [2].

9.56. More generally, all activities concerning radioactive and hazardous chemical effluents and waste (including those arising from decontamination activities) shall be conducted in accordance with an integrated waste management policy, the management system and regulatory requirements.

9.57. Discharges of radioactive and hazardous chemical effluents shall be monitored and the details recorded in order to verify compliance with the applicable regulatory requirements. The details shall be reported periodically to the regulatory body in accordance with its requirements.

MANAGEMENT OF INDUSTRIAL AND CHEMICAL SAFETY IN OPERATION

9.58. Depending on the nature of the facility, the degree of risk to the public or the workforce posed by chemical and industrial hazards may be greater or less than that posed by radioactive material. The operating organization shall, as appropriate, have access to the necessary safety expertise, and shall introduce arrangements to minimize the risks posed by chemical and industrial hazards to the public, the workforce and the environment.

9.59. The operating organization shall make arrangements for ensuring fire safety on the basis of a fire safety analysis, which shall be reviewed periodically and updated as necessary. Such arrangements shall include: control of combustibles (limitation) and ignition sources (separation) in accordance with the licensing documentation; assessment of the potential impacts of modifications on the fire safety analysis or fire protection systems; maintenance, testing and inspection of fire protection measures; establishment of a manual firefighting capability; and training of facility personnel.

9.60. In particular:

(a) Written procedures and monitoring shall be used to ensure that the concentration in air of flammable gases (e.g. hydrogen) is below the corresponding lower flammability limit in air, with an adequate margin.
(b) The operating team shall be properly and regularly trained.
(c) Drills shall be carried out on a regular basis.

9.61. Together with the conventional fire safety concerns associated with an industrial installation, fire safety issues relating to nuclear materials shall be assessed (e.g. for uranium metal).

EMERGENCY PREPAREDNESS

9.62. The operating organization, taking into account the potential hazards of the facility, shall develop an emergency plan in coordination with other bodies having responsibilities in an emergency, including public authorities; shall establish the necessary organizational structure; and shall assign responsibilities for managing emergency response. Requirements on planning for emergency preparedness and response are established in Ref. [3].

9.63. The emergency plan of the operating organization shall include:

(a) The designation of persons who will be responsible for directing on-site activities and for ensuring liaison with off-site organizations;
(b) The requirements for personnel training;
(c) A listing of possible accidents and, if relevant, descriptions of the accidents and their foreseeable consequences;
(d) The conditions under which, and criteria according to which, an emergency shall be declared, a list of job titles and/or functions of the persons empowered to declare an emergency, and a description of suitable means for alerting response personnel and public authorities;
(e) The arrangements for assessment of radiological conditions on and off the site (for water, vegetation and soil, and by air sampling);
(f) Provisions for minimizing the exposure of persons to radiation and for ensuring the medical treatment of casualties;
(g) Assessment of the state of the facility and the actions to be taken on the site to limit the extent of radioactive releases and the spread of contamination;
(h) The chain of command and communication, including a description of related facilities and procedures;

(i) An inventory of the emergency equipment to be kept in readiness at specified locations;
(j) The actions to be taken by persons and organizations involved in the implementation of the emergency plan;
(k) Provisions for declaring the termination of an emergency.

9.64. The emergency plan shall, as necessary, include arrangements for responses to emergencies involving a combination of non-radiological and radiological hazards, such as a fire in conjunction with significant levels of radiation or contamination, or toxic and/or asphyxiating gases in conjunction with radiation or contamination, with account taken of the specific site conditions.

9.65. The emergency plan shall include a means of informing all persons on the site of the actions to be taken in the event of an emergency.

9.66. The emergency plan shall be subject to approval of the regulatory body, as appropriate, and shall be tested in an exercise before radioactive material is introduced into the facility. There shall thereafter be exercises of the emergency plan at suitable intervals, some of which shall be observed by the regulatory body. Some of these exercises shall be integrated with local, regional and national response organizations, as appropriate, and shall involve the participation of as many as possible of the organizations concerned. The plans shall be subject to review and to updating in the light of the experience gained.

9.67. Instruments, tools, equipment, documentation and communication systems to be used in emergency responses shall be maintained in good operating condition and shall be kept available in such a manner that they are unlikely to be affected by, or made unavailable by, the occurrence of postulated accidents.

VERIFICATION OF SAFETY

Periodic safety review

9.68. The operating organization shall carry out a systematic reassessment of the safety of the facility at regular intervals, and in accordance with national regulatory requirements, to deal with the cumulative effects and implications of ageing, modifications, technical developments, operating experience (see para. 4.26) and changes in the site characteristics (see paras 5.9 and 5.10).

9.69. The results of the periodic safety reviews shall be presented by the operating organization to the regulatory body and shall be reflected in updates of the facility licensing documentation.

Audit and review

9.70. Central to the management and verification of safety is the ability of an organization to establish effective review and improvement as an ongoing process. To establish this process, the operating organization shall periodically conduct a review of the facility's operational and safety performance to identify, investigate and correct adverse trends that may have an impact on safety. Such a process shall also cover safety culture, and the improvement of attitudes and the operating environment for safe operation.

9.71. To assist in this process, the operating organization shall carry out a self-assessment programme, including audits and inspections, with the possible use of appropriate performance indicators.

9.72. Guidance on audit and review for nuclear power plants is provided in Ref. [22].

10. DECOMMISSIONING OF THE FACILITY

GENERAL

10.1. The operating organization shall put in place arrangements for the eventual decommissioning of the facility (including funding arrangements), which shall be subject to approval by the regulatory body, well in advance of the shutdown of the facility. Requirements for the decommissioning of a facility are established in Ref. [23].

DECOMMISSIONING PLAN

10.2. **"The licensee shall prepare a decommissioning plan and shall maintain it throughout the lifetime of the facility, in accordance with the requirements of the regulatory body, in order to show that decommissioning can be accomplished safely to meet the defined end state"** (Ref. [23], Requirement 10).

Although some existing facilities may not have been designed or operated with eventual decommissioning in mind, all operational activities, including maintenance, modification and experiments, shall be conducted by the operating organization in a way that will facilitate eventual decommissioning.

10.3. The decommissioning plan shall take into account the storage, treatment, transport and disposal of the waste that is generated during the decommissioning stage.

10.4. To facilitate the implementation of the decommissioning plan and completion of the decommissioning, the operating organization:

(a) Shall retain the necessary resources, expertise and knowledge for design and operation for decommissioning, and shall keep records and documentation relevant to the design, construction, operation and decommissioning processes so that such information can be transferred to any supporting or successor operating organization;
(b) Shall ensure the maintenance of records and documentation for a period of time as specified by the regulatory body following the completion of decommissioning, including key information such as the results of the final radiological survey;
(c) Shall report to the regulatory body on a scheduled basis any safety related information as required by the terms of the licence.

10.5. The decommissioning plan shall be reviewed regularly and shall be updated, as required, to reflect, in particular, changes in the facility or in regulatory requirements, advances in technology and, finally, the needs of the decommissioning operation. If an abnormal event occurs, a new decommissioning plan or modification of the existing decommissioning plan shall be required.

DECOMMISSIONING OPERATION

10.6. When it has been decided to shut down a facility, the organization legally responsible for its decommissioning shall submit to the regulatory body an application for permission to decommission the facility, together with the final decommissioning plan [2, 23].

10.7. If it is intended to shut the facility down and defer decommissioning, it shall be demonstrated in the final decommissioning plan that such an option is safe and that possible occurrences during this shutdown period are taken into account in developing the decommissioning plan. It shall be demonstrated that no undue burdens will be imposed on future generations. An adequate maintenance and surveillance programme, which shall be subject to the approval of the regulatory body, shall be developed to ensure safety during the period of deferment.

10.8. If the shutdown of a facility is sudden, as, for example, in the event of an accident, the facility shall be brought to a safe state before decommissioning is commenced in accordance with an approved decommissioning plan.

10.9. Decommissioning activities may generate large volumes of waste over short time periods, and the waste may vary greatly in type and activity, and may include large objects. The operating organization shall ensure that appropriate means are available to manage the waste safely. Dismantling and decontamination techniques shall be chosen such that the generation of waste and airborne contamination are minimized.

10.10. Decommissioning activities such as decontamination, cutting and handling of large equipment and the progressive dismantling or removal of some existing safety systems have the potential for creating new hazards. The impacts on safety of these activities shall be assessed and managed so that these hazards are mitigated.

10.11. The operating organization shall ensure the protection of both workers and members of the public against exposure, not only in decommissioning but also as a result of any subsequent occupancy or use of the decommissioned site. The operating organization shall apply national radiation protection requirements, established in accordance with Ref. [12].

10.12. Personnel who carry out the decommissioning of the facility shall be properly trained and qualified for such work. The operating organization shall ensure that personnel clearly understand and implement the relevant environmental, health and safety standards.

COMPLETION OF DECOMMISSIONING

10.13. Before a site may be released for unrestricted use, a survey shall be performed to demonstrate that the end point conditions, as established by the regulatory body, have been met. (See Ref. [23], Requirement 15.)

10.14. If a site cannot be released for unrestricted use, appropriate control shall be maintained to ensure protection of human health and the environment. (See Ref. [23], para. 9.3.)

10.15. A final decommissioning report, including any necessary final confirmation survey, shall be prepared and retained with other records, as appropriate.

Appendix I

REQUIREMENTS SPECIFIC TO URANIUM FUEL FABRICATION FACILITIES

The following requirements are specific to uranium fuel fabrication facilities where fuel assemblies (e.g. PWR, BWR, HWR, CANDU and AGR fuel assemblies) are manufactured from UF_6 with low enriched uranium that has a ^{235}U concentration of no more than 6%, derived from natural, highly enriched or reprocessed uranium. They do not apply to facilities that handle natural uranium or uranium metal fuels. Guidance on meeting the requirements for uranium fuel fabrication facilities is provided in Ref. [24].

DESIGN

SAFETY FUNCTIONS

I.1. The facility shall be designed to prevent a criticality accident and the accidental release of hazardous materials. The design shall keep radiation exposures from normal operations as low as reasonably achievable.

ENGINEERING DESIGN

I.2. As with radioactive material, the containment of chemical hazards shall include the control of any route into the workplace or to the environment.

CRITICALITY PREVENTION

I.3. Criticality safety shall be ensured by means of preventive measures.

I.4. Preference shall be given to achieving criticality safety by design, to the extent practicable, rather than by administrative measures.

I.5. Criticality safety shall be achieved by keeping one or more of the following parameters of the system within subcritical limits in normal operations, for anticipated operational occurrences (e.g. the overfilling of a vessel) and for design basis accident conditions or the equivalent (e.g. due to fire, flooding or loss of cooling):

(a) Mass and enrichment of fissile material present in a process;
(b) Geometry (limitation of the dimensions or shape) of processing equipment;
(c) Concentration of fissile material in solutions;
(d) Degree of moderation;
(e) Control of reflectors;
(f) Presence of appropriate neutron absorbers.

I.6. The safety of the design for a uranium fuel fabrication facility shall be demonstrated by means of a specific criticality analysis in which the following important factors are considered both singly and in combination:

(a) Enrichment: the maximum authorized enrichment in any part of the facility shall be used in all assessments unless the impossibility of reaching this level of enrichment is demonstrated in accordance with the double contingency principle.
(b) Mass: criticality safety shall be assessed with significant margins.
(c) Geometry: the analysis shall include the layout of the facility and the dimensions of pipes, vessels and other process units.
(d) Concentration and density: a conservative approach shall be taken.
(e) Moderation: the analysis shall consider a range of degrees of moderation to determine the most reactive conditions that could occur.
(f) Reflection: a conservative assumption concerning reflection shall be made.
(g) Neutron interaction: consideration shall be given to neutron interaction between all facility units that may be involved.
(h) Neutron absorbers: when taken into account in the safety analysis, and if there is a risk of degradation, the presence and the integrity of neutron absorbers shall be verifiable during periodic testing. Uncertainties in absorber parameters (e.g. mass and density) shall be considered in the criticality calculations.

I.7. In accordance with national regulations, criticality safety shall be demonstrated for uranium fuel fabrication facilities in areas where the mass of fissile material exceeds a threshold amount. SSCs important to safety and operational limits and conditions relating to criticality safety shall be derived from such analysis.

CONFINEMENT AGAINST INTERNAL EXPOSURE AND CHEMICAL HAZARDS

Occupational radiation protection

I.8. For the use of gloveboxes (e.g. for the confinement of reprocessed uranium), specifications of design shall be commensurate with the specific hazards of the uranium fuel fabrication facility.

Environmental protection

I.9. The efficiency of filters and their resistance to chemicals (e.g. HF), high temperatures of the exhaust gases and fire conditions shall be taken into consideration.

POSTULATED INITIATING EVENTS

Protection against internal fires and explosions

I.10. A detection and/or suppression system shall be installed that is commensurate with the risks of internal fires and explosions and is in compliance with national requirements.

I.11. The installation of automatic devices with water sprays shall be carefully assessed for areas where uranium may be present, with account taken of the risk of criticality.

I.12. In areas with potentially explosive atmospheres, the electrical network and equipment shall be protected in accordance with industrial safety regulations.

INSTRUMENTATION AND CONTROL SYSTEMS

Safety related instrumentation and control systems for accident conditions

Criticality control

I.13. Radiation detectors (gamma and/or neutron detectors), with audible and, where necessary, visible alarms for initiating immediate evacuation from the affected area, shall cover all the areas where a significant quantity of fissile material is present, unless it can be demonstrated that a criticality accident is highly unlikely to occur.

Monitoring of chemical releases

I.14. Detectors shall be installed in areas with a significant chemical hazard (e.g. due to UF_6, HF) and with limited occupancy, unless it can be demonstrated that a chemical release is highly unlikely.

OPERATION

QUALIFICATION AND TRAINING OF PERSONNEL

I.15. For uranium fuel fabrication facilities, specific attention shall be paid to the qualification and training of personnel for dealing with radiological hazards (mainly criticality and contamination) and specific conventional hazards such as chemical hazards and fire hazards.

I.16. An inappropriate response to a fire or explosion at the facility could increase the consequences of the event (e.g. radiological hazards including criticality, chemical hazards). Specific training and drills for personnel and external fire and rescue staff shall be organized by the operating organization.

FACILITY OPERATION

I.17. If the facility is designed to produce in parallel fuel pellets of different enrichments, operations shall be managed to exclude the mixing of powders, pellets and rods of different enrichments.

I.18. To minimize the number of events occurring, close attention shall be paid to their prevention in anticipated operational occurrences, non-routine operations and secondary operations such as decontamination, washing and preparation for maintenance or testing.

CRITICALITY PREVENTION

I.19. For the transfer of uranium powder or uranium solutions in a uranium fuel fabrication facility, ‘double batching’ (i.e. the transfer of two batches of fissile material instead of one batch in a fuel fabrication process) shall be prevented by design and by means of administrative control measures.

I.20. If uranium has to be removed from vessels or pipework, only approved containers shall be used.

ON-SITE SOLID UF_6 HANDLING

I.21. Consideration shall be given to the impact of a fire on a solid UF_6 cylinder (e.g. fire involving a UF_6 cylinder transporter).

RADIATION PROTECTION

I.22. Close attention shall be paid to the confinement of uranium powders and the control of contamination in the workplace.

EMERGENCY PLANNING AND PREPAREDNESS

I.23. Emergency arrangements shall be put in place for criticality accidents, the release of radioactive material and hazardous chemical materials, principally F_2, UF_6, HF and NH_3, the spread of fires and explosions.

I.24. In dealing with a fire, a firefighting medium shall be used that does not itself create a criticality hazard.

Appendix II

REQUIREMENTS SPECIFIC TO MIXED OXIDE FUEL FABRICATION FACILITIES

The following requirements are specific to MOX fuel fabrication facilities that handle, process and store: (a) weapon grade and civil grade plutonium oxide; (b) depleted, natural or reprocessed uranium oxide; and/or (c) MOX manufactured from the above to be used as a feed material to form MOX fuel rods and assemblies for export and subsequent use in LWRs and FBRs. The processes covered are dry, and these requirements do not apply to preprocessing, or polishing, of oxide powders. Guidance on meeting the requirements for MOX fuel fabrication facilities is provided in Ref. [25].

DESIGN

SAFETY FUNCTIONS

II.1. The facility shall be designed to prevent a criticality accident and the accidental release of hazardous materials. The design shall keep radiation exposures from normal operations as low as reasonably achievable.

ENGINEERING DESIGN

II.2. By design, occupational radiation exposure shall be solely external exposure and there shall be no measurable internal doses to workers in normal operation. To avoid internal doses in normal operation, the design objective shall be to contain radioactive material, to minimize its spread to work areas and to detect very low levels of airborne contamination.

CRITICALITY PREVENTION

II.3. Criticality safety shall be ensured by means of preventive measures.

II.4. Preference shall be given to achieving criticality safety by design, to the extent practicable, rather than by means of administrative measures.

II.5. Criticality safety shall be achieved by keeping one or more of the following parameters of the system within subcritical limits in normal operations, for anticipated operational occurrences and for design basis accident conditions (or the equivalent):

(a) PuO_2 (input):
   (i) Mass and geometry in accordance with the safety specification of PuO_2 isotopic composition and moderation;
   (ii) Presence of appropriate neutron absorbers.
(b) UO_2 (input): mass and geometry in accordance with the safety specification of UO_2 isotopic composition and moderation.
(c) MOX powder: MOX powder is formed in the fuel fabrication process, and the associated criticality hazard shall be assessed in accordance with the isotopic specification and the PuO_2 content at each stage of the process. Mass, geometry and moderation shall be considered.

II.6. For laboratories and, if necessary, for solid plutonium waste, the safe mass and geometry (for storage) of plutonium shall be assessed with the isotopic composition as determined in para. II.5(a) or para. II.5(c).

II.7. The safety of the design for a MOX fuel fabrication facility shall be demonstrated by means of a specific criticality analysis in which the following important factors are considered both singly and in combination:

(a) Plutonium isotopic composition, PuO_2 content and uranium enrichment (if $^{235}U > 1\%$): the maximum authorized compositions in any part of the process shall be used in all assessments unless the impossibility of reaching this Pu composition or content (and uranium enrichment, if needed) is demonstrated in accordance with the double contingency principle.
(b) Mass: criticality safety shall be assessed with significant margins.
(c) Geometry: the analysis shall include the layout of the facility (storages), and the dimensions of pipes, vessels and other process units.
(d) Density and form of materials: a conservative approach shall be taken.
(e) Concentration and density (in analytical laboratories and liquid effluent units): a conservative approach shall be taken.
(f) Moderation: the analysis shall consider a range of degrees of moderation to determine the most reactive conditions that could occur.
(g) Reflection: a conservative assumption concerning reflection shall be made in the criticality analysis.
(h) Neutron interaction: consideration shall be given to neutron interaction between all facility units that may contain fissile materials.

(i) Neutron absorbers: when taken into account in the safety analysis, and if there is a risk of degradation, the presence and integrity of neutron absorbers shall be verifiable during periodic testing. Uncertainties in absorber parameters (e.g. mass and density) shall be considered in the criticality calculations.

II.8. In accordance with national regulations, criticality safety shall be demonstrated for MOX fuel fabrication facilities in areas where the mass of the fissile material exceeds a threshold amount. SSCs important to safety and operational limits and conditions relating to criticality safety shall be derived from such analysis.

CONFINEMENT OF NUCLEAR MATERIAL

II.9. Containment shall be the primary method for confinement against the spread of powder contamination. Containment shall be provided by two complementary containment systems — static and dynamic:

(a) The static containment system shall consist of at least two static barriers between radioactive material and the environment.
(b) The dynamic containment system shall be used to create airflow towards equipment with higher levels of contamination.

II.10. The MOX fuel fabrication facility shall be specifically designed to ensure that, in normal operations, radioactive material is confined inside the first static barrier. The second static barrier shall be designed with features for the control of airborne contamination to minimize the radiation exposures of workers in operational states and to limit contamination within the facility to the extent practicable.

II.11. In the design of a MOX fuel fabrication facility, account shall be taken of the performance criteria for ventilation and containment systems, including the pressure difference between zones, the types of filter to be used, the differential pressure across filters and the appropriate flow velocity for operational states.

II.12. The efficiency of filters and their resistance to chemicals, high temperatures of the exhaust gases and fire conditions shall be taken into consideration.

Occupational protection

II.13. MOX fuel fabrication facilities shall be designed with an appropriately sized ventilation system in areas of the facility that have been identified as having significant potential for concentrations of airborne hazardous material.

Environmental protection

II.14. If there is a likelihood that leakage may occur at, or may bypass, the filter connection, the design shall accommodate the testing (in accordance with accepted standards such as those of the International Organization for Standardization (ISO) and the American Society of Mechanical Engineers (ASME)) of removal efficiencies for last stage filters to ensure that they correspond to the removal efficiency used in the design.

POSTULATED INITIATING EVENTS

Protection against internal fires and explosions

II.15. A detection and/or suppression system shall be installed that is commensurate with the risk of fire and is in compliance with national requirements.

II.16. Extinguishing devices, automatically or manually operated, with the use of an adequate extinguishing material shall be installed in areas where a fire is possible and where the consequences of a fire could lead to the wide dispersion of contamination outside the first static barrier. The installation of automatic devices with water sprays shall be carefully assessed for areas where uranium, plutonium and/or MOX powder may be present, with account taken of the risk of criticality.

II.17. In areas with potentially explosive atmospheres, the electrical network and equipment shall be protected in accordance with industrial safety regulations.

Leaks and spills

II.18. In process areas where a moderation mode is used for criticality control, unless account is taken of the presence of liquids or the possible leakage of liquids in criticality assessments, liquid pipes shall be excluded or a minimum of two physical barriers shall be used in normal conditions and in other facility conditions, or the amount of liquid shall be limited and controlled by design (e.g. oil for the pellet press).

II.19. Liquids may be used in laboratories. Their use shall be limited and controlled, if necessary, by means of detection systems to detect spillage.

II.20. Spillages of radioactive material (powder) from process vessels shall be contained in gloveboxes, but such spillages may still lead to criticality hazards. The possibility of such events shall be considered in the safety analysis.

Loss of decay heat removal

II.21. The cooling systems shall be assessed in accordance with the safety functions of the MOX fuel fabrication facility.

Load drops

II.22. Handling systems shall be designed to reduce the frequency of occurrence of load drops. The consequences of possible load drops shall be minimized.

Mechanical failure

II.23. Measures for the industrial safety of non-nuclear-designed equipment installed in gloveboxes (e.g. mechanical guards) shall be adapted to the nuclear environment.

INSTRUMENTATION AND CONTROL SYSTEMS

Safety related instrumentation and control systems in normal operations

Criticality control

II.24. In normal operations, a number of parameters shall be measured and controlled to prevent a criticality. These parameters shall be of high integrity and shall be calibrated against known standards. Changes to computer codes and data shall be controlled to a high standard by means of the management system.

Glovebox control

II.25. Gloveboxes shall be equipped with instrumentation and control systems for fulfilling the requirements for a negative pressure.

Monitoring of internal doses

II.26. Equipment shall be installed to continuously sample air in the breathing zone of workers for the retrospective assessment of doses due to internal exposure. Portable and installed equipment shall be able to detect surface contamination on people, equipment, products and other objects to verify the effective confinement of radioactive material.

Control of gaseous effluents

II.27. Real time measurements shall be made to confirm that filtration systems are working effectively. Discharges shall be measured continuously.

Safety related instrumentation and control systems for accident conditions

Criticality control

II.28. Radiation detectors (gamma and/or neutron detectors), with audible and, where necessary, visible alarms for initiating immediate evacuation from the affected area, shall cover all the areas where a significant quantity of fissile material is present, unless it can be demonstrated that a criticality accident is highly unlikely to occur.

RADIOACTIVE WASTE MANAGEMENT

Generation of waste

II.29. All situations in which waste may be generated shall be considered in order to ensure that the potential impact of the waste on the safety of the facility is considered, that its generation is minimized, and that a means is available for its handling, collection and disposition.

Removal of waste

II.30. Waste shall be first bagged in the glovebox and then removed from the glovebox using bagging ports in which a bag is attached to the glovebox and the waste is inserted and then removed after sealing to maintain confinement. The size of the port shall be such as to accommodate the expected waste, which may include equipment that has been replaced. Filters from the gloveboxes and the ventilation system shall have engineered features. In all cases, the arrangements shall ensure confinement, criticality control (if necessary) and control of operator doses.

Collection of waste

II.31. Design features shall be provided for the collection and transport of waste in containers to provide an additional level of confinement. Consideration shall be given to criticality control, if necessary, and radiation exposure of the operator when a number of bags of waste are collected.

Interim storage of waste

II.32. Stores shall be designed to ensure control of criticality, if necessary, control of confinement and control of the radiation exposure of operators.

MANAGEMENT OF AERIAL AND LIQUID RELEASES

II.33. Discharges shall be measured continuously.

OTHER DESIGN CONSIDERATIONS SPECIFIC TO MOX FUEL FABRICATION FACILITIES

Intermediate MOX and PuO_2 storages

II.34. In the design of intermediate MOX and PuO_2 storages for MOX fuel fabrication facilities, consideration shall be given to:

(a) Criticality;
(b) Fire;
(c) Confinement;
(d) Heat removal (if appropriate);

(e) Exposure of operators due to entering the store and handling the material;
(f) Access to respond to anticipated operational occurrences such as dropped trays of pellets;
(g) Maintenance of the in-store handling, lifting and transfer equipment.

Maintenance policy

II.35. The maintenance policy shall be determined before the design is established.

CONSTRUCTION

II.36. The construction of MOX fuel fabrication facilities tends to take a number of years, as they are complex facilities, and construction workers, including engineers and architects, may move away to other work and be replaced. Knowledge and experience relating to construction shall be maintained during the construction period.

COMMISSIONING

II.37. Plutonium or 'hot processing' commissioning requires major changes in personnel and equipment, containment, criticality and radiation control arrangements:

— For the workforce, the safety culture shall be enhanced so as to ensure safe operation with plutonium.
— The management shall ensure that both the facility and the workforce are fully ready for the change before it is implemented.

OPERATION

QUALIFICATION AND TRAINING OF PERSONNEL

II.38. Special attention shall be paid to training workers in glovebox operations, including actions to be taken if contamination occurs.

II.39. For MOX fuel fabrication facilities, specific attention shall be paid to the qualification and training of personnel for dealing with the radiological hazards (e.g. criticality, external exposure, contamination) and specific conventional hazards (e.g. fire), security and emergency drills.

II.40. An inappropriate response to a fire or explosion at the facility could increase the consequences of the event (e.g. radiological hazards including criticality, chemical hazards). Specific training of external firefighters and rescue staff shall be organized by the operating organization.

CRITICALITY PREVENTION

II.41. If PuO_2 or MOX powder has to be removed from equipment, only approved containers shall be used.

RADIATION PROTECTION

II.42. Close attention shall be paid to the confinement of PuO_2 and MOX powders and to the control of contamination in the workplace.

II.43. Dose measuring equipment shall be adapted to ensure that it correctly measures gamma and neutron radiation doses.

EMERGENCY PLANNING AND PREPAREDNESS

II.44. Emergency arrangements shall be put in place for criticality accidents, the release of radioactive material, the spread of fires and explosions.

II.45. In dealing with a fire, a firefighting medium shall be used that does not itself create a criticality hazard.

DECOMMISSIONING

II.46. Criticality safety shall be ensured for the temporary storage of waste contaminated with plutonium that is generated by the dismantling of gloveboxes and their contents.

Appendix III

REQUIREMENTS SPECIFIC TO CONVERSION FACILITIES AND URANIUM ENRICHMENT FACILITIES

The following requirements are specific to conversion facilities and enrichment facilities that handle, process and store depleted, natural and low enriched uranium that has a ^{235}U concentration of no more than 6%, which could be derived from natural, highly enriched, depleted or reprocessed uranium. Guidance on meeting the requirements for conversion facilities and uranium enrichment facilities is provided in Ref. [26].

DESIGN

SAFETY FUNCTIONS

III.1. The facility shall be designed to prevent a criticality accident and the accidental release of hazardous materials. The design shall keep radiation exposures from normal operations as low as reasonably achievable.

ENGINEERING DESIGN

III.2. With regard to the engineering design:

(a) For criticality prevention, vessels shall be designed for the maximum authorized enrichment limit.
(b) As with radioactive material, in conversion facilities and enrichment facilities, protection against chemical hazards shall include the control of any route for chemicals into the workplace and to the environment.

CRITICALITY PREVENTION

III.3. Criticality safety shall be ensured by means of preventive measures.

III.4. Preference shall be given to achieving criticality safety by design, to the extent practicable, rather than by administrative measures.

III.5. Criticality safety for conversion facilities and enrichment facilities shall be achieved by keeping one or more of the following parameters of the system within subcritical limits in normal operations, for anticipated operational occurrences and for design basis accidents (or the equivalent):

(a) Mass and enrichment of fissile material present in a process;
(b) Geometry and interaction (limitations on dimensions, shape or spacing) of processing equipment;
(c) Concentration of fissile material in solutions;
(d) Degree of moderation;
(e) Presence of appropriate neutron absorbers.

III.6. The safety of the design for conversion facilities and enrichment facilities shall be demonstrated by means of a specific criticality analysis in which the following important factors are considered both singly and in combination:

(a) Enrichment: the maximum authorized enrichment in any part of the facility able to process fissile material shall be used in all assessments, unless for a particular part of the facility it can be demonstrated, in accordance with the double contingency principle, that a lower enrichment can be used for the assessment.
(b) Mass: criticality safety shall be assessed with significant margins.
(c) Geometry: the analysis shall include the layout of the facility, and the dimensions of pipes, vessels and other process units. The potential for changes in dimensions during operation shall be considered.
(d) Concentration: a conservative approach shall be taken. A range of uranium concentrations for solutions shall be considered in the analysis to determine the most reactive conditions that could occur. Unless the homogeneity of the solution can be guaranteed, the worst case concentration of uranium in the processing and storage parts of the facility shall be considered.
(e) Moderation: the analysis shall consider a range of degrees of moderation to determine the most reactive conditions that could occur.
(f) Reflection: a conservative assumption for reflection shall be made in the criticality analysis.
(g) Neutron interaction: consideration shall be given to neutron interaction between all facility units that may be involved, including any mobile unit that may approach the array.
(h) Neutron absorbers: when taken into account in the safety analysis, and if there is a risk of degradation, the presence and the integrity of neutron absorbers shall be verifiable during periodic testing. Uncertainties in absorber parameters shall be considered in the criticality calculations.

III.7. In accordance with national regulations, criticality safety shall be demonstrated for conversion facilities and enrichment facilities in areas where the mass of fissile material exceeds a threshold amount. SSCs important to safety, and operational limits and conditions relating to criticality safety shall be derived from such analysis.

CONFINEMENT OF RADIOACTIVE MATERIAL

Occupational protection

III.8. The care taken to minimize contamination shall be commensurate with the enrichment and the proportion of the uranium that is reprocessed uranium. The higher the enrichment (and thus the effect of ^{234}U) and the greater the proportion of the uranium that is reprocessed uranium (and thus the effects of ^{234}U and of traces of transuranic elements and fission products), the greater the care that shall be taken to minimize contamination.

Environmental protection

III.9. The efficiency of filters and their resistance to chemicals (e.g. HF and NH_3), high temperatures of the exhaust gases and fire conditions shall be taken into consideration.

POSTULATED INITIATING EVENTS

Protection against internal fires and explosions

III.10. A detection and/or suppression system shall be installed, in accordance with the risks and the national requirements.

III.11. The installation of automatic firefighting devices with water sprays shall be assessed with care for areas where UF_6 is present, with account taken of the potential risk of HF generation and criticality events for enriched material.

III.12. In areas with potentially explosive atmospheres, the electrical network and equipment shall be protected in accordance with industrial safety regulations.

INSTRUMENTATION AND CONTROL SYSTEMS

Safety related instrumentation and control systems in normal operations

III.13. Before heating a UF_6 cylinder, the weight of UF_6 shall be measured and shall be confirmed to be below the fill limit (e.g. by using a second independent weighing scale).

III.14. If the system has the capability of reaching a temperature where hydraulic rupture can occur, the temperature during heating shall be limited by means of two independent systems.

III.15. In diffusion enrichment facilities, in-line contaminant concentration detectors shall be used (e.g. detectors using freons and oil infrared analysers) to avoid uncontrolled chemical reactions between UF_6 and possible impurities.

Safety related instrumentation and control systems for accident conditions

Criticality control

III.16. Radiation detectors (gamma and/or neutron detectors), with audible and, where necessary, visible alarms for initiating immediate evacuation from the affected area, shall cover all the areas where a significant quantity of fissile material is present, unless it can be demonstrated that a criticality accident is highly unlikely to occur.

Monitoring of chemical releases

III.17. Detectors shall be installed in areas with a significant chemical hazard (e.g. due to UF_6, HF or ClF_3) and with limited occupancy, unless it can be demonstrated that a chemical release is highly unlikely.

OPERATION

QUALIFICATION AND TRAINING OF PERSONNEL

III.18. In conversion facilities and enrichment facilities, specific attention shall be paid to the qualification and training of personnel for dealing with radiological hazards (mainly criticality and contamination) and specific conventional hazards such as chemical hazards or fire hazards.

III.19. The operators shall be given training in the safe handling and processing of large quantities of UF_6 and other hazardous chemicals, the level of detail of which shall be commensurate with the risks associated with the operation. For releases of UF_6 and other chemical releases that result in visible clouds, periodic training shall be given to all site personnel to follow the procedure of "see, evacuate or shelter, and report".

III.20. Training shall be conducted on:

(a) Prevention and mitigation of fires and explosions that could result in radioactive releases;
(b) The implementation of criticality controls associated with operations involving enriched uranium.

III.21. An inappropriate response to a fire or explosion at the facility could increase the consequences of the event (e.g. radiological hazards including criticality, chemical hazards). Specific training of external firefighting and rescue staff shall be organized by the operating organization.

MAINTENANCE, PERIODIC TESTING AND INSPECTION

III.22. Long term deterioration of UF_6 cylinders and corrosion damage to the plugs and valves due to both internal and external influences are recognized as possible sources of leakage problems. An inspection programme shall be established at long term storage facilities to monitor and record the level of corrosion (particularly at plugs and valves, and along the skirt welds).

CRITICALITY PREVENTION

III.23. Where there could be high concentrations of HF in the product stream of an enrichment facility, the pressure shall be maintained below the vapour pressure of HF at that temperature to avoid the condensation of HF during crystallization (desublimation) of UF_6 in a cylinder or intermediate vessel.

III.24. If uranium has to be removed from vessels or pipework, only approved containers shall be used.

RADIATION PROTECTION

III.25. Adequate ventilation and/or respiratory protection shall be provided for protecting workers and for controlling the spread of contamination when equipment and containers holding radioactive material such as UF_6 cylinders are opened.

III.26. Adequate time, distance and shielding requirements shall be instituted for workers, such as UF_6 cylinder handlers, who could potentially be exposed to significant direct radiation fields.

RISK OF OVERFILLING OF CYLINDERS

III.27. Cylinder fill limits shall be established to ensure that heating of an overfilled cylinder does not result in the rupture of the cylinder.

RISK OF OVERHEATING OF CYLINDERS

III.28. Where there is a potential to heat a cylinder to a temperature above that of the UF_6 triple point, the weight of the cylinder shall be verified to be below its fill limit by means of a weighing scale, which shall be identified as important to safety.

III.29. If the system has the capability of reaching a temperature where hydraulic rupture can occur, the temperature during heating shall be limited by means of two independent systems. In the event of an overfilled cylinder, UF_6 in excess shall be transferred by sublimation only.

ON-SITE SOLID UF_6 HANDLING

III.30. Consideration shall be given to the impact of a fire on a solid UF_6 cylinder (e.g. fire involving a UF_6 cylinder transporter).

EMERGENCY PLANNING AND PREPAREDNESS

III.31. An emergency plan shall be prepared and shall be focused on the following aspects for immediate response:

(a) The chemical toxicity of UF_6 and its reaction products (HF and UO_2F_2), which is predominant over uranium's radiotoxicity;
(b) The rapid progression, with no grace period, of most scenarios leading to toxicological consequences.

III.32. In dealing with a fire or a UF_6 release, the actions taken or the medium used to respond to the emergency shall not create a criticality event or add to the chemical hazard.

DECOMMISSIONING

III.33. The uranium from the post-operational clean-out shall be recovered as far as is practicable.

III.34. In the active decommissioning of conversion facilities and enrichment facilities, before wet cleaning, loss of criticality control shall be prevented by means of the following process, which may be iterative:

(1) Visually checking for uranium hold-up;
(2) Proceeding to dry cleaning in the event of uranium hold-up;
(3) Measuring ^{235}U mass hold-up if visual inspection is not possible (further dismantling and dry cleaning shall be conducted if a significant amount of ^{235}U is measured).

III.35. Special procedures shall be implemented to ensure that criticality control is maintained in dismantling equipment whose criticality is controlled by geometry.

Appendix IV

REQUIREMENTS SPECIFIC TO REPROCESSING FACILITIES

The following requirements are specific to reprocessing facilities using liquid–liquid extraction processes (e.g. plutonium and uranium recovery by extraction (PUREX) processes) on an industrial scale. Reprocessing facilities are involved in the treatment of spent fuel from nuclear power plants and from research reactors to recover fissile material (uranium and plutonium) for the manufacture of fresh fuel, e.g. MOX fuel for light water reactors or fuel for fast breeder reactors. The processes covered here are: the shearing, decladding and dissolution of spent fuel; all the chemical cycles of separation and purification (including removal of solvents from aqueous solutions, treatment and reconditioning of solvents, and recovery of acids); the concentration of fission products and plutonium nitrate and uranium nitrate; the conversion of plutonium nitrate and uranium nitrate to oxides; and the storage of these products and the interim storage of waste from the process stream (e.g. the storage of solutions of fission products in vessels).

In reprocessing facilities, the full range of radioactive materials and risks that may be encountered in the nuclear fuel cycle are present.

This appendix does not cover processes such as those that are carried out in cask unloading facilities, spent fuel storage facilities and waste conditioning facilities, e.g. facilities for vitrification of high level waste or for immobilization of radioactive sludge. Safety requirements for waste conditioning facilities are provided in Ref. [2].

SITING

IV.1. In the siting of new reprocessing facilities on complex and large site areas, which may contain a number of facilities, account shall be taken of the potential for interactions with existing facilities, irrespective of their status (i.e. under construction, under commissioning, in operation, shutdown or being decommissioned). Requirements for site evaluation for nuclear installations are established in Ref. [17].

DESIGN

SAFETY FUNCTIONS

IV.2. The facility shall be designed to prevent a criticality accident and the accidental release of hazardous materials. The design shall keep radiation exposures from normal operations and accident conditions as low as reasonably achievable.

ENGINEERING DESIGN

IV.3. The design shall take into account feedback from operating experience at similar facilities and relevant operating experience at other industrial facilities.

Cooling

IV.4. Cooling systems, including any support features, shall have adequate capacity, availability and reliability to remove heat from radioactive decay or, if necessary, heat due to chemical reactions.

IV.5. Cooling systems, including any support features, for removing heat due to chemical reactions shall have adequate capacity, availability and reliability to prevent an uncontrolled increase in temperature, e.g. from a fire during the dissolution of metal spent fuel in nitric acid.

IV.6. Cooling systems shall be designed to minimize the risk from coolant leaking into areas where this could cause a criticality hazard.

Sampling and analysis

IV.7. Appropriate means shall be provided for measuring the parameters that are relevant to the safety of the reprocessing facility:

- In normal operation to ensure that all processes are being conducted within the operating limits and conditions and to monitor their environmental impact;
- For detecting and managing accident conditions, such as criticality.

IV.8. Provision shall be made for monitoring radioactive effluents and effluents with possible contamination, prior to and during their discharge from the facility to the environment.

CRITICALITY PREVENTION

IV.9. Criticality safety shall be ensured by means of preventive measures.

IV.10. Preference shall be given to achieving criticality safety by engineering design, to the extent practicable, rather than by administrative measures.

IV.11. As part of the overall safety assessment of the facility, a criticality safety assessment shall be performed prior to the commencement of any activity involving fissile material. The wide range of possible forms of fissile material and their associated process conditions shall be taken into account in the assessment. Safety criteria and safety margins shall be developed to ensure subcriticality on the basis of the neutron multiplication factor, k_{eff}, and/or on the basis of control parameters such as geometry, mass, concentration, density, enrichment or moderation.

IV.12. A reference composition for the fissile material (reference fissile medium) shall be defined. The criticality safety assessment performed using such a reference shall be a conservative bounding case for the actual composition of the fissile material being handled or processed, e.g. on the basis of its mass, volume and isotopic composition. It shall be ensured by means of the assessment that processes are conducted within the operating limits and conditions.

IV.13. A reference flowsheet shall be defined. This shall specify compositions and flow rates for active feed material and reagent feed material. Faults relating to incorrect reagent flows or compositions having the potential to impact criticality safety shall be assessed.

IV.14. Particular consideration shall be given to those system interfaces[9] for which there is a change in the state of the fissile material[10] or in the criticality control mode. Particular consideration shall also be given to the transfer of fissile

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[9] System interfaces may occur in the course of transfer of fissile material between different locations, e.g. between different processes, process vessels, subfacilities or rooms.

[10] The state of the fissile material includes, for example, its physical and chemical forms and concentration.

material from equipment with a safe geometry to equipment with a geometry not meeting the safety criteria.

IV.15. If the design of the reprocessing facility takes into account burnup credit, its use shall be appropriately justified in the criticality safety assessment.

IV.16. In the criticality safety assessment, account shall be taken of the potential for misdirection, accumulation, overflow and spills of fissile material (e.g. mis-transfer due to human error) or for carry-over of fissile material (e.g. from evaporators). Consideration shall be given to the potential for leaks to evaporate, leading to an increase in concentrations, particularly if there is a potential for fissile material to leak onto a hot surface.

IV.17. In the criticality safety assessment, the choice of fire extinguishing media (e.g. water or powder) and the safety of their use shall be addressed.

IV.18. In the criticality safety assessment, account shall be taken of the effects of corrosion, erosion and vibration in systems exposed to oscillations, e.g. leaks and changes in geometry. When criticality control of fissile liquid is achieved by geometry, loss of containment shall be anticipated by, for example, the use of criticality safe drip trays or detection of liquid level.

IV.19. In the criticality safety assessment, consideration shall be given to the potential for internal and external flooding and other internal and external hazards that may compromise measures for criticality prevention.

IV.20. In the criticality safety assessment, the potential use of neutron poisons such as gadolinium or boron shall be addressed, in normal operation (e.g. to increase the safe mass of fissile material in a dissolver), during deviations from normal operation (e.g. dilutions of soluble neutron poisons below a specified limit of concentration) and in accident conditions.

CONFINEMENT OF RADIOACTIVE MATERIAL

IV.21. Containment shall be the primary method for confinement against the spread of contamination. Confinement shall be provided by two complementary containment systems — static (e.g. physical barrier) and dynamic (e.g. ventilation). The containment systems shall be designed:

- To prevent unacceptable dispersion of airborne contamination within the facility;
- To keep the levels of airborne contamination within the facility below authorized limits and as low as reasonably achievable.

IV.22. The static containment shall have at least one static barrier between radioactive materials and operating areas (workers) and at least one additional static barrier between operating areas and the environment.

IV.23. The dynamic containment shall be designed to create a pressure differential to induce airflow toward areas that are more contaminated. The static containment shall be designed such that its effectiveness is maintained as far as achievable in case of loss of dynamic confinement.

IV.24. In the design, account shall be taken of the performance criteria for the ventilation system, including the pressure difference between zones, the types of filter to be used, the differential pressure across filters and the appropriate flow velocity for operational states.

IV.25. The efficiency of filters, including improper installation resulting in efficiency loss, and factors potentially damaging the filters (e.g. their resistance to high humidity, chemicals, high temperatures and high pressure of the exhaust gases, and to fire conditions), and the buildup of materials shall be taken into consideration. The ventilation system design, including filters, shall facilitate testing.

Occupational protection

IV.26. In normal operation, internal exposure shall be minimized by design and shall be as low as reasonably achievable.

IV.27. Consideration shall be given to the potential for radiation exposure from leakage or misdirection of radioactive material.

IV.28. The design and layout of plant equipment shall include provisions to minimize exposure arising from maintenance, inspection and testing activities, as far as practicable. Specific attention shall be paid to design of equipment installed in hot cells, e.g. high active units.

IV.29. Within the design of the facility, consideration shall be given to further increasing shielding designed to address external exposure, where practicable, in order to reduce the consequences of a criticality accident.

IV.30. The design and layout of shielding shall take account of its potential for degradation.

Protection of the public and environmental protection

IV.31. Systems shall be provided at the reprocessing facility for the treatment of liquid and gaseous radioactive effluents to keep their amounts below the authorized limits for discharges and as low as reasonably achievable.

IV.32. In the design of the reprocessing facility, it shall be ensured that aerial and liquid radioactive effluents from the reprocessing facility site are collected, appropriately treated (e.g. filtered) and confirmed to be within authorized limits prior to their discharge, through appropriate means, to the environment.

POSTULATED INITIATING EVENTS

Internal initiating events

Fire and explosion

IV.33. The risk of fire, explosion and excess internal pressure due to the following shall be considered, and appropriate safety measures shall be implemented:

— The use of explosive gases, flammable liquids and chemical substances such as hydrogen or hydrogen peroxide, nitric acid, tributyl phosphate (TBP) and its diluents, and hydrazine nitrate;
— The generation of hydrogen by radiolysis in aqueous or organic solutions and solids;
— The formation of explosive or flammable products by chemical reactions, e.g. nitrated organic substances (red oils);
— Pyrophoric materials, e.g. small particles of zircaloy.

IV.34. In areas with potentially explosive atmospheres, the electrical network and equipment shall be adequately protected.

IV.35. A detection and alarm system and/or suppression system shall be installed that is commensurate with the risk of fires and explosions.

IV.36. In order to prevent the propagation of a fire through ventilation ducts and to maintain the integrity of firewalls, ventilation systems shall be equipped with fire dampers at appropriate locations.

Equipment failure

IV.37. In the design of a reprocessing facility, plant equipment for use in a radiological and nuclear environment shall be suitably assessed for its adequate performance or potential failure. Measures for the industrial safety of non-nuclear-designed equipment installed in gloveboxes or hot cells (e.g. mechanical guards, fuses, seals, insulation) shall be adapted to the environment, if necessary.

Leaks

IV.38. Provisions to prevent, detect and collect leaks arising from corrosion, erosion and vibration in systems exposed to oscillations shall be implemented. Consideration shall be given to equipment containing acid solutions, especially when such solutions are at high temperatures.

Flooding

IV.39. Reprocessing facilities shall be designed to prevent leakage of contaminated liquid to the environment in the event of internal flooding.

Loss of support systems

IV.40. In the design of a reprocessing facility, the potential for a long term loss of support systems and support features, such as cooling and energy supplies, that are required by a safety system shall be considered and the impact of such a loss on safety shall be assessed.

IV.41. The design of the electrical power supply to a reprocessing facility shall ensure its adequate availability, sustainability[11] and reliability. In the event of a loss of normal power, even for a significant period, e.g. several days, an

[11] Sustainability, in this context, means having the capability to perform its required function for an extended period of time, such that a safe state can be reached or alternative provisions can be put in place.

emergency electrical supply shall be provided to the relevant items important to safety, which will depend on the operational status of the reprocessing facility (e.g. normal operation, shutdown, maintenance or clean-out of the facility). The restoration of the electrical power supply shall be planned and exercises shall be carried out to ensure its adequate and timely deployment following such a loss of normal power.

Load drops

IV.42. In the design of a reprocessing facility, the possibility of load drops shall be considered and their impact on safety shall be assessed.

Missiles

IV.43. In the design of a reprocessing facility, the possibility of missiles generated by rotating components shall be considered and their impact on safety shall be assessed.

External initiating events

Earthquake

IV.44. Considering seismic hazards, an adequately conservative ground motion shall be selected to ensure:

— The stability of buildings and transfer canals between buildings and to ensure the ultimate barrier of confinement in the case of an earthquake, taking into consideration the consequences to the workers, the public and the environment;
— Availability of relevant SSCs during and after the earthquake.

IV.45. Provisions (e.g. instrumentation, support systems, procedures) shall be provided for post-earthquake monitoring of the status and safety functions of the reprocessing facility.

Extreme weather conditions

IV.46. Extreme weather conditions shall be taken into account in the design of items important to safety (including their location), in particular for cooling systems for the removal of decay heat in the storage of high level waste.

INSTRUMENTATION AND CONTROL SYSTEMS

Instrumentation

IV.47. Adequate means shall be provided for measuring process parameters that are relevant to the safety of the reprocessing facility:

— In normal operation, to ensure that all processes are being conducted within the operating limits and conditions, and to provide an indication of significant deviations in processes;
— For detecting and managing accident conditions, such as criticality or adverse effects due to external hazards such as an earthquake or flooding (e.g. fire, release of hazardous materials, loss of support systems).

IV.48. When used, automated control systems shall be designed to be highly reliable, consistent with their role in the safety of the facility.

RADIOACTIVE WASTE AND EFFLUENT MANAGEMENT

IV.49. The design of the reprocessing facility shall enable safe management of radioactive waste and effluents arising from operational states, maintenance and periodic clean-out of the facility. Due consideration shall be given to the various natures, compositions and activity levels of the waste generated in the facility.

IV.50. The design of reprocessing facilities shall endeavour, as far as practicable, to ensure that all wastes anticipated to be produced during the life cycle of the facility have designated disposal routes. Where these routes do not exist at the design stage of the reprocessing facility, provisions shall be made to facilitate envisioned future options.

COMMISSIONING

COMMISSIONING PROGRAMME[12]

IV.51. Particular consideration shall be given to ensuring that no commissioning tests are performed that might place the facility in an unanalysed or unsafe condition. Each safety function shall be verified as fully as practicable before proceeding to a stage in which that function becomes necessary.

IV.52. The ability to test and maintain the reprocessing facility's SSCs after operation commences shall be addressed in the commissioning programme, especially for hot cells and remote equipment.

COMMISSIONING STAGES

Inactive commissioning

IV.53. Inactive commissioning (or 'cold processing') includes all commissioning and inspection activities with and without the use of non-active solutions, before the introduction of radioactive material.

IV.54. The following activities shall, as a minimum, be performed[13]:

- — Confirmation of the performance of shielding and confinement systems, including confirmation of the weld quality of the static containment;
- — Confirmation, where practicable, of the performance of criticality control measures;
- — Demonstration of the availability of criticality detection and alarm systems;
- — Demonstration of the performance of emergency shutdown systems;
- — Demonstration of the availability of the emergency power supply;
- — Demonstration of the availability of any other support systems, e.g. compressed air supply and cooling.

[12] Owing to the large size of commercial reprocessing facilities, handover from construction to commissioning is often carried out in phases.

[13] In some States, some of the activities are performed at the construction stage, in accordance with national requirements.

Active commissioning

IV.55. By the end of active commissioning (or ‘hot processing’), all the safety requirements for active operations shall be met. Any exceptions shall be justified in the safety case for commissioning.

IV.56. During commissioning, operational limits and normal values for safety significant parameters shall be confirmed, as shall acceptable variation values due to facility transients and other small perturbations.

Commissioning report

IV.57. The commissioning report shall identify any updates required to the safety case and any changes made to safety measures or work practices during commissioning.

OPERATION

IV.58. Spent fuel acceptance criteria and a feed programme[14] shall be prepared and assessed to ensure that the requirements established in the operating licence and in the safety assessment are met throughout the reprocessing processes, and to ensure that there is no unacceptable impact on products from the reprocessing facility, on the waste generated or on discharges.

MANAGEMENT SYSTEM

IV.59. In accordance with the complexity of the design of the reprocessing facility and its hazard potential, the operating organization shall establish and maintain the quality of the interfaces and communication channels between different groups of personnel within the reprocessing facility and between the reprocessing facility and other facilities both on the site and off the site.

[14] The feed programme is the planned sequence of fuel feeding to the head-end part of the reprocessing facility, including the dissolver.

Receipt of radioactive material

IV.60. Procedures shall be developed to ensure that radioactive material received at the facility is appropriately characterized and acceptable before it is stored at or used within the facility.

FACILITY OPERATION

IV.61. The feed programme shall be supported by appropriate fuel data, prior to committing to dissolution of the fuel, to confirm that the characteristics of the fuel meet the safety requirements for the feed programme.

IV.62. For each reprocessing campaign, the values of control parameters shall be determined on the basis of the actual characteristics of the fuel and fuel solution to be reprocessed in the actual feed programme for that campaign, and as required by the safety assessment.

Operational documentation

IV.63. Operating instructions and procedures shall include the action(s) to be taken in the event that the operational limits and conditions are exceeded, to ensure that corrective action is taken to prevent the exceeding of a safety limit.

IV.64. Particular attention shall be paid to the arrangements for the efficient and accurate transfer of information and records between shift teams (shift handovers) and between shift teams and day teams.

Specific provisions

IV.65. The operating organization shall take actions to minimize the risks associated with maintenance during shutdown (inter-campaign periods).

CRITICALITY PREVENTION

IV.66. Relevant personnel shall be trained in the general principles of criticality control, including the requirements of the emergency response plan.

IV.67. A sufficient number of qualified criticality staff, knowledgeable about the criticality aspects of the design, operation and hazards of the facility, shall be appointed at the reprocessing site to support criticality safety.

IV.68. Procedures for the transfer or movement of fissile material during operational states (including maintenance) shall be defined and submitted for review by criticality staff that are, to the extent necessary, independent of the operations management.

IV.69. Fissile material, in particular waste and residues that have not been monitored for fissile content, shall not be collected or placed in containers unless these have been specifically designed and approved for that purpose.

IV.70. Prior to changing the location of process equipment or its process connections, or of neutron reflectors, the criticality assessment shall be updated to determine whether such a change is acceptable.

IV.71. Specific provisions shall be provided to reduce the risk of accumulation of organic phase in tanks that handle aqueous solutions containing fissile material and to detect such accumulations, where necessary.

IV.72. All transfers of fissile material, including waste and residues, shall be performed in accordance with the criticality safety requirements of both the sending area/facility and the receiving area/facility, and shall be made subject to certification by the sending area/facility and acceptance by the receiving area/facility prior to sending.

IV.73. The potential for the inadvertent addition of water, weak acids or neutralizing chemicals (often used for decontamination) to fissile solutions, which can cause precipitation or a change in the flowsheet conditions (e.g. failure of the extraction process) with a criticality risk, shall be minimized. Such feedlines for liquids shall be isolated or shall be made subject to appropriate administrative controls.

IV.74. Depending on the risk arising from accumulations of fissile material, including waste and residues, a surveillance programme shall be developed and implemented to ensure that uncontrolled accumulations of fissile material are detected and further accumulation is prevented.

IV.75. Adequate arrangements for responding to a criticality accident shall be established and maintained. These arrangements shall include the development of an emergency plan, definition of responsibilities and provision of equipment, and shall include emergency operating procedures.

IV.76. Non-fissile chemical reagents[15] that are important to process chemistry shall be assessed. If addition of either the wrong composition or the wrong quantity of a chemical reagent could pose a criticality hazard, then this shall be controlled.

RADIATION PROTECTION

IV.77. Appropriate equipment, either stationary or mobile, shall be provided at the reprocessing facility to ensure that there is adequate radiation monitoring in operational states and, as far as is practicable, in accident conditions.

Control of internal and external exposure

IV.78. During operation (including during maintenance operations), the prevention of internal and external exposure shall be controlled by both physical and administrative means, in order to limit the need to use personnel protective equipment as far as practicable.

MANAGEMENT OF FIRE SAFETY, CHEMICAL SAFETY AND INDUSTRIAL SAFETY

IV.79. The potential for fire or explosion and the control of ignition sources and potential combustible materials, including hazardous and toxic process chemicals, shall be considered, including during maintenance operations.

MANAGEMENT OF RADIOACTIVE WASTE

IV.80. Waste pretreatment, treatment and storage shall be organized in accordance with pre-established criteria and the national waste classification scheme, and shall take into consideration both on-site storage capacity and disposal options (see Ref. [2]).

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[15] Reagents in this context can include acid, solvent, water and any other chemical that may be added to the process.

IV.81. High level waste shall be stored in facilities that maintain a suitably reliable heat removal function in addition to adequate confinement and shielding.

IV.82. Where a decision is made to store radioactive waste pending the provision of disposal routes, all the available information characterizing the waste shall be held in secure and recoverable archives (this applies to the full range of design, technical and operational records).

DECOMMISSIONING

IV.83. In applying decommissioning actions, including the dismantling of equipment that was used to process fissile material (e.g. vessels, gloveboxes), procedures shall be implemented to ensure that criticality control is maintained.

IV.84. Criticality safety shall be ensured for the temporary storage of waste from decommissioning that is contaminated with fissile material.

Appendix V

REQUIREMENTS SPECIFIC TO FUEL CYCLE RESEARCH AND DEVELOPMENT FACILITIES

The following requirements are specific to fuel cycle research and development facilities[16] at laboratories and to facilities at pilot and demonstration scales that receive, handle, process, examine and store a large variety of radioactive materials with very different physical characteristics (e.g. uranium, thorium, plutonium), other actinides (e.g. americium, neptunium, curium), separated isotopes (fissile and non-fissile), fission products, activated materials and irradiated fuel. Furthermore, a wide range of other materials are used in such facilities, e.g. graphite, boron, gadolinium, hafnium, zirconium, aluminium, heavy water and various metal alloys.

Fuel cycle research and development facilities can be used to investigate various fuel manufacturing techniques, and reprocessing and waste handling techniques and processes, as well as to investigate material properties of fuel before and after irradiation in the reactor, and to develop equipment whose use is envisaged at an industrial scale later.

The following are safety issues that are specific to fuel cycle research and development facilities:

— The manipulation of small amounts of radioactive material;
— The diversity of the experiments carried out and the associated safety assessment, which might cover several different experiments;
— The manipulation of unusual radionuclides, such as ‘exotic’ actinides, with associated risks;
— Organizational and human factors, as operations are mainly manual and require cooperation between operating personnel of the facility and personnel responsible for research and development.

[16] Fuel cycle research and development facilities are generally characterized by a need for a large degree of flexibility in their operations and processes, but they typically have low inventories of fissile materials and can include both hands-on and remote handling operations.

DESIGN

SAFETY FUNCTIONS

V.1. The facility shall be designed to prevent a criticality accident and the accidental release of hazardous materials. The design shall keep radiation exposures from normal operation and accident conditions as low as reasonably achievable.

ENGINEERING DESIGN

V.2. The design shall, as far as practicable, prevent hazardous concentrations of gases and other explosive or flammable materials.

V.3. Consideration shall be given in the design to the possible need for clean-up or recovery of radioactive material following an incident.

CRITICALITY PREVENTION

V.4. Criticality safety shall be ensured by means of preventive measures.

V.5. Preference shall be given to achieving criticality safety by engineering design, to the extent practicable, rather than by administrative measures.

V.6. In the criticality safety assessment, the choice of fire extinguishing media (e.g. water, inert gas or powder) and the safety of their use shall be addressed.

CONFINEMENT OF RADIOACTIVE MATERIAL

V.7. Containment shall be the primary method for ensuring confinement against the spread of contamination. Containment shall be provided by two complementary containment systems — static (e.g. physical barriers) and dynamic (e.g. ventilation). In view of the large range of potential radiological hazards present in fuel cycle research and development facilities, a graded approach shall be used in the design of the containment systems with respect to the nature and number of barriers and their performance, in accordance with the potential severity of the radiological consequences of the failure of a containment system.

PROTECTION AGAINST EXPOSURE TO RADIATION

V.8. The activities carried out in fuel cycle research and development facilities generally rely on analytical data from samples. Sampling devices, sample transfer methods, sample storage and the analytical laboratories shall be designed to keep exposures as low as reasonably achievable.

POSTULATED INTIATING EVENTS

Internal initiating events

Fire and explosion

V.9. A detection and/or suppression system shall be installed that is commensurate with the risk of fire.

V.10. In areas with potentially explosive atmospheres, the electrical network and equipment shall be adequately protected.

OPERATION

MANAGEMENT SYSTEM

Receipt of radioactive material

V.11. The operating organization shall develop procedures to ensure that radioactive material received at the facility is appropriately characterized and is acceptable before it is allowed to be stored or used within the facility.

Qualification and training of personnel

V.12. Operators and researchers shall be qualified and trained to handle radioactive material and to conduct tests and experiments.

V.13. Specific training and drills for personnel and external firefighters and rescue staff shall be organized by the operating organization. The operating organization and operators shall recognize that an inappropriate response to a fire or explosion at the facility could increase the consequences of the event (e.g. radiological hazards including criticality, chemical hazards).

CRITICALITY PREVENTION

V.14. As criticality hazards may be encountered in research and development activities involving fissile material, including maintenance work, a criticality safety assessment shall be performed. If fissile material has to be removed from equipment, only approved containers shall be used.

V.15. Any wastes and residues arising from experiments, pilot processes or sampling, decontamination or maintenance activities that involve fissile material shall be collected in containers with a favourable geometry, and shall be recorded and stored in dedicated criticality safe areas.

V.16. Consideration shall be given to the unintentional mixing of chemicals which could increase criticality risk (e.g. dilution of acid causing precipitation of fissile material).

EMERGENCY PLANNING AND PREPAREDNESS

V.17. An emergency plan shall be prepared and shall be focused on the following aspects for immediate response:

— Fire and explosion;
— Criticality accidents;
— The release of hazardous materials, both radioactive material and chemicals;
— Loss of services, e.g. electrical power supply and coolants.

V.18. In dealing with a fire or a release of hazardous materials (e.g. UF_6), the actions taken or the medium used to respond to the emergency shall not create a criticality hazard or add to the chemical hazard.

DECOMMISSIONING

V.19. Special procedures shall be implemented to ensure that criticality control is maintained in dismantling equipment whose criticality is controlled by geometry.

V.20. Criticality safety shall be ensured for the temporary storage of waste contaminated with fissile material, including plutonium that is generated from decommissioning, including the dismantling of gloveboxes and their contents.

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Annex I

SELECTED POSTULATED INITIATING EVENTS

EXTERNAL POSTULATED INITIATING EVENTS

Natural phenomena

Natural phenomena would include:

(a) Extreme weather conditions: precipitation including rain, hail, snow, ice; frazil ice; wind including tornadoes, hurricanes, cyclones, dust storms, sand storms; lightning; extreme high or low temperatures; extreme humidity.
(b) Flooding.
(c) Earthquakes and eruptions of volcanoes.
(d) Natural fires.
(e) Effects of terrestrial and aquatic flora and fauna (leading to blockages of inlets and outlets, and damage to structures).

Human induced phenomena

Human induced phenomena would include:

(a) Fires, explosions, or releases of corrosive or hazardous substances (from surrounding industrial or military installations or transport infrastructures);
(b) Aircraft crashes;
(c) Missile strikes (arising from structural and/or mechanical failure in surrounding installations);
(d) Flooding (e.g. failure of a dam, blockage of a river);
(e) Loss of power supply;
(f) Civil strife (leading to infrastructure failure, strikes and blockades).

INTERNAL POSTULATED INITIATING EVENTS

Internal events would include:

(a) Loss of energy and fluids (e.g. loss of electrical power supplies, air and compressed air, vacuum, superheated water and steam, coolant, chemical reagents and ventilation);

(b) Failures in use of electricity or chemicals;
(c) Mechanical failure, including drop loads, rupture (of pressure retaining vessels or pipes), leaks (due to corrosion), plugging;
(d) Failures of, and human errors with, instrumentation and control systems;
(e) Internal fires and explosions (due to gas generation and process hazards);
(f) Flooding (e.g. vessel overflows).

Annex II

AVAILABILITY AND RELIABILITY PRINCIPLES USED IN FUEL CYCLE FACILITY SAFETY

REDUNDANCY

II–1. The principle of redundancy will need to be applied as a design principle for improving the reliability of systems important to safety. The design will need to ensure that no single failure can result in a loss of capability of SSCs important to safety to perform their intended safety functions. Multiple sets of equipment that cannot be tested individually cannot be considered redundant.

II–2. The degree of redundancy adopted will also need to reflect the potential for undetected failures that could degrade reliability.

INDEPENDENCE

II–3. The principle of independence (as functional isolation, or as physical separation by means of distance, barriers or layout of process equipment or components) will need to be applied, as appropriate, to enhance the reliability of systems, in particular with regard to common cause failures.

DIVERSITY

II–4. The principle of diversity can enhance reliability and reduce the potential for common cause failures. It will need to be adopted for safety significant systems wherever appropriate and practicable.

DOUBLE CONTINGENCY

II–5. Process designs will need to incorporate sufficient safety factors to require at least two unlikely, independent and concurrent changes in process conditions before a criticality accident is possible [II–1].

FAIL-SAFE DESIGN

II–6. Where practicable, the fail-safe principle will need to be applied to components important to safety, i.e. if a system or component should fail, the fuel cycle facility will pass into a safe state without the need to initiate any protective or mitigatory actions.

TESTABILITY

II–7. All SSCs important to safety will need to be designed and arranged so that their safety functions can be adequately inspected and tested, and the SSCs important to safety can be maintained, as appropriate, before commissioning and at suitable and regular intervals thereafter, in accordance with their importance to safety. If it is not practicable to provide adequate testability of a component, the safety analysis will need to take into account the possibility of undetected failures of such equipment.

REFERENCE TO ANNEX II

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Annex III

SAFETY IN THE DESIGN OF A FUEL CYCLE FACILITY

This annex gives an overview of the approach to safety in the design of a fuel cycle facility.

STEP 1: INPUT DATA

III–1. Input data consist of:

(a) Specification of data for the facility design basis on the basis of the product to be used, the processes to be performed, the production capability, etc.;
(b) Safety objectives of the facility;
(c) Definition of the safety functions to be fulfilled by the facility.

III–2. In the context of fuel cycle facilities, a safety function is a function the loss of which may lead to radiological or chemical consequences for the workforce, the public or the environment:

(a) Confinement against dispersion of radioactive material and chemical hazards, and associated secondary safety functions: structural integrity, cooling (evacuation of decay heat) and prevention of radiolysis.
(b) Protection against external irradiation.
(c) Prevention of criticality.

STEP 2: IDENTIFICATION OF HAZARDS

III–3. Identification of all external and internal hazards (radiological and chemical hazards):

(a) External hazards, from an established list.
(b) Radiological and chemical internal hazards (facility specific or from an established list, e.g. para. III–4). Chemical hazards are taken into account only when they may lead to radiological consequences.

III–4. Non-nuclear internal hazards

The following is a list of the main non-nuclear internal hazards:

(a) Loss of energy and fluids (e.g. loss of electrical power supplies, air and pressurized air, vacuum, superheated water and steam, coolant, chemical reagents and ventilation);
(b) Failures in use of electricity or chemicals;
(c) Mechanical failure, including drop loads, rupture (of pressure retaining vessels or pipes), leaks (due to corrosion), plugging;
(d) Failures of, and human errors with, instrumentation and control systems;
(e) Internal fires and explosions (due to gas generation and process hazards);
(f) Flooding (e.g. vessel overflows).

STEP 3: HAZARD EVALUATION

Step 3.A. Development of event scenarios and identification of the postulated initiating events

III–5. In this step, the hazards identified during the hazard identification step are linked with the postulated initiating events to produce event scenarios. These event scenarios may be grouped by event and hazard type (e.g. loss of confinement, criticality, fire).

III–6. A postulated initiating event is an event identified in the design as capable of leading to anticipated operational occurrences or accident conditions. Postulated initiating events could lead to a release of significant amounts of radiation and/or radioactive material and associated chemical materials, depending on the hazards.

Step 3.B. Evaluation of the consequences of event scenarios

III–7. For each event scenario or group of event scenarios, the consequences to workers, the public and the environment are estimated.

Step 3.C. Identification of structures, systems and components important to safety and their safety requirements

III–8. For those scenarios potentially leading to unacceptable consequences, SSCs important to safety that fulfil the necessary safety functions are identified.

III–9. In the context of fuel cycle facilities, a barrier specifically for preventing the occurrence of initiating events and for mitigating the consequences of accidents is an SSC important to safety.

III–10. In the context of fuel cycle facilities, a design basis accident (DBA) is an accident against which a facility is designed according to established design criteria such that the consequences are kept within defined limits. These accidents are events against which design measures are taken when designing the facility. The design measures are intended to prevent an accident or to mitigate its consequences if it does occur. Accidents may be grouped together with one representative bounding case if they are related to the same identified hazard and therefore have a common set of SSCs important to safety. For criticality accidents, specific preventive measures are implemented (e.g. double contingency principle). Mitigatory measures for and assessment of the consequences of a criticality accident are regulated by national legislation. Therefore, mitigatory measures for and consequence assessments of criticality accidents are not necessarily part of the DBA approach.

III–11. In addition to DBAs, anticipated operational occurrences are specified and their possible consequences are assessed. Safe design is achieved by ensuring that the possible consequences of all DBAs and anticipated operational occurrences are acceptable.

III–12. Facility states

Operational states		Accident conditions	
Normal operation[1]	Anticipated operational occurrences[2]	Design basis accidents	Beyond design basis accidents

III–13. The emergency preparedness and response plan is determined; this plan defines the mitigatory measures that will need to be taken to ensure that any plan off-site consequences are acceptable.

[1] Normal operation is operation within specified operational limits and conditions (OLCs).

[2] An anticipated operational occurrence is an operational process deviating from normal operation which is expected to occur at least once during the operating lifetime of a facility but which, in view of appropriate design provisions, does not cause any significant damage to items important to safety or lead to accident conditions.

III–14. To perform the safety analysis, DBAs are postulated, using bounding assumptions.

Step 3. D. Evaluation of the mitigated consequences and likelihood

III–15. If the consequences of an event after mitigatory measures have been taken and/or the likelihood of occurrence of the event make the event still not acceptable (see Fig. 2 of the main part of this publication), the evaluation (step 3.B) is iterated and the SSCs important to safety (step 3.C) are modified until the results become acceptable.

STEP 4: ESTABLISHMENT OF OPERATIONAL LIMITS AND CONDITIONS

III–16. In this step, the operational limits and conditions are defined.

III–17. Operational limits and conditions are a set of rules setting forth parameter limits, and the functional capability and the performance levels of equipment and personnel approved by the regulatory body for safe operation of an authorized facility.

STEP 5: JUSTIFICATION OF SAFETY MEASURES

III–18. In this step, the licensing documentation of the facility is prepared (see para. 2.9).

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No. 23

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