

IAEA Safety Standards

for protecting people and the environment

Safety of Uranium and Plutonium Mixed Oxide Fuel Fabrication Facilities

Specific Safety Guide

No. SSG-7 (Rev. 1)



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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

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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.

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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.

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

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SAFETY OF URANIUM AND
PLUTONIUM MIXED OXIDE FUEL
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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".

IAEA SAFETY STANDARDS SERIES No. SSG-7 (Rev. 1)

SAFETY OF URANIUM AND PLUTONIUM MIXED OXIDE FUEL FABRICATION FACILITIES

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2023

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FOREWORD

by Rafael Mariano Grossi
Director General

The IAEA's Statute authorizes it to "establish...standards of safety for protection of health and minimization of danger to life and property". These are standards that the IAEA must apply to its own operations, and that States can apply through their national regulations.

The IAEA started its safety standards programme in 1958 and there have been many developments since. As Director General, I am committed to ensuring that the IAEA maintains and improves upon this integrated, comprehensive and consistent set of up to date, user friendly and fit for purpose safety standards of high quality. Their proper application in the use of nuclear science and technology should offer a high level of protection for people and the environment across the world and provide the confidence necessary to allow for the ongoing use of nuclear technology for the benefit of all.

Safety is a national responsibility underpinned by a number of international conventions. The IAEA safety standards form a basis for these legal instruments and serve as a global reference to help parties meet their obligations. While safety standards are not legally binding on Member States, they are widely applied. They have become an indispensable reference point and a common denominator for the vast majority of Member States that have adopted these standards for use in national regulations to enhance safety in nuclear power generation, research reactors and fuel cycle facilities as well as in nuclear applications in medicine, industry, agriculture and research.

The IAEA safety standards are based on the practical experience of its Member States and produced through international consensus. The involvement of the members of the Safety Standards Committees, the Nuclear Security Guidance Committee and the Commission on Safety Standards is particularly important, and I am grateful to all those who contribute their knowledge and expertise to this endeavour.

The IAEA also uses these safety standards when it assists Member States through its review missions and advisory services. This helps Member States in the application of the standards and enables valuable experience and insight to be shared. Feedback from these missions and services, and lessons identified from events and experience in the use and application of the safety standards, are taken into account during their periodic revision.

I believe the IAEA safety standards and their application make an invaluable contribution to ensuring a high level of safety in the use of nuclear technology. I encourage all Member States to promote and apply these standards, and to work with the IAEA to uphold their quality now and 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 measures¹ have in common the aim of protecting human life and health and the environment. Safety measures and security measures must be designed and implemented in an integrated manner so that security measures do not compromise safety and safety measures do not compromise security.

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

Safety Fundamentals

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

Safety Requirements

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

Safety Guides

Safety Guides provide recommendations and guidance on how to comply with the safety requirements, indicating an international consensus that it

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

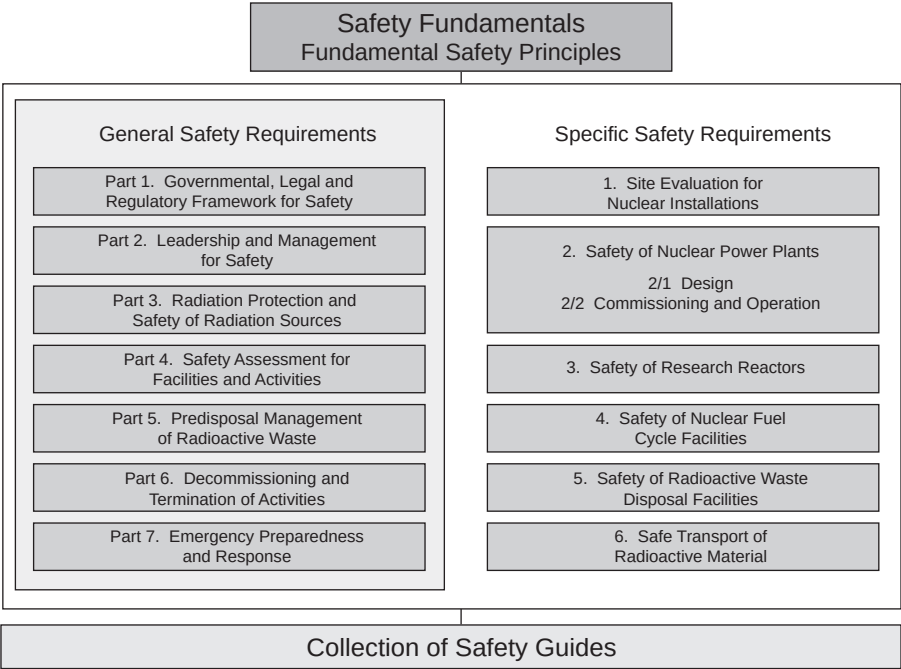


FIG. 1. The long term structure of the IAEA Safety Standards Series.

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 five Safety Standards Committees, for emergency preparedness and response (EPReSC) (as of 2016), nuclear safety (NUSSC), radiation safety (RASSC), the safety of radioactive waste (WASSC) and the safe transport of radioactive material (TRANSSC), and a Commission on Safety Standards (CSS) which oversees the IAEA safety standards programme (see Fig. 2).

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

A management system has been established for the processes of planning, developing, reviewing, revising and establishing the IAEA safety standards.

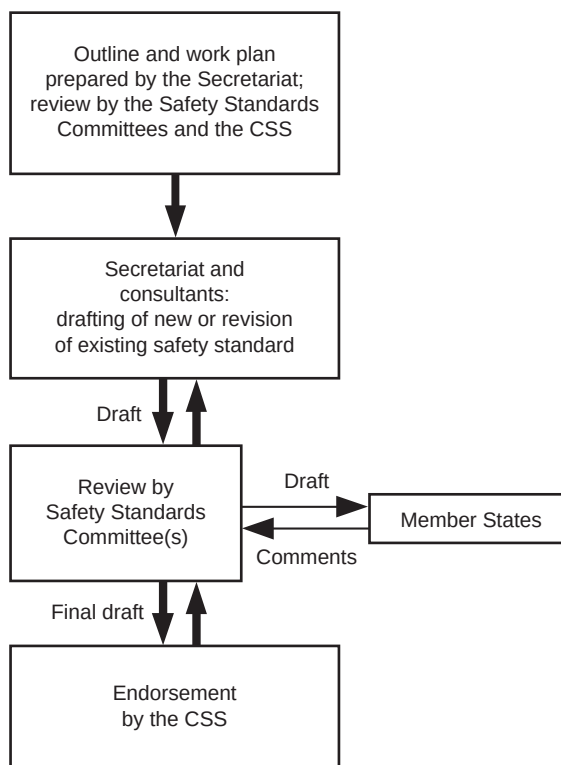


FIG. 2. The process for developing a new safety standard or revising an existing standard.

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 <https://www.iaea.org/resources/publications/iaea-nuclear-safety-and-security-glossary>). 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.

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1. INTRODUCTION

BACKGROUND

1.1. Requirements for all the important areas of safety in all stages of the lifetime of a nuclear fuel cycle facility are established in IAEA Safety Standards Series No. SSR-4, Safety of Nuclear Fuel Cycle Facilities [1].

1.2. This Safety Guide provides specific recommendations on the safety of uranium and plutonium mixed oxide (MOX) fuel fabrication facilities.

1.3. Plutonium is a valuable energy resource that arises from the civil and military industries in a number of States. When plutonium oxide (PuO_2) is mixed with uranium oxide (UO_2), the resulting mixed oxide can be fabricated into fuel suitable for loading into thermal reactors and fast reactors, thereby utilizing this energy resource.

1.4. The MOX fuel fabrication processes rely to a large extent on passive and active engineered safety measures in addition to administrative controls to ensure safety. The potential hazards of a MOX fuel fabrication facility are release of actinides (i.e. plutonium, americium and uranium, in order of significance), increased radiotoxicity due to transuranium actinides and nuclear criticality.

1.5. As the toxicity of plutonium is high, it is important that best practices be employed at all stages of the fabrication of MOX fuel and that plutonium be handled, processed, treated and stored safely. It is important that best practices also be considered as part of applying optimization to the generation and management of all radioactive waste and effluents generated in MOX fuel fabrication facilities.

1.6. This Safety Guide supersedes IAEA Safety Standards Series No. SSG-7, Safety of Uranium and Plutonium Mixed Oxide Fuel Fabrication Facilities¹.

¹ INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Uranium and Plutonium Mixed Oxide Fuel Fabrication Facilities, IAEA Safety Standards Series No. SSG-7, IAEA, Vienna (2010).

OBJECTIVE

1.7. The objective of this Safety Guide is to provide recommendations on the siting, design, construction, commissioning, operation including management for safety, and preparation for decommissioning of MOX fuel fabrication facilities to meet the applicable requirements established in SSR-4 [1].

1.8. The recommendations in this Safety Guide are aimed primarily at operating organizations of MOX fuel fabrication facilities, regulatory bodies, designers and other relevant organizations.

SCOPE

1.9. The safety requirements applicable to fuel cycle facilities (i.e. facilities for uranium refining; conversion; enrichment; reconversion²; storage of fissile material; fabrication of fuel including MOX fuel; storage and reprocessing of spent fuel; associated conditioning and storage of waste; and facilities for fuel cycle related research and development) are established in SSR-4. [1]. This Safety Guide provides recommendations on meeting these requirements for MOX fuel fabrication facilities.

1.10. This Safety Guide deals with the handling, processing, material transfer, and storage of (i) plutonium oxide powder; (ii) depleted, natural or reprocessed uranium oxide powder as it relates to MOX fuel fabrication facilities; and (iii) MOX fuel pellets, rods and assemblies fabricated from plutonium oxide and uranium oxide powders for use in thermal reactors and fast reactors. This Safety Guide also deals with the generation and management of wastes and effluents arising from the handling and processing of these materials.

1.11. This Safety Guide is limited to the safety of MOX fuel fabrication facilities; it does not deal with any impact that the fabricated fuel assemblies might have on the safety of the reactors in which they are to be used.

1.12. The fuel fabrication processes covered by this Safety Guide are dry processes and processes related to the mixing and processing of uranium dioxide and plutonium dioxide powders. The wet MOX fabrication process and the production of oxide powders are not addressed in this Safety Guide. IAEA Safety Standards Series Nos SSG-6 (Rev. 1), Safety of Uranium Fuel Fabrication

² Also called 'deconversion'.

Facilities [2], and SSG-42, Safety of Nuclear Fuel Reprocessing Facilities [3], provide additional recommendations on the safety of producing uranium and plutonium oxide powders.

1.13. This Safety Guide covers the production of MOX fuel from mixtures of uranium and plutonium oxides, obtained either by blending separate uranium oxide powders and plutonium oxide powders or as a prepared blend. Many aspects, such as the facility design, the safety analysis and the operation of the facility, depend on the nuclide compositions of these oxides. This Safety Guide covers all possible combinations of oxide composition.

1.14. The recommendations on ensuring criticality safety in a MOX fuel fabrication facility in this publication supplement the recommendations provided in IAEA Safety Standards Series No. SSG-27 (Rev. 1), Criticality Safety in the Handling of Fissile Material [4].

1.15. The implementation of safety requirements on the legal and governmental framework and regulatory supervision (e.g. requirements for the authorization process, regulatory inspection and regulatory enforcement) as established in IAEA Safety Standards Series No. GSR Part 1 (Rev. 1), Governmental, Legal and Regulatory Framework for Safety [5], is not addressed in this Safety Guide.

1.16. This Safety Guide does not include recommendations on nuclear security for a MOX fuel fabrication facility. Recommendations on nuclear security are provided in IAEA Nuclear Security Series No. 13, Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/Revision 5) [6], and guidance is provided in IAEA Nuclear Security Series No. 27-G, Physical Protection of Nuclear Material and Nuclear Facilities (Implementation of INFCIRC/225/Revision 5) [7]. However, this Safety Guide includes recommendations on managing interfaces between safety, nuclear security and the State system for nuclear material accounting and control.

STRUCTURE

1.17. Section 2 provides an overview of the hazards in a MOX fuel fabrication facility. Section 3 provides recommendations on the development of a management system for a MOX fuel fabrication facility and the activities associated with it. Section 4 describes the safety aspects to be considered in the evaluation and selection of a site to avoid or minimize any environmental impact of operations. Section 5 addresses safety in the design stage; it provides recommendations on the

safety analysis for operational states and accident conditions and covers the safety aspects of radioactive waste management in the MOX fuel fabrication facility, and other design considerations. Section 6 addresses safety aspects in the construction stage. Section 7 addresses safety considerations in commissioning. Section 8 deals with safety in the stage of operation of the facility; it provides recommendations on the management of operation, maintenance and periodic testing, control of modifications, criticality control, radiation protection, industrial safety, the management of waste and effluents, and emergency preparedness and response. Section 9 provides recommendations on meeting the safety requirements for the preparation for decommissioning of a MOX fuel fabrication facility. Annex I shows the typical process routes in a MOX fuel fabrication facility. Annex II provides examples of structures, systems and components important to safety in MOX fuel fabrication facilities, grouped in accordance with process areas. Annex III provides examples of parameters for defining the operational limits and conditions for a MOX fuel fabrication facility.

2. HAZARDS IN MOX FUEL FABRICATION FACILITIES

2.1. In MOX fuel fabrication facilities, large amounts of fissile material and radioactive material are present in a dispersible form. This is particularly the case in the early stages of the fuel fabrication process, when the material is in powder form. In addition, the radioactive material encountered exists in diverse physical forms. Thus, in MOX fuel fabrication facilities the main hazards are potential nuclear criticality, loss of confinement and radiation exposure (both internal and external).

2.2. In MOX fuel fabrication facilities, plutonium oxide and uranium oxide and/or mixed oxide are processed. The factors affecting the safety of a MOX fuel fabrication facility include the following:

- Plutonium having high radiological toxicity, the consequences to the personnel, the public and the environment following an accident might be expected to be high.
- The powder processes used for MOX fuel fabrication have a potential for the dispersion of radioactive material.
- The isotopic characteristics of plutonium have an effect on nuclear criticality safety, radiation exposure and heat generation.

2.3. External exposure assessment should include exposure due to neutron emission from ^{238}Pu and ^{240}Pu isotopes and gamma radiation from ^{241}Am , which is formed through the radioactive decay of ^{241}Pu during storage. Gamma radiation from ^{228}Th decay products (including ^{208}Tl) should also be considered.

2.4. The decay heat of ^{238}Pu should be included in the calculation of heat generation.

2.5. A MOX fuel fabrication facility using only dry processes does not store or process significant quantities of hazardous chemicals. Thus, chemical hazards that could lead to radiological consequences are low. However, this would not be the case for MOX fuel fabrication facilities using wet processes. To meet the requirements established in SSR-4 [1], the operating organization is required to perform a safety analysis in which potential accidents are analysed to ensure that they are adequately prevented and, if they do occur, detected and their consequences mitigated. This requires application of the concept of defence in depth (see Requirement 10 of SSR-4 [1]). For the MOX fuel fabrication facility to also remain in a safe state when the fuel fabrication process is stopped (i.e. when there is no movement or transfer of material), the following systems should continue to operate:

- Heat removal systems in storage areas to remove decay heat from reactor grade plutonium;
- Systems supporting confinement functions to supplement the physical confinement barriers and to provide mitigation and monitoring of radioactive discharges;
- Inert gas feed systems of sintering furnaces and gloveboxes;
- Criticality accident detection and alarm systems.

3. MANAGEMENT SYSTEM AND VERIFICATION OF SAFETY FOR MOX FUEL FABRICATION FACILITIES

3.1. A documented management system that integrates safety, health, environmental, security, quality, and human and organizational factors of the operating organization is required to be established and implemented with adequate resources, in accordance with Requirement 4 of SSR-4 [1]. The integrated management system should be established and put into effect by the operating organization early in the design stage of a MOX fuel fabrication facility, to ensure

that safety measures are specified, documented, implemented, monitored, audited and periodically reviewed throughout the lifetime of the facility or the duration of the activity.

3.2. Requirements for the management system are established in IAEA Safety Standards Series No. GSR Part 2, Leadership and Management for Safety [8]. Associated recommendations are provided in IAEA Safety Standards Series Nos GS-G-3.1, Application of the Management System for Facilities and Activities [9]; GS-G-3.5, The Management System for Nuclear Installations [10]; GSG-16, Leadership, Management and Culture for Safety in Radioactive Waste Management [11]; and TS-G-1.4, The Management System for the Safe Transport of Radioactive Material [12].

3.3. Coordination of the nuclear safety and security interface in the establishment of the integrated management system should be ensured. The management system should consider the specific concerns of each discipline regarding the management of information. Potential conflicts between the need for transparency of information relating to safety matters and the need for protection of information for security reasons should be addressed.

3.4. In determining how the management system for the safety of MOX fuel fabrication facilities is to be developed and applied, a graded approach is required to be used (see Requirement 7 and para. 4.15 of GSR Part 2 [8]). This approach should be based on the relative importance to safety of each item or process.

3.5. The management system is required to support the development and maintenance of a strong safety culture, including in all aspects of criticality safety (see Requirement 12 of GSR Part 2 [8]).

3.6. In accordance with paras 4.15–4.23 of SSR-4 [1], the management system is required to address the following functional areas:

- (a) Management responsibility, which includes the necessary support and commitment of the management to achieve the objectives of the operating organization.
- (b) Resource management, which includes the measures necessary to ensure that the resources essential to the implementation of safety policy and the enhancement of safety and the achievement of the objectives of the operating organization are identified and made available.
- (c) Process implementation, which includes the actions and tasks necessary to achieve the goals of the operating organization.

- (d) Measurement, assessment, evaluation and improvement, which provide an indication of the effectiveness of management processes and work performance compared with objectives or benchmarks. It is through measurement, assessment and evaluation that opportunities for improvement are identified.

MANAGEMENT RESPONSIBILITY

3.7. The prime responsibility for safety, including criticality safety, rests with the operating organization. In accordance with para. 4.11 of GSR Part 2 [8], the management system for a MOX fuel fabrication facility is required to clearly specify the following:

- (a) The organizational structure;
- (b) Functional responsibilities;
- (c) Levels of authority.

3.8. The documentation of the management system should describe the interactions between the individuals managing, performing and assessing the adequacy of the processes and activities important to safety. The documentation should also cover other management measures, including planning, scheduling and resource allocation (see para. 9.9 of SSR-4 [1]).

3.9. Paragraph 4.15 of SSR-4 [1] states:

“[T]he management system shall include provisions for ensuring effective communication and clear assignment of responsibilities, in which accountabilities are unambiguously assigned to individual roles within the organization and to suppliers, to ensure that processes and activities important to safety are controlled and performed in a manner that ensures that safety objectives are achieved.”

The management system should include arrangements for empowering relevant personnel to stop unsafe operations at the MOX fuel fabrication facility.

3.10. The operating organization is required to ensure that safety assessments and analyses are conducted, documented and updated (see Requirement 24 and para. 4.65 of IAEA Safety Standards Series No. GSR Part 4 (Rev. 1), Safety Assessment for Facilities and Activities [13], and Requirement 5 of SSR-4 [1]).

3.11. In accordance with para. 4.2(d) of SSR-4 [1], the operating organization is required to audit all safety related matters on a regular basis. This should include the examination of arrangements for emergency preparedness and response, such as emergency communications, evacuation routes and signage. Checks should be performed by the nuclear criticality safety personnel who performed the safety assessments to confirm that the data used and the implementation of criticality safety measures are correct. Audits should be performed by personnel who are independent of those who performed the safety assessments or conducted the activities important for safety. The data from audits should be documented and submitted for management review and for action, if necessary.

RESOURCE MANAGEMENT

3.12. The operating organization is required to provide adequate resources (both human and financial) for the safe operation of the MOX fuel fabrication facility (see Requirement 9 of GSR Part 2 [8]), including resources for mitigating the consequences of accidents.

3.13. The management of the operating organization should undertake the following:

- (a) Determine the necessary competence of personnel and provide training, as necessary;
- (b) Prepare and issue specifications and procedures on safety related activities and operations;
- (c) Support the conduct of and perform safety assessments, including modifications;
- (d) Have frequent personal contact with personnel, including observing work in progress;
- (e) Make provisions for adequate staffing³, succession planning and retention of corporate knowledge.

3.14. Requirement 58 of SSR-4 [1] states that “**The operating organization shall ensure that all activities that may affect safety are performed by suitably qualified and competent persons.**”

3.15. In accordance with Requirement 58 and paras 9.39–9.47 of SSR-4 [1], the operating organization is required to ensure that these personnel receive

³ Including for situations when a large number of personnel might be unavailable, such as during an epidemic or a pandemic affecting an area where personnel live.

training and refresher training at suitable intervals, appropriate to their level of responsibility. In particular, personnel involved in activities with fissile material (both uranium and plutonium), radioactive material (including waste) and chemicals should understand the nature of the hazard posed by these materials and how these risks are controlled by the established safety measures, operational limits and conditions, and operating procedures.

3.16. Requirement 11 of GSR Part 2 [8] states that **“The organization shall put in place arrangements with vendors, contractors and suppliers for specifying, monitoring and managing the supply to it of items, products and services that may influence safety.”** In accordance with paras 4.33–4.36 of GSR Part 2 [8], the management system for a MOX fuel fabrication facility is required to include arrangements for procurement.

3.17. In accordance with para. 4.16(b) of SSR-4 [1], the operating organization is required to ensure that suppliers of items and resources important to safety have an effective management system in place. To meet these requirements, the operating organization should conduct audits of the management systems of the suppliers.

PROCESS IMPLEMENTATION

3.18. Requirement 63 of SSR-4 [1] states:

“Operating procedures shall be developed that apply comprehensively for normal operation, anticipated operational occurrences and accident conditions, in accordance with the policy of the operating organization and the requirements of the regulatory body.”

Paragraph 9.66 of SSR-4 states that “Operating procedures shall be developed for all safety related operations that may be conducted over the entire lifetime of the facility.” The operating procedures should specify all parameters intended to be controlled and the criteria that should be fulfilled.

3.19. The management system for a MOX fuel fabrication facility should include management for criticality safety. Further recommendations on the management system for criticality safety are provided in SSG-27 (Rev. 1) [4].

3.20. Any proposed modifications to existing facilities or activities, or proposals for the introduction of new activities, are required to be assessed for their implications for existing safety measures and appropriately approved before implementation

(see paras 9.57(b) and (c) of SSR-4 [1]). Modifications of safety significance are required to be subjected to safety assessment and regulatory review and, where necessary, they are required to be authorized by the regulatory body before they are implemented (see paras 9.57(h) and 9.59 of SSR-4 [1]). The facility or activity documentation is required to be updated to reflect modifications (see paras 9.57(f) and (g) of SSR-4 [1]). The operating personnel, including supervisors, should receive adequate training on the modifications.

3.21. Requirement 75 of SSR-4 [1] states:

“The interfaces between safety, security and the State system of accounting for, and control of, nuclear material shall be managed appropriately throughout the lifetime of the nuclear fuel cycle facility. Safety measures and security measures shall be established and implemented in a coordinated manner so that they do not compromise one another.”

The activities for ensuring safety throughout the lifetime of the facility or duration of the activity involve different groups and interface with other areas such as those relating to nuclear security and to the system for nuclear material accounting and control. The activities with such interfaces should be identified in the management system, and should be coordinated, planned and conducted to ensure effective communication and clear assignment of responsibilities. Communications regarding safety and security should ensure that confidentiality of information is maintained. This includes the system of nuclear material accounting and control, for which information security should be coordinated in a manner ensuring that subcriticality is not compromised.

MEASUREMENT, ASSESSMENT, EVALUATION AND IMPROVEMENT

3.22. The audits performed by the operating organization (see para. 3.11), as well as proper control of modifications to facilities and activities (see para. 3.20), are particularly important for ensuring subcriticality. The results of audits are required to be evaluated by the operating organization, and corrective actions are required to be taken where necessary (see para. 4.2(d) of SSR-4 [1]).

3.23. Deviations from operational limits and conditions, deviations from operating procedures and unforeseen changes in process conditions that could affect nuclear criticality safety are required to be reported and promptly investigated by the

operating organization, and the operating organization is required to inform the regulatory body (see paras 9.34, 9.35 and 9.84 of SSR-4 [1]). The depth and extent of the investigation should be proportionate to the safety significance of the event, in accordance with a graded approach. The investigation should cover the following:

- (a) An analysis of the causes of the deviation to identify lessons and to determine and implement corrective actions to prevent a recurrence;
- (b) An analysis of the operation of the facility or conduct of the activity, including an analysis of human factors;
- (c) A review of the safety assessment and analyses that were previously performed, including the safety measures that were originally established.

3.24. Requirement 73 of SSR-4 [1] states that **“The operating organization shall establish a programme to learn from events at the facility and events at other nuclear fuel cycle facilities and in the nuclear industry worldwide.”** Recommendations on operating experience programmes are provided in IAEA Safety Standards Series No. SSG-50, Operating Experience Feedback for Nuclear Installations [14].

VERIFICATION OF SAFETY

3.25. In accordance with Requirement 5 of SSR-4 [1], the safety of a MOX fuel fabrication facility is required to be assessed in the safety analysis and verified by periodic safety reviews. The operating organization should ensure that these periodic safety reviews of the facility form an integral part of the organization’s management system.

3.26. Requirement 6 of SSR-4 [1] states that **“An independent safety committee (or an advisory group) shall be established to advise the management of the operating organization on all safety aspects of the nuclear fuel cycle facility.”**

3.27. The safety committee of a MOX fuel fabrication facility should have members or access to experts in areas of human factors, criticality safety and radiation protection. Such experts should be available to the facility at all times during operation.

4. SITE EVALUATION FOR MOX FUEL FABRICATION FACILITIES

4.1. The site evaluation process for a MOX fuel fabrication facility will depend on a large number of variables. At the earliest stage of planning a facility, a list of these variables should be prepared and considered in accordance with their safety significance. The risks posed by possible significant external hazards (e.g. earthquakes, accidental aircraft crashes, fires, nearby explosions, floods, extreme meteorological conditions) will probably dominate in the site evaluation process and should be taken into account in the design of the facility. Requirements for site evaluation for MOX fuel fabrication facilities are established in IAEA Safety Standards Series No. SSR-1, Site Evaluation for Nuclear Installations [15], and further recommendations are provided in IAEA Safety Standards Series No. SSG-35, Site Survey and Site Selection for Nuclear Installations [16].

4.2. The scope of the site evaluation for a MOX fuel fabrication facility is established in Requirement 3 of SSR-1 [15] and Requirement 11 and paras 5.1–5.14 of SSR-4 [1] and should reflect the specific hazards listed in Section 2 of this Safety Guide.

4.3. For a MOX fuel fabrication facility where a dry process is used to manufacture fuel, appropriate design and operation can ensure that gaseous releases are negligible under normal operating conditions. The main hazard in accident conditions is the potential release of plutonium (as plutonium oxide or MOX) as particles to the atmosphere or to the air of the working zone.

4.4. A MOX fuel fabrication facility should be considered to be a facility with a high hazard potential. This should be taken into consideration when applying a graded approach to the implementation of the requirements of SSR-4 [1] to the facility. The following characteristics of the site should be considered, to ensure the safety of the facility:

- Legal requirements: Using a site for which regulatory consent to process plutonium has already been granted.
- Transport links: Minimizing the distance by which fissile material needs to be transported (e.g. by siting a MOX fuel fabrication facility on the same site as the plutonium production).

Combined hazards and hazard interactions between the facilities on the same site should be understood and taken into consideration.

4.5. The population density and population distribution in the vicinity of a MOX fuel fabrication facility are required to be considered in the site evaluation process to minimize any possible health consequences for people in the event of a release of radioactive material and hazardous chemicals (see Requirements 4 and 12 of SSR-1 [15]). Also, in accordance with Requirement 25 and paras 6.1 and 6.2 of SSR-1 [15], the dispersion in air and water of radioactive material released from the MOX fuel fabrication facility is required to be assessed, taking into account the orography, land cover and meteorological features of the region. The environmental impact from the facility under all facility states is required to be evaluated (see para. 5.3 of SSR-4 [1]) and should meet the applicable criteria.

4.6. Security advice is required to be taken into account in the selection of a site for a MOX fuel fabrication facility (see para. 11.4 of SSR-4 [1]). Considering the presence of plutonium in the facility, special attention should be given to the management of the interface between nuclear safety and nuclear security during site evaluation (see Requirement 75 of SSR-4 [1]). The selection of a site should take into account both safety and security aspects and should be facilitated by both safety experts and security experts.

4.7. Even if an existing nuclear site is used for a MOX fuel fabrication facility, the site evaluation should be performed using a process similar to that used for the siting of a new facility at a new site (see paras 3.24–3.27 of SSG-35 [16]).

4.8. The operating organization should maintain a full record of the decisions taken on the selection of a site for a MOX fuel fabrication facility and the reasons behind those decisions.

4.9. The site characteristics should be reviewed periodically for their adequacy and persistent applicability during the lifetime of a MOX fuel fabrication facility. Any changes to these characteristics that might require safety reassessment should be identified and evaluated (see para. 5.14 of SSR-4 [1]). This includes the case of an increase of the production capacity beyond the original envelope.

5. DESIGN OF MOX FUEL FABRICATION FACILITIES

MAIN SAFETY FUNCTIONS

5.1. Requirement 7 of SSR-4 [1] states:

“The design shall be such that the following main safety functions are met for all facility states of the nuclear fuel cycle facility:

- (a) Confinement and cooling of radioactive material and associated harmful materials;**
- (b) Protection against radiation exposure;**
- (c) Maintaining subcriticality of fissile material.”**

All these safety functions are applicable to MOX fuel fabrication facilities.

5.2. The requirements on the confinement and cooling of radioactive material are established in Requirements 35 and 39 and paras 6.123–6.128 and 6.157–6.159 of SSR-4 [1].

5.3. The requirements on protection against internal radiation exposure are established in Requirement 34 and paras 6.120–6.122 of SSR-4 [1]. The requirements on protection against external radiation exposure are established in Requirement 36 and paras 6.129–6.134 of SSR-4 [1]. Concerning the radiation associated with plutonium (i.e. neutron emissions and gamma radiation), an appropriate combination of requirements on source limitation, distance, time and shielding is necessary for the protection of personnel as relates to whole body exposure, exposure of the hands and exposure of the lens of the eye. For neutron emissions, a general design principle is to place the shielding as close as possible to the source. In some cases, remote operation should be considered if necessary. Individual monitoring of neutron doses to the personnel should be conducted in addition to individual monitoring of gamma radiation.

5.4. The requirements on maintaining subcriticality are established in Requirement 38 and paras 6.138–6.156 of SSR-4 [1]. Recommendations on the design of a MOX fuel fabrication facility to ensure subcriticality are provided in section 3 of SSG-27 (Rev. 1) [4].

Design basis and safety analysis

5.5. A design basis accident is a postulated accident leading to accident conditions for which a facility is designed in accordance with established design criteria and conservative methodology, and for which releases of radioactive material are kept within acceptable limits [1].

5.6. The safety requirements relating to the design basis for items important to safety and for the design basis analysis for a nuclear fuel cycle facility are established in Requirements 14 and 20 of SSR-4 [1], respectively.

5.7. The specification of a design basis (or equivalent) will depend on the design of the facility, the siting of the facility and regulatory requirements. However, particular consideration should be given to the following hazards in the specification of the design basis safety analysis for MOX fuel fabrication facilities:

- (a) Release of plutonium inside and/or outside the facility;
- (b) Internal and external hazards, including internal and external explosions (in particular hydrogen explosions), internal and external fires, dropped loads and handling errors, extreme meteorological phenomena (in particular earthquakes, flooding and tornadoes) and accidental aircraft crashes.

5.8. These hazards are of major safety significance as they might result in radiological consequences for the facility personnel. In addition, these hazards could also result in some adverse off-site consequences for the public or the environment.

5.9. The hazards listed in para. 5.7 might occur as a consequence of a postulated initiating event. Selected postulated initiating events for nuclear fuel cycle facilities are provided in the appendix to SSR-4 [1].

Structures, systems and components important to safety

5.10. Paragraph 6.21 of SSR-4 [1] states:

“The design of the nuclear fuel cycle facility:

.....

(e) Shall provide for structures, systems and components and procedures to control the course of and, as far as practicable, to limit the consequences of

failures and deviations from normal operation that exceed the capability of safety systems.”

Annex II to this Safety Guide presents examples of structures, systems and components and representative events that might challenge the associated safety functions in MOX fuel fabrication facilities.

Confinement of radioactive material

5.11. To meet Requirement 35 of SSR-4 [1] in a MOX fuel fabrication facility, three static barriers (or more, as dictated by the safety analysis) should be provided, in accordance with a graded approach. The first static barrier normally consists of gloveboxes, fuel cladding, material containers or other equipment containing radioactive material. The second static barrier normally consists of the rooms around the gloveboxes. The third static barrier is the building itself. The design of the static containment system should consider openings between the different confinement zones (e.g. doors, penetrations). Such openings should be designed to ensure that confinement is maintained in all operational states, especially during maintenance (e.g. by the provision of permanent or temporary additional barriers) and, as far as practicable, in accident conditions.

5.12. Each physical barrier of the containment system should be complemented by one or more associated systems, which should establish a cascade of pressure between the environment outside the building and the air that might contain contaminated material inside the building, and across all static barriers within the building. The associated systems should be designed to prevent the movement or diffusion of radioactive or toxic gases, vapours and airborne particulates through any openings in the barriers to areas of lower contamination or concentration of these materials. The design of the associated systems should address the following, as far as applicable:

- (a) Operational states and accident conditions;
- (b) Maintenance, which may cause localized changes to conditions (e.g. opening access doors, removing access panels);
- (c) Where more than one ventilation system is used, protection in case of a failure of a lower pressure (higher contamination) system, causing pressure differentials and airflows to be reversed;
- (d) The need to ensure that all static barriers, including any filters or other effluent control equipment, can withstand the maximum differential pressures and airflows generated by the system, including increasing the

filter resistance during operation and considering conservative assumptions regarding the meteorological conditions.

5.13. Specific attention should be paid in the design to operations that lead to the transfer of contaminated materials outside the static containment system. Normal operations should not involve any transfer of radioactive powders outside the first barrier (with gloveboxes and tunnels linking them). Design features should be provided for the removal of materials and items (such as waste or scrap) from the gloveboxes when needed.

5.14. Devices for monitoring air contamination should be included in the design of confinement areas close to working locations, especially at gloveboxes. The location of such devices should be finalized during cold commissioning, when precise airflows are established.

5.15. In confinement areas, appropriate equipment should be provided for monitoring surfaces for contamination. Contamination can be detected by smear sampling of surfaces or by using portable devices.

5.16. The design of a MOX fuel fabrication facility should be such as to facilitate operation, maintenance and decontamination activities. Building compartmentalization should be considered in the design to prevent contamination of large areas of the MOX fuel fabrication facility.

5.17. The ventilation system normally includes filters in series to protect the public and the environment. The air drawn into the ventilation system from the environment as well as the air discharged from the facility should be filtered. The filters filter the air during normal operation and ensure the continuity of the static barriers in the event of loss of ventilation.

5.18. The ventilation system should be designed and operated to minimize the opportunity for buildup of particulates. Appropriate procedures should be established and instruments should be provided to control the potential buildup of plutonium powder or MOX powder particulates in the ventilation ducts and in the high efficiency particulate air (HEPA) filters.

5.19. Primary filters should be located as close to the source of contamination as practicable (e.g. near or in the gloveboxes) to minimize the potential buildup of plutonium powder or MOX particulates in the ventilation ducts. Multiple primary filters in series should preferably be used to prevent any transfer of contamination during maintenance of one of the filters.

5.20. Filtration should be provided at ventilation inlet points to prevent the loss of particulates due to reverse or static flow conditions in case of ventilation system failure.

5.21. In addition, operating fans and standby fans should be provided and should be powered such that, in the case of loss of normal power, the uninterrupted functioning of glovebox ventilation systems is ensured. Local monitoring systems and alarm systems should be installed to alert operators to system malfunctions that might result in differential pressures that are considered too high or too low.

5.22. Last stage filters (see also para. 5.35) should be used to protect the public and the environment and should normally be located close to the location at which discharges to the environment occur.

5.23. To prevent the propagation of a fire through the ventilation ducts and to maintain the integrity of firewalls, ventilation systems should be equipped with fire and smoke dampers (see also para. 5.61).

5.24. At the design stage, provision should be made for the installation of equipment for monitoring airborne radioactive material. Monitoring points should be chosen that would correspond most accurately to the exposure of personnel and would minimize the time for detection of any leakage from the first barrier.

5.25. The design of a MOX fuel fabrication facility should allow all planned activities associated with operation or maintenance to be performed without breaching the primary containment.

Protection of workers

5.26. Requirements on the design of MOX fuel fabrication facilities to ensure radiation protection are established in Requirement 8 of SSR-4 [1].

5.27. The first static barrier normally protects the workers. The specifications for the design of the first static barrier should be established to ensure and to control the integrity of this barrier. The design should include specifications for: welding; selection of materials; leaktightness (for gloveboxes, for the ratio of the leak rate to the flow rate); the ability to withstand seismic loads; the design of the equipment (internal equipment for gloveboxes); penetration seals for electrical and mechanical penetrations; and the ease of performing maintenance work.

5.28. Gloveboxes often consist of welded stainless steel enclosures with windows, arranged either singly or in interconnected groups. Access to equipment inside the glovebox is provided through access holes in the glovebox window that are fitted with gloves (made of various materials depending on the work being performed in the glovebox) which maintain the confinement barrier.

5.29. Gloveboxes, fume hoods and filtered ventilation systems should be used to minimize the radiation exposure of personnel and their exposure to hazardous material that could become airborne and be inhaled. In addition, personal protective equipment should be used to avoid contamination of workers with radioactive material and other hazardous material, if protection cannot be achieved by design solutions only.

5.30. For normal operation, the need for the use of respiratory protection should be minimized through careful design of the static and dynamic containment systems and of devices for the immediate detection of low thresholds of airborne radioactive material. Respiratory protection during normal operation should be used only as a complementary means of protection in addition to existing barriers (see also paras 9.100 and 9.101 of SSR-4 [1]).

5.31. Audio alarm systems should be installed to alert operators to fan failures and to high or low differential pressures across filters. At the design stage, provision is also required to be made for the installation of equipment for monitoring airborne uranium concentration and/or gas concentration (see para. 6.120 of SSR-4 [1]). Monitoring points should be chosen that would correspond most accurately to the exposure of personnel and would minimize the time for detection of any leakage (see para. 6.121 of SSR-4 [1]).

5.32. To facilitate decontamination and decommissioning of the facility, the walls, floors and ceilings in areas of the uranium fuel fabrication facility where contamination is likely should be made non-porous and easy to clean. This may be done by applying special coatings, such as epoxy, to surfaces. In addition, all surfaces that could become contaminated should be made readily accessible to allow for periodic decontamination as necessary.

Protection of the public and the environment

5.33. Paragraph 3.9 of IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [17], states:

“Any person or organization applying for authorization:

.....

(e) Shall, as required by the regulatory body, have an appropriate prospective assessment made for radiological environmental impacts, commensurate with the radiation risks associated with the facility or activity.”

Further recommendations for performing environmental impact assessment of MOX fuel fabrication facilities are provided in IAEA Safety Standards Series No. GSG-10, Prospective Radiological Environmental Impact Assessment for Facilities and Activities [18].

5.34. The uncontrolled dispersion of radioactive substances to the environment as a result of an accident can occur if multiple confinement barriers are impaired. Barriers that may provide environmental protection comprise the room and the building itself. The provision of multiple redundant filters in parallel should be considered for the final stage of filtration before the discharge of exhaust gases through a stack. Filtration, including final stage filtration, also provides a means of minimizing the release of radioactive particulates to the environment under normal operating conditions, usually reducing gaseous discharges to acceptably low levels.

5.35. The design of a MOX fuel fabrication facility should also provide measures for ensuring that the performance of filtration is the same as that claimed in the facility safety analysis, particularly for the last stage filters. Provisions to ensure the performance of filtration may include testing the particulate removal efficiency (e.g. by aerosol challenge testing), differential pressure measurements and monitoring of alpha particles in ductwork. The design should include provisions to monitor the environment around the facility and to identify breaches of the confinement barriers.

Protection against external exposure

5.36. Relevant requirements on design provisions for protection against external radiation exposure are established in Requirement 36 and paras 6.129–6.134 of SSR-4 [1].

5.37. External exposure of workers should be controlled by means of an appropriate combination of requirements on source reduction, distance, time and shielding. Owing to the specific activity of plutonium, the shielding provided by