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Safety of Uranium and Plutonium Mixed Oxide Fuel Fabrication Facilities (Revision of SSG-7)

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DRAFT SPECIFIC SAFETY GUIDE

CONTENTS

1. INTRODUCTION

BACKGROUND

1.1. This Safety Guide supersedes the Safety Guide on the Safety of Uranium and Plutonium Mixed Oxide (MOX) Fuel Fabrication Facilities that was issued as IAEA Safety Standard Series No. SSG-7 in 2010. It supplements and elaborates upon ~~recommends how to meet the safety requirements established in~~ the Safety Requirements publication on the Safety of Nuclear Fuel Cycle Facilities, IAEA Safety Standards Series No. SSR-4 [1] ~~and supplements and elaborates on those requirements~~.

~~1.2. The safety of uranium and plutonium mixed oxide (MOX) fuel fabrication facilities is ensured by means of their proper siting, design, construction, commissioning, and operation, including management, and decommissioning. This Safety Guide addresses all of these stages in the lifetime of MOX fuel fabrication facilities on an industrial scale only, with emphasis placed on the safety of their design and operation.~~

~~1.3.~~1.2. Plutonium is a valuable energy resource that arises from the civil and military industries in a number of States. When plutonium oxide is mixed with uranium oxide, the resulting mixed oxide can be ~~manufactured~~fabricated into fuel suitable for loading into ~~water~~ thermal reactors and fast ~~breeder~~ reactors, thereby utilizing this energy resource.

~~1.4.~~1.3. ~~MOX fuel and the waste generated in uranium fuel fabrication facilities are handled, processed, treated and stored with defined pathways for waste disposal at the facility.~~ The MOX fuel fabrication processes rely to a large extent on passive and active engineered safety measures ~~operator intervention and~~in addition to administrative controls to ensure safety~~, in addition to active and passive engineered safety measures~~. The principle hazards of a MOX fuel facility are release of actinides (plutonium, americium and uranium in order of significance), increased radiotoxicity due to trans-uranium actinides, and nuclear criticality. ~~The potential for a release of energy in the event of an accident at a uranium fuel fabrication facility is associated with nuclear criticality or chemical reactions. The potential for release of energy is small in comparison with that of a nuclear power plant, with generally limited environmental consequences. The wastes from MOX fuel fabrication facilities are handled, processed, treated and stored with defined pathways for waste disposal at the facility.~~

1.4. The toxicity of plutonium is high and therefore it is important that where possible best practice be employed at all stages of the ~~manufacture~~ fabrication of MOX fuel, and that plutonium ~~and~~ including all waste ~~from~~ in MOX fuel fabrication facilities be handled, processed, treated and stored safely. ~~The goal is to maintain the lowest possible levels of discharges to the environment and limit the impact of accident conditions on workers, the public and the environment.~~

1.5. The safety of uranium and plutonium mixed oxide (MOX) fuel fabrication facilities is addressed by means of their proper siting, design, construction, commissioning, and operation, including management for safety, and preparation for decommissioning.

OBJECTIVE

1.6. The objective of this Safety Guide is to provide operating organizations, regulatory bodies, designers and other relevant organizations with recommendations and guidance on meeting the requirements established in SSR-4 [1] applicable to ~~that, in the light of experience in States and the present state of technology, should be followed to ensure safety for all stages in the lifetime of~~ a MOX fuel fabrication facility. ~~These recommendations specify actions, conditions or procedures necessary for meeting the requirements established in Ref. [1]. This Safety Guide is intended to be of use to designers, operating organizations and regulators for ensuring the safety of MOX fuel fabrication facilities.~~

SCOPE

1.7. The safety requirements applicable to fuel cycle facilities (i.e. facilities for uranium ~~ore processing and~~ refining, conversion, enrichment, reconversion, interim 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) ~~and for related research and development)~~are established in SSR-4 Ref. [1]. ~~The requirements applicable specifically to MOX fuel fabrication facilities are established in Appendix II of Ref. [1]~~This Safety Guide provides recommendations on meeting these requirements ~~established in Sections 5–10 and in Appendix II of Ref. [1]~~for MOX fuel fabrication facilities during their siting, design, construction, commissioning, operation and preparation for decommissioning.

1.8. This Safety Guide deals with the handling, processing, material transfer, ~~-~~and storage of: (1) plutonium oxide powder; (2) depleted, natural or reprocessed uranium oxide powder as related to MOX fuel fabrication facilities; (3) MOX fuel pellets, rods and assemblies ~~manufactured~~ fabricated from plutonium oxide and uranium oxide powders~~for use as a feed material~~ ~~to form MOX fuel rods and assemblies in~~ for use in thermal reactors and fast ~~breeder~~ reactors.

1.9. The fuel fabrication processes covered by this Safety Guide are dry processes; the production ~~pre-processing, or polishing,~~ of oxide powders is not addressed. The IAEA Safety Standards Series No. SSG-6, Safety of Uranium Fuel Fabrication Facilities [2], and IAEA Safety Standards Series No. SSG-42, Safety of Nuclear Fuel Reprocessing Facilities [3] provide additional guidance ~~Guidance~~ on the safety of producing uranium and plutonium oxide powders.

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

1.11. This publication includes specific elements of ensuring criticality safety in a MOX fuel fabrication facility. The recommendation supplement more detailed guidance provided in the IAEA Safety Standards Series No. SSG-27, Criticality Safety in the Handling of Fissile Material [4].

~~1.11.~~1.12. This Safety Guide is limited to the safety of MOX fuel fabrication facilities; it does not deal with any impact that the ~~manufactured~~fabricated fuel assemblies may have on safety for the reactors in which they are to be used.

1.13. The implementation of ~~other~~ safety requirements ~~such as those~~ on the legal and governmental framework and regulatory supervision (e.g. requirements for the authorization process, regulatory inspection and regulatory enforcement) as established in the IAEA Safety Standards Series No. GSR Part 1 (Rev.1), Governmental, Legal and Regulatory Framework for Safety ~~Ref.~~ [~~2~~5]~~, and those on the management system and the verification of safety (e.g. requirements for the management system and for safety culture) as established in Ref. [3],~~ are not addressed in this Safety Guide. ~~Recommendations on meeting the requirements for the management system and for the verification of safety are provided in Ref. [4].~~

~~1.12.~~1.14. This Safety Guide does not include nuclear security recommendations for a MOX fuel fabrication facility as established 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 in IAEA Nuclear Security Series No. 27-G, (Implementation of INFCIRC/225/Revision 5) [7].~~Sections 3–8 of this publication provide recommendations on radiation protection measures for meeting the safety requirements established in the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources [5]. The recommendations in the present Safety Guide supplement the recommendations on occupational radiation protection provided in Ref. [6].~~

~~THE TYPICAL PROCESS ROUTES OF MOX FUEL FABRICATION FACILITIES ARE SHOWN IN A SCHEMATIC DIAGRAM IN ANNEX I.~~

STRUCTURE

~~1.13.~~1.15. This Safety Guide consists of ~~eight~~ nine sections and three annexes. Section 2 provides general safety recommendations for a MOX fuel fabrication facility. Section 3 of this publication provides guidance on the development of a management system for a MOX fuel fabrication facility and the activities associated with it. Section ~~3~~ 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 ~~4~~ 5 deals with safety in the design stage: it provides recommendations on safety analysis for operational states and accident conditions and discusses the safety aspects of radioactive waste management in the MOX fuel fabrication facility and other design considerations. Section ~~5~~ 6 addresses the safety aspects in the construction stage. Section ~~6~~ 7 discusses safety considerations in commissioning. Section ~~7~~ 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 ~~planning and~~ preparedness and response. Section ~~8~~ 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 for 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. GENERAL SAFETY RECOMMENDATIONS

2.1. In MOX fuel fabrication facilities, large amounts of fissile material and radioactive material are present in a dispersible form. This is particularly so in the early stages of the fuel fabrication process, when the material is in powder form. In addition, the radioactive materials encountered exist in diverse physical forms. Thus, in MOX fuel fabrication facilities the main ~~hazards are potential criticality, loss of confinement and radiation exposure (both internal and external), from which workers~~safety objectives are the prevention of nuclear criticality, prevention and mitigation of loss of confinement of radioactive material and protection against radiation exposure (requirement 7 of SSR-4 [1]). ~~, the public, and the environment must be protected by means of adequate design, siting, construction, commissioning and safe operation, and~~ preparation for ~~decommissioning.~~

2.2. In MOX fuel fabrication facilities, both plutonium oxide (PuO_2) and uranium oxide (UO_2) are processed. The factors affecting the safety of a MOX fuel fabrication facility should include ~~the~~ consideration of the following:

- While the radiological toxicity of uranium is low, this is not the case for plutonium, and thus consequences to the personnel, the public and the environment ~~potential off-site radiological consequences~~ following an accident might be expected to be high;
- ~~The dry process~~The powder processes used for MOX fuel fabrication ~~method~~ hasve a potential for the dispersion of radioactive material;
- The isotopic characteristics of the plutonium ~~used in MOX fuel fabrication facilities~~ have an effect on ~~the potential for~~ nuclear criticality safety, ~~external~~radiation exposure and ~~thermal effects~~heat generation.

2.3. External exposure assessment should include ~~is 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. ~~Thermal hazards come mainly from t~~The decay heat of ^{238}Pu should be included in the calculation of heat generation.

~~2.4.~~ A MOX fuel fabrication facility using dry processes only does not store or process significant quantities of hazardous chemicals. Thus, ~~in MOX fuel fabrication facilities,~~ chemical hazards that could lead to radiological consequences are low. However, this would not be the case of MOX fuel fabrication facilities using compared with those for wet processes used in other fuel cycle facilities.

2.5. The wide variety of hazards posed by MOX fuel fabrication facilities has determined the various safety measures employed in such facilities. The main safety objectives in a MOX fuel fabrication facility are the prevention of criticality, confinement of radioactive material and protection against radiation exposure.

2.6. SSR-4 requires to Thus, it is important to perform a safety analysis in which potential accidents are analysed to ensure that they are adequately prevented, detected and, if they do occur, mitigated. This requires application of the concept of defence in depth (requirement 10 of SSR-4 [1]). The safety requirements are to be applied by means of a graded approach, as stated in Section 1 of Ref. [1].

2.4. For the application of the requirement that the concept of defence in depth be applied at the facility (see Section 2 of Ref. [1]), tTThe first two levels of defence- in depth (see Section 2 of Ref [1]) are the most important, as risks can be reduced to insignificant levels by means of design and appropriate operating procedures (see Sections 4 5 and 78). For MOX fuel fabrication facilities Tthe third level of defence in depth (physical barrier between the working area and environment) (e.g. a ventilation system) should be also available and reliable at all times.

2.7. ForWith respect to the hazard of potential criticality, the MOX fuel fabrication process facilities to remain reach in a safe state also when the process of fuel fabrication is brought to awhen stopped (i.e. there is no movement or transfer of material)., the

2.8.2.5. There are, however, some systems of the facility that should continue to operate to maintain the facility in a safe state, such as the following systems should continue to operate:

— Heat removal systems in storage areas to remove decay heat from reactor grade plutonium (however, the buildup of heat is not immediate);
— Systems executing confinement functions should continue to operate to prevent release of radioactive material from the facility, taking into account alfa decay during prolonged shut-down of the facility Albecausethough static barriers ensure a certain degree of confinement of radioactive material only for a finite period of time, dynamic containment systems should continue to operate to prevent leakage of radioactive material from the facility;
— Inert gas feed systems of sintering furnaces or gloveboxes.

3. MANAGEMENT SYSTEM FOR MOX FUEL FABRICATION FACILITIES

MANAGEMENT SYSTEM

3.1. The following recommendations provide a means of meeting the requirements 4 and 5 of SSR-4 [1] for the management for and verification of safety for MOX fuel fabrication facilities. The following recommendations are supplementary to, and should be read in conjunction with, the recommendations provided in the IAEA Safety Standards Series No. GS-G-3.1, Application of the Management System for Facilities and Activities [8] and IAEA Safety Standards Series No. GS-G-3.5, The Management System for Nuclear Installations [9].

~~2.9.~~3.2. A documented management system that integrates the safety, health, environmental, security, quality, human-and-organizational-factor, societal and economic elements of the operating organization is required to be in place in accordance with GSR Part 2, Leadership and Management for Safety [10] and Requirement 4 of SSR-4 [1].

3.3. The integrated management system should be established and put into effect by the operating organization, early in the lifetime of a MOX fuel fabrication facility, to ensure that safety measures are specified, implemented, monitored, audited, documented and periodically reviewed throughout the lifetime of the facility.

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

3.5. In determining how the requirements of the management system for safety of a MOX fuel fabrication facility are to be applied, a graded approach based on the relative importance to safety of each item or process should be used. However, taking into account the specific hazards of a MOX fuel fabrication facility, the potential for grading should be limited (see para. 4.4).

3.6. The management system should provide structure and direction to the organization in a way that permits and promotes the development of a strong safety culture together with the achievement of high levels of safety performance. Special consideration should be given to all activities covered by the management system associated with handling plutonium. This includes transition to hot commissioning or assigning new staff to activities involving plutonium handling (see also para. 8.27 of SSR-4 [1]).

3.7. The management system should address the following four functional areas: management responsibility; resource management; process implementation; and measurement, assessment, evaluation and improvement. In general:

— Management responsibility includes the support and commitment of management necessary to achieve the safety objectives of the operating organization in such a manner that safety is not compromised by other priorities.
— Resource management includes the measures necessary to ensure that the resources essential to the implementation of safety strategy and the achievement of the safety objectives of the operating organization are identified and made available.
— Process implementation includes the activities and tasks necessary to achieve the safety goals

of the organization.

— Measurement, assessment, evaluation and improvement provides an indication of the effectiveness of management processes and work performance compared with objectives or benchmarks; it is through measurement and assessment that opportunities for improvement can be identified.

MANAGEMENT RESPONSIBILITY

3.8. The prime responsibility for nuclear and radiation safety, including criticality safety, rests with the operating organization. The documentation of the management system of MOX fuel fabrication facility should include description of the organizational structure, functional responsibilities and levels of authority. Provisions for ensuring effective communication and clear assignment of responsibilities should be provided to ensure that processes and activities which are important to safety are controlled and performed in a manner that ensures that safety objectives are achieved.

3.9. The management of the operating organization should ensure that all aspects of safety, including monitoring the performance of activities and processes are developed and documented. The management should also ensure that all staff are adequately trained to perform assigned roles and should establish a system for keeping records that ensures control of performance and verification of activities that are important to safety. The records keeping system should provide for their identification, approval, review, filing, retrieval, and disposal.

3.10. There should be clear, written assignment of responsibilities for key safety functions, as for example criticality safety officer and radiation protection officer.

RESOURCE MANAGEMENT

3.11. The operating organization should provide adequate resources (both human and financial) for the safe operation of a MOX fuel fabrication facility as well as resources for mitigation of the consequences of accidents. The management of the operating organization should:

— participate in the activities by determining the required personnel competence and providing initial and periodic training, as necessary;
— prepare and issue specifications and procedures on safety related activities and operations;
— support and participate in safety assessment of modifications;
— make provisions for adequate interfaces and frequent contact between operating personnel and plant managers, including observation of work in progress.

3.12. In meeting requirement 58 of SSR-4 [1] the operating organization should ensure that operating personnel receive training and refresher training at suitable intervals, appropriate to their level of responsibility. In particular, operating personnel involved in activities with fissile material (both uranium and plutonium), with radioactive waste and with chemicals should understand the nature of the hazard posed by these materials and how the risks are controlled with the established safety measures, the operational limits and conditions and operating procedures.

3.13. The management system should include procurement activities and should be extended to include vendors and sub-contractors. The operating organization should ensure, through audits, that suppliers have management systems that are adequate for ensuring the safety of a MOX fuel fabrication facility.

PROCESS IMPLEMENTATION

3.14. All activities should be performed in accordance with approved procedures and instructions. The operating procedures should cover all facility states (see Definitions in SSR-4 [1]). The procedures should specify all parameters which are intended to control and the criteria to be fulfilled.

3.15. The management system of a MOX fuel fabrication facility should include also the management for criticality safety. Further guidance on the management system for criticality safety is provided in SSG-27 [4].

3.16. Any proposed modification to an existing MOX fuel fabrication facility, or a proposal for introduction of new activities, should be assessed for their implications on existing safety measures and appropriately approved prior to implementation. Modifications of safety significance should be subjected to safety assessment and regulatory review and appropriately approved before they are implemented. The modification process should also apply to procedures for design, fabrication, construction, commissioning and operation. The facility or activity documentation should be updated to reflect modifications, and the operating personnel, including supervisors, should receive adequate training on the modifications.

3.17. The activities for ensuring safety throughout the facility lifetime or activity duration involve different groups and interface with other areas such as those related to nuclear security and to the system for accounting for, and control of nuclear material. These activities should be identified, coordinated, planned, and conducted to ensure effective communication and clear assignment of responsibilities.

MEASUREMENT, ASSESSMENT, EVALUATION AND IMPROVEMENT

3.18. Audits of the management system performed by the operating organization as well as proper control of modifications are particularly important for ensuring the safety of a MOX fuel fabrication facility (para. 4.23 of SSR-4 [1]). In addition, independent audits should be also implemented. Audits should be carried out regularly and should cover also measures for emergency preparedness and response.

3.19. Deviations from operating procedures which were not pre-authorized and unforeseen changes in operations or in operating conditions should be reported and authorized by the management. Such events should be promptly investigated by the operating organization to analyze the causes of the deviation, to identify lessons to be learned, and to determine and implement corrective actions to prevent recurrences. There is also a danger that conditions may change slowly over time in response to factors such as ageing of the facility or owing to increased production pressures.

3.20. The management system should include a means of incorporating lessons learned from operating experience and accidents at facilities in the State and in other States, to ensure continuous improvement in operational practices and assessment methodology. Guidance on and recommendations for establishing a system for the feedback of operating experience are provided in IAEA Safety Standards Series No. SSG-50, Operating Experience Feedback for Nuclear Installations Ref. [11].

VERIFICATION OF SAFETY

3.21. In accordance with requirement 5 of SSR-4 [1], the operating organization is responsible for ensuring the continued verification of safety. Verification of safety in a MOX fuel fabrication facility should include the following programmes:

(1) Radiation protection programme
- Continuous monitoring and alarm of aerial contamination inside the facility and in surrounding area;
- Contamination of surfaces;
- Glovebox containment and shielding;
- Radiation protection zone controls for personnel and equipment;
- Surveillance programme for equipment and systems;
- Confinement controls for radiological protection and heat removal;
- Ventilation control and maintenance of pressure differentials;
- HEPA filtration;
- Glovebox integrity

(2) Criticality safety programme
- Control of material arriving, internal transfers and prevention of accumulation of fissile material;
- Real-time material inventory control;
- Moderator control procedures;
- Calibration and maintenance of safety instrumentation;
- Control of neutron absorbing material;
- Criticality accident alarm system including personnel evacuation;

(3) Fire safety programme
- Testing of fire detectors, ventilation dampers, spark arrestors, maintenance of fire barriers;
- Mitigation based on extinguishants compatible with criticality safety and control of pressure

differentials ensured by ventilation systems;

(4) Training, retraining and qualification of personnel

- Selection of personnel, with appropriate clearance, education and skills necessary to understand and apply procedural rules for glovebox and remote working, and the flexibility to work in an environment possessing strong safety culture;
- Training and qualification of personnel that includes the criticality and radiation protection aspects related to handling plutonium in a safe and secure manner;
- Safety culture;
- Planning for ageing and replacement of highly developed personnel skills (succession planning);

(5) Ageing management Programme

- Optimization of preventive maintenance inside gloveboxes;
- Equipment Surveillance;
- Management of obsolescence;

(6) Emergency response plan

- Training and exercises for emergencies at gloveboxes; e.g: split gloves, fire, criticality;
- Means for decontamination and screening of personnel as well as protective active substances related to specific hazards of the installation;
- Instrumentation for monitoring the facility state.

3.22. These programmes should focus on preventing plutonium from reaching places where it should not belong.

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

3.4. SITE EVALUATION

3.1.4.1. The site evaluation process for a MOX fuel fabrication facility will depend on a large number of criteriavariables, some of which are more important than others. At the earliest stage of planning a facility, a list of these criteria should be prepared and considered in accordance with their safety significance. In most cases, it is unlikely that all the desirable criteria can be met, and the risks Risks posed by possible safety significant external initiating eventshazards (e.g. earthquakes, accidental aircraft crashes, fires, explosions in nearby public traffic, floods and extreme weather conditions) will probably dominate in the site evaluation process and need to be incorporated into the design of the facility. Requirements for site evaluation for MOX fuel fabrication facilities are provided in IAEA Safety Standards Series No. SSR-1, Site Evaluation for Nuclear Installations [12] and further guidance is provided in SSG-35, Site Survey and Site Selection for Nuclear Installations [13].

4.2. The scope of the site evaluation for a MOX fuel fabrication facility is established by Requirement 3 of SSR-1 [12] and Requirement 11 and paras. 5.1 to 5.14 of SSR-4 [1] and should reflect the specific hazards listed in Section 2 of this Safety Guide.

~~3.2.~~4.3. For a MOX fuel fabrication facility, ~~liquid discharges of hazardous materials are generally negligible owing to the~~ where dry process is used to manufacture fuel~~. Appropriate~~ appropriate design and operation can ensure that ~~gaseous~~ aerial releases are negligible under normal operating conditions. The major hazard in accident conditions is the potential release of plutonium (as plutonium oxide or MOX) as particles to the atmosphere.

~~3.3.~~4.4. A MOX fuel fabrication facility should be considered to be a facility with a high hazard potential and therefore the potential for grading requirements of SSR-4 [1] should be limited. The following characteristics of the site ~~that should be considered~~ to ensure the safety of the facility should be considered~~include the following~~:

— *Legal requirements.* ~~In some States, the licensing process for a MOX fuel fabrication facility is facilitated by using~~ Using a site for which regulatory consent to process plutonium has already been granted.

— *Transport links.* ~~In principle, the aim should be to minimize~~ Minimize the ~~extent~~ distance ~~to~~ by which fissile material needs to be transported (as for example by siting a MOX fuel fabrication facility on the same site as plutonium production). ~~Export of MOX fuel will require ready access to safe and effective transport networks, e.g. ports (for overseas transport), roads and railways.~~

~~3.1. However, the following characteristics of MOX fuel fabrication facilities tend to diminish some of the constraints that usually apply to the siting of nuclear facilities:~~

~~Mox fuel fabrication facilities do not require the availability of large volumes of water for their processes, for cooling purposes or for diluting discharges of liquid effluents.~~

~~Mox fuel fabrication facilities do not require tall structures such as chimneys or cooling towers.~~

~~The main hazards are flooding, which could result in criticality issues, and earthquakes, which could result in loss of confinement, and potential criticality events due to loss of safe geometry. However, the consequences of these hazards can be minimized by means of proper design.~~

~~The need for land (the environmental 'footprint' of the buildings and the surrounding site area) is relatively small compared with that for other fuel cycle facilities.~~

4.5. The density and distribution of population in the vicinity of the MOX fuel fabrication facility and the direction of the prevailing wind at the site should 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.

4.6. Considering the presence of plutonium in a MOX fuel fabrication facility, special attention should be given to the management of interface between nuclear safety and nuclear security aspects during site evaluation (requirement 75 of SSR-4 [1]).

~~3.4.~~4.7. Even if an existing nuclear site is used for a MOX fuel fabrication facility, the complete site evaluation should be performed (see para. 3.24 - 3.27 of SSG-35 [13]).

4.8. A full record should be kept of the decisions taken on the selection of a site for a MOX fuel fabrication facility and the reasons behind those decisions.

~~3.5.~~4.9. The adequacy of the site evaluation should be reviewed periodically during the lifetime of the facility including in case of an increase of a production capacity beyond the original envelope (para 5.14 of SSR-4 [1]).

~~4.~~5. DESIGN

~~GENERAL~~

~~Safety functions for MOX fuel fabrication facilities~~

~~4.1. Safety functions (see Ref. [1], Appendix II, para. II.1), i.e. those functions the loss of which may lead to releases of radioactive material having possible radiological consequences for workers, the public or the environment, are those designed for:~~

~~(1) prevention of criticality;~~
~~(2) confinement of radioactive material, including removal of decay heat;~~
~~(3) protection against external exposure.~~

Specific engineering design ~~requirements~~guidance

~~4.2. The following requirements apply:~~

~~4.2.~~5.1. ~~(1)~~ The requirements on ~~prevention of criticality~~maintaining subcriticality are~~as~~ established in requirement 38 and para. 6.~~43~~138 – 6.~~51~~156 ~~and II.3–II.8 of Appendix II~~ of SSR-4~~Ref.~~ [1]. Further guidance on the design of a MOX fuel fabrication facility to ensure subcriticality is provided in Section 3 of SSG-27 [4].

~~4.3.~~5.2. ~~(2)~~ The requirements on confinement and cooling of radioactive materials ~~as~~ are established in requirements 35, 39 and in para. 6.123 – 6.128 and 6.157 – 6.159 ~~6.37–6.39, 6.52 and II.9–II.14 of Appendix II~~ of SSR-4~~Ref.~~ [1].

~~4.4.~~5.3. ~~(3)~~ The requirements on protection against external radiation exposure are established in requirement 36 and para. 6.129 – 6.134~~6.40–6.42~~ of ~~Ref.~~SSR-4 [1]. Owing to the radiation fields associated with plutonium (neutron emissions and gamma radiation), an appropriate combination of requirements on source limitation, distance, time and shielding is necessary for the protection of personnel ~~workers~~ in respect of whole body exposures~~, and~~ exposures of the hands and eye doses. 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. There should be individual monitoring of neutron doses for personnel ~~workers~~ in addition to individual monitoring of gamma.

Design basis ~~accidents~~ and safety analysis

~~4.5.~~5.4. ~~The definition of a design basis accident in the context of fuel cycle facilities can be found in para. III-10 of Annex III of Ref. [1].~~ The safety requirements relating to design basis ~~accidents~~ are established in requirements 14 and 20 ~~paras 6.4–6.9~~ of SSR-4~~Ref.~~ [1].

~~4.6.~~5.5. The specification of a design basis ~~accident~~ (or equivalent) will depend on the facility design, its siting and ~~national criteria~~regulatory requirements. However, particular consideration should be given to the following hazards in the specification of design basis ~~accidents~~ safety analysis for MOX fuel fabrication facilities:

a) ~~A n~~Nuclear criticality accident;

~~b) A hydrogen explosion;~~

~~c)~~b) ~~A f~~Fire (in particular in gloveboxes);

~~d)~~c) ~~Natural phenomena such as earthquakes, flooding or tornadoes;~~Loss of electrical power;

d) ~~An aircraft crash.~~Loss of heat removal;

e) Internal and external events, including:

   (i) Internal and external explosions (in particular hydrogen explosions);

   (ii) Internal and external fire;

   (iii) Dropped loads and associated handling events;

   (iv) Natural phenomena (including earthquakes, flooding and tornadoes);

   ~~(i)~~(v) Aircraft crashes.

~~4.7.~~5.6. ~~The first two events~~Events associated with criticality accident or hydrogen explosions might result primarily in radiological consequences for ~~on-site~~ personnel~~workers~~. The ~~last three~~other events might have both on-site and off-site consequences.

~~4.8.~~5.7. The events listed in para. ~~4.4~~ 5.6 may occur as a consequence of a postulated initiating event (PIE). Selected PIEs are listed in ~~Annex I~~ Appendix of ~~Ref.~~SSR-4 [1].

Structures, systems and components important to safety

~~4.9.~~5.8. Paragraph 6.21 of SSR-4 [1] states that: "The design of the nuclear fuel cycle facility […] 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.".~~The likelihood of design basis accidents (or equivalent) should be minimized, and any associated radiological consequences should be controlled by means of structures, systems and components important to safety (see paras 6.5–6.9 and Annex III of Ref. [1]).~~ Annex II of this Safety Guide presents examples of structures, systems and components and representative events that may challenge the associated safety functions.

Prevention of nuclear criticality

4.10.5.9. Prevention of nuclear criticality is an important topic with various aspects to be considered during the design and operation of a facility or activity. The following paragraphs highlight some of the main elements that are specific for MOx MOX fuel fabrication facilities. The principal guidance is obtained in the general parts and the relevant parts of IAEA Safety Standards Series No. SSG-27 Criticality Safety in the Handling of Fissile Material [94].

4.11.5.10. The aim of the criticality safety analysis, is to demonstrate that the design of equipment / facility together with the related safety measures areis such that the facility is in a sub-critical state at all times i.e. the values of the controlled parameters are always maintained in the subcritical range. In order to accomplish the calculated value of the effective multiplication factor (k_{eff} including all uncertainties and biases) which mainly depends on the mass, heterogeneity of the material and the moderation, geometry, density, reflection and nuclear properties of the fissionable material has to be compared with the value specified by the design limit (which should be set in accordance with para. 2.4-2.7 [SSG27]2.8 – 2.11 of SSG-27 [4]) and maintained under this limit.

5.11. "For the prevention of criticality by means of design, the double contingency principle shall be the preferred approach" (Ref.SSR-4 [1], para. 6.45142). Paragraph II.5 of Appendix II of Ref. [1] establishes requirements for the control of system parameters for the prevention of criticality. For ensuring criticality safety in a MOX fuel fabrication facility one or more of the following parameters of the system should be kept within subcritical limits:

a) PuO_2 (receipt)

(i) Mass and geometry (limitation of the dimensions or shape) in accordance with the safety specification of PuO_2 isotopic composition and moderation.

(ii) Presence of appropriate neutron absorbers.

b) UO_2 (receipt) Mass and geometry in accordance with the safety specification of UO_2 isotopic composition and moderation.

c)c)MOX powder (receipt or preparation) is formed in the fuel fabrication process, and the associated criticality hazard should be assessed in accordance with the isotopic specification and the PuO_2 content at each stage of the process. Mass, geometry and moderation should be considered.

4.12.5.12. Some examples of the parameters subject to control for the prevention of criticality are listed in the following.

Powder receipt and storage

a) PuO_2 (receiptinput).

– The ratios of the amount of (239Pu + 241Pu) to the total amount of plutonium, and of the amount of 240Pu to the total amount of plutonium (the isotopic composition of the plutonium); and the amount of moisture (degree of moderation), for control of criticality by means of mass and geometry; — The presence of appropriate neutron absorbers, in, for example, the materials used for the construction of storage equipment, cans for powder and shipment containers;

— The isotopic composition of the plutonium (ratios of the amount of a particular isotope of plutonium to the total amount of plutonium: $^{239}Pu/Pu$, $^{240}Pu/Pu$, $^{241}Pu/Pu$, $^{242}Pu/Pu$). ^{238}Pu should not be taken into account as ^{238}Pu is a neutron absorbent;

— The amount of moisture (degree of moderation), for control of criticality on the next stages of the MOX fuel fabrication process;

— The upper bounded PuO_2 density.

b) UO_2 (receiptinput).

— The ratio of the amount of 235U to the total amount of uranium (the isotopic composition of the uranium; if this ratio is less than 1%, there may be considered to be no criticality hazard); and the amount of moisture (degree of moderation), for control of criticality by means of mass and geometry.

— The isotopic composition of the uranium i.e. the ratio of the amount of ^{235}U to the total amount of uranium ($^{235}U/U$). When this ratio is less than 1%, and given that there is no heavy water (D_20), beryllium, graphite or other moderators more effective than light water present in the facility, no criticality hazard is to be considered;

— The amount of moisture (degree of moderation), for control of criticality on the next stages of the MOX fuel fabrication process;

— The upper bounded UO_2 density.

c) MOX powder (receipt or preparation).

— The ratios of the amount of (239Pu + 241Pu) to the total amount of plutonium, of the amount of 235U to the total amount of uranium, and of the amount of 240Pu to the total amount of plutonium (Pu isotopic specification); the ratio of PuO2 to the total amount of oxides (the PuO2 concentration); and the level of moisture and the amount of additives (the degree of moderation), for assessment of the criticality hazard at each stage of the process;

— The ratio of PuO_2 to the total amount of oxides ($PuO_2/(UO_2 + PuO_2)$);

— The amount of moisture (degree of moderation) and the amount of additives (the degree of moderation), for assessment of the criticality hazard at each stage of the process;

— The upper boundary of the UO_2-PuO_2 (MOX) density;

— The presence of non-homogeneous distributions of moderators, if considered necessary.

4.13.5.13. The aim of the criticality analysis, as required in para. II.7 of Appendix II of Ref. [1], is should be to demonstrate that the design of equipment is such that one or more the values of controlled parameters are always maintained in the subcritical range. Various methods One method to accomplish this are described in SSG-27, Section 4 [4]is by determining the effective multiplication factor (keff), which mainly depends on the mass, heterogeneity of the material and the moderation, geometry, density, reflection and nuclear properties of the fissionable material. The calculated value of keff is then compared with the value specified by the design limit.

5.14. In order to perform criticality analysis of a MOX fuel fabrication plant, the following input data should be specified:

i. the PuO_2 content of the final MOX powder mix (PuO_2/(UO_2+PuO_2) value;

ii. the maximum density of the final MOX powder mix;

iii. and the final moderator material content in the mix (powder "moisture" and hydrogen / carbon content (composition) of the additives).

4.14.5.15. The methods of calculation vary widely in basis and form, and each has its place in the broad range of situations encountered in the field of nuclear criticality safety. The criticality analysis should involve:

— The use of a conservative approach, with account taken of:

- Uncertainties in physical parameters, the physical possibility of worst caseoptimal moderation conditions and the presence potential of non-homogeneous distributions of moderators;
- Optimal geometry configuration of a system with fissile material;
- Plausible operational occurrences and their combinations if they cannot be shown to be independent;
- Operational states that may result from external hazards.

— The use of appropriate verified and validated computer codes that are validated together with the should be within their applicable range and of appropriate data libraries of nuclear reaction cross-sections, for the normal and credible abnormal conditions being analyzed, while taking into account any bias (see para. 4.25.Section 4 of SSG-27 [4]). If sufficient benchmarks are not available the upper subcriticality limit should be reduced.

5.16. Consideration should be given to criticality safety during pelletizing the final MOX powder mix as the powder undergoes compression and changes "geometry". The approach to the criticality safety including safety analysis after this stage in the production is similar to approach undertaken in a uranium fuel fabrication facility with additional considerations applicable to plutonium in MOX as presented in SSG-27 [4].

4.15. Another method of calculation is to specify the 'safe mass' as a factor of the critical mass, and demonstrating that the system inventory will always be less than this safe mass under all normal and abnormal conditions.

4.16.5.17. The following are recommendations for conducting a criticality analysis for a MOX fuel fabrication facility to meet the safety requirements established in para. 6.144 of SSR-4Ref. [1],

Appendix II, para. II.7:

— *Enrichment*. In criticality calculations the use of an effective enrichment[1] should be avoided unless the validity of the data used can be demonstrated with high level of confidence.

— *Mass*. "Criticality safety shall be assessed with significant margins" (Ref. [1], para. II.7(b)). The mass margin should be sufficient to compensate for possible over-batching of PuO_2 or MOX or under-batching of UO_2.

— *GeometryDensity and forms of materials*. "A conservative approach shall be taken" (Ref. [1], para. II.7(d)). The analysis should cover possible changes in dimensions due to operation (e.g. bulging of slab tanks or slab hoppers)a range of densities and moderators for different forms of MOX (e.g. powder, green and sintered pellets, and rods) to determine the most reactive conditions that could occur.

— *Concentration and, density and form of materials (in an analytical laboratory and in liquid effluent units.*). "A conservative approach shall be taken" (Ref. [1], para. II.7(e)). The analysis should cover a range of: (i) plutonium and uranium concentrations for solutions; and (ii) powder and pellet densities for and moderators for different forms of MOXsolids (e.g. powder, green and sintered pellets, and rods), to determine the most reactive conditions that could occur.

— *Moderation*. "The analysis shall consider a range of moderation to determine the most reactive conditions that could occur" (Ref. [1], para. II.7(f)). Water, oil and other hydrogenous substances such as additives are common moderators that are present in MOX fuel fabrication facilities or that may be present in accident conditions (e.g. water from firefighting). Special consideration should be given to cases of inhomogeneous moderation.

— *Reflection*. "A conservative assumption concerning reflection shall be made in the criticality analysis" (Ref. [1], para. II.7(g)). The most conservative margin should be retained of those resulting from different assumptions such as: (i) a hypothetical thickness of water around the processing unit; and (ii) consideration of the actual neutron reflection effect due, for example, to the presence of human beings, organic materials, shielding materials, or the concrete or steel of the container in or around the processing unit. Consideration should be given to situations where material may be present that could lead to a greater increase of the neutron multiplication factor than in a full water reflection system.

— *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" (Ref. [1], para. II.7 (i)). The neutron absorbers that may be used in MOX fuel fabrication facilities include cadmium, gadolinium and boron and the safety analysis should incorporate their effect as neutron absorbers; however, ignoring their effects would yield

[1] effective enrichment takes credit for neutron absorption characteristics of elements/isotopes present such as gadolinium, ^{236}U or ^{238}Pu

conservative results. The use of mobile neutron absorbers should be avoided.

4.17.5.18. For processes in which radioactive fissile material is handled in a discontinuous manner (batch processing), the process and the related equipment should be designed to ensure that radioactive fissile material is transferred only when the limits defined for the next process are satisfied.

Confinement of radioactive material

4.18. The requirements for confinement are established in para. II.9 of Ref. [1]: "Confinement shall be the primary method for protection against the spreading of powder contamination" (e.g. in areas where significant quantities of plutonium powder are held). "Confinement shall be provided by two complementary containment systems — static and dynamic."

4.19.5.19. In a MOX fuel fabrication facility, three static barriers (or more, as required by the safety analysis) should be provided, in accordance with a graded approach. The first static barrier normally consists of gloveboxes, fuel claddings or material containers. The second static barrier normally consists of rooms around the gloveboxes and/or the walls of the building. The third static barrier is the building itself. In theThe design of the static containment system should accountconsider should be taken of typical openings between 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.

4.20. To complement the effectiveness of the static barriers, a "dynamic containment system shall be used to create airflow towards equipment that is more contaminated" (normally the gloveboxes). Such airflow will establish a cascade of reducing absolute pressures (i.e. creating negative pressure) between the environment outside the building and the contaminated material inside.

5.20. 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 contaminated material inside the building, and across all static barriers within the building. The associated systems system should be designed to prevent the movement or diffusion of radioactive or toxic gases, vapors 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, as far as practicable:

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 the event 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.

~~4.21.~~5.21. 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 powders outside the first barrier (with gloveboxes and tunnels linking them). Design features should be provided for removal of materials and items (such as waste or scrap) from the gloveboxes when needed.

~~4.22.~~5.22. Devices for monitoring air contamination should be included in the design of confinement areas close to working locations, specifically at gloveboxes. The location of such sampling should be finalized during cold commissioning, when precise airflows are established. Surface contamination can be detected by swabbing or by portable devices for which equipment should be provided.

~~4.23.~~5.23. The design of a MOX fuel fabrication facility should be such as to facilitate operation, especially maintenance and decontamination activities. ~~; consequently b~~Building compartmentalization should be considered in the design to prevent contamination of large areas of the MOX fuel fabrication facility ~~and a balance should be achieved between possible consequences of contamination and economic considerations~~.

5.24. The ventilation system normally includes filters in series to protect ~~the workers,~~ the public and the environment. The air drawn into the ventilation system from the environment ~~Filters should be used when airflow crosses confinement zones and~~as well as air discharged from the facility should be filtered ~~when airflow exits the facility~~. The filters filter the air during normal operation and ensure the continuity of the static barriers in the event of loss of ventilation.

~~4.24.~~5.25. Procedure and instrumental means to control the potential buildup of plutonium powder or MOX powder particulates in the ventilation ducts should be established.

5.26. 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 ~~powder~~ particulates in the ventilation ducts. Multiple primary filters in series should preferably be used since this configuration will prevent any transfer of contamination during maintenance of one of the filters.

~~4.25.~~5.27. 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.

~~4.26.~~5.28. 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 may result in differential pressures that are considered too high or too low.

4.27.5.29. Last stage filters are used to protect the public and the environment and are normally located close to the location at which discharges to the environment occur. Last stage filters are discussed in para. 4.30 and 4.315.35 – 5.36.

4.28.5.30. 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 dampers, unless the likelihood of a fire spreading is considered to be acceptably low.

5.31. At the design stage, provision should also 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 workers and would minimize the time for detection of any leakage from the first barrier.

4.29.5.32. 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 personnelworkers

5.33. Requirements on the design of MOX fuel fabrications facilities to ensure radiation protection are stablished in Requirement 8 of SSR-4 [1].

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

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

4.32.5.36. The dynamic containment system, along with the usage of personal protective equipment, is used to minimize the radiation exposure of personnel workers and their exposure to hazardous material that could become airborne and so could be inhaled.

5.37. For normal operation, the need for the use of protective respiratory equipment 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. The use of protective respiratory equipment for normal operation should be used only as a complementary mean of protection in addition to existing barriers (para. 9.100 of SSR-4 [1]).

Protection of the public and the environment

4.33.5.38. The uncontrolled dispersion of radioactive substances to the environment as a result of an accident can occur if all themultiple containment 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 In addition, ventilation of the containment systems, by the discharge of exhaust gases through a stack after passing through a particulate removal filter, reduces the normal environmental discharges of radioactive material to very low levels.

4.34.5.39. In addition to meeting the requirement established in para. II.14 of Appendix II of Ref. [1], the The design of a MOX fuel fabrication facility should also provide measures for the testing of removal efficiencies for last stage filters, for uninterrupted monitoring and control of the stack exhaust, for monitoring of the environment around the facility and for identification of breaches of the containment barriers.

Protection against external exposure

5.40. Relevant requirements on design provisions for protection against external radiation exposure are established in Requirement 36 of SSR-4 [1].

4.35.5.41. External exposure can 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 the vessels and/or gloveboxes of a MOX fuel fabrication facility may not be sufficient to control exposure adequately, and thus additional controls on time, distance and shielding should be considered, where necessary.

4.36.5.42. If necessary, consideration should be given to the remote operation of process equipment and the installation of equipment for powder collection to prevent any spreading of powder in gloveboxes.

4.37.5.43. Provision of shielding in material storage areas, at process gloveboxes (e.g. where powder processing or pellet processes are carried out) and in the fuel assembly area should be considered. For new MOX fuel fabrication facilities, the design of shielding should be such as to ensure compliance with targets for occupational exposure (see para. 6.4 of Ref. [1]) based on assumptions about the spread of contamination in gloveboxes, the time of occupancy and the sources of radiation.

Internal ~~initiating events~~hazards

Fire and explosion

~~4.38.~~5.44. ~~MOX fuel fabrication facilities, like all industrial facilities, have to be designed to control fire hazards to protect workers, the public and the environment.~~ Fire in MOX fuel fabrication facilities may lead to the dispersion of radioactive material ~~and/or toxic material~~ by breaching the containment barriers or may cause a criticality accident by affecting the system or the parameters used for the control of criticality (e.g. the moderation control system or the dimensions of processing equipment).

~~4.39.~~5.45. The fire hazards that are specifically encountered in a MOX fuel fabrication facility are associated with the presence of flammable and combustible materials such as electrical cabling and shielding, in particular when associated with gloveboxes and hydrogen in the sintering furnaces. ~~.~~

Fire hazard analysis

~~4.40.~~5.46. As an important aspect of fire hazard analysis for a MOX fuel fabrication facility, areas of the facility that require special consideration should be identified (see requirement 22 of SSR-4 [1]). Fire hazard analyses of the facility should give particular consideration for the following~~Special fire hazard analyses should be carried out for~~:

a) Areas where fissile material is processed and stored;
b) Gloveboxes, especially those in which nuclear material is processed as powder or powder is produced;
c) Workshops and laboratories in which flammable liquids and/or combustible liquids, solvents and resins and reactive chemicals are used, or zirconium metal is mechanically treated (e.g. producing cuttings or shavings);
d) Areas with high fire loads, such as waste storage areas;
e) Waste treatment areas~~, especially those where incineration is carried out;~~
f) Rooms housing safety related equipment, e.g. items, such as air filtering systems, and electrical switch rooms, whose ageing issues ~~degradation~~ may lead to radiological consequences or consequences in terms of criticality that are considered to be unacceptable;
g) Process control rooms and emergency control rooms;
h) Evacuation routes.

~~4.41.~~5.47. Fire hazard analysis should involve~~s~~ identification of the causes of fires, assessment of the potential consequences of a fire and, where appropriate, estimation of the frequency or probability of occurrence of fires. Fire hazard analysis is used to assess the inventory of fuels and initiation sources, and to determine the appropriateness and adequacy of measures for fire protection. Computer modelling of fires may sometimes be used in support of the fire hazard analysis.

~~4.42.~~5.48. The estimation of the likelihood of fires can be used as a basis for making decisions or for identifying weaknesses that might otherwise go undetected. Even if the estimated likelihood of fire may seem low, a fire might have significant consequences for safety, and thus certain protective measures should be undertaken, such as delineating small fire areas, to prevent fires or prevent the fire from spreading.

~~4.43.~~5.49. The analysis of fire hazards should also involve a review of the provisions made at the design stage for preventing, detecting and ~~fighting~~ mitigating fires.

Fire prevention, detection and mitigation

~~4.44.~~5.50. Prevention is the most important aspect of fire protection. Facilities should be designed to limit fire risks through the incorporation of measures to ensure that fires do not break out. Measures for mitigation should be put in place to minimize the consequences of a fire in the event that a fire breaks out despite preventive measures.

~~4.45.~~5.51. To accomplish the ~~two-fold aim~~goal of fire prevention and mitigation of the consequences of a fire, a number of general and specific measures should be taken, including the following:

- Minimization of the amount of combustible material present in gloveboxes; nevertheless it may be necessary to maintain inert atmospheres and alarms for monitoring oxygen levels to minimize the risk of a large fire.
- Separation of the areas where non-radioactive hazardous material is stored from the process areas.
- Minimization of the fire load of individual rooms.
- Selection of materials, including building materials, process and glovebox components and materials for penetrations, in accordance with functional criteria and fire resistance ratings.
- Compartmentalization of the building~~s~~ and ventilation ducts as far as possible to prevent the spreading of fires. The ~~B~~buildings~~s~~ should be divided into fire zones and structural design should consider respective fire load. Measures should be put in place to prevent or severely curtail the capability of a fire and smoke to generate soot and spread beyond the fire zone in which it breaks out. The higher the fire risk, the greater the number of fire zones the~~a~~ building should have.
- Suppression or limitation of the number of possible ignition sources such as open flames or electrical sparks.

5.52. ~~"~~Extinguishing devices, automatically or manually operated, with the use of an adequate extinguishing material ~~shall~~ should be installed in areas where a fire is possible and where the consequences of a fire could lead to the ~~wide~~ dispersion of plutonium contamination outside the first static barrier. The installation of automatic devices with water sprays ~~shall~~ should be ~~carefully assessed~~avoided for areas where uranium, plutonium and/or mixed oxide ~~(MOX)~~ may be present, with account taken of the risk of criticality. ” (Ref. [1], Appendix II, para. II.16) Extinguishing gas other than CO_2 may be used in the event of a fire breaking out in a glovebox.

5.53. A detection and/or suppression system should be installed that is commensurate with the risks from internal fires and explosions and is in compliance with national requirements.

4.46.5.54. The design of ventilation systems should be given particular consideration with regard to fire prevention. Dynamic containment comprises ventilation ducts and filter units which may constitute weak points in the fire protection system unless they are of suitable design. Fire dampers should be mounted in the ventilation system. unless the likelihood of widespread fires is acceptably low. The fire dampers should close automatically on receipt of a signal from the fire detection system or by means of temperature sensitive fusible links. Spark arrestors should be used to protect the filters if necessary. The required operational performance of the ventilation system should be specified so as to comply with fire protection requirements.

4.47.5.55. Lines that cross the boundaries between fire areas or fire zones (e.g. electricity, gases and process lines) should be designed to ensure that fire does not spread.

Explosions

4.48.5.56. In MOX fuel fabrication facilities, the use of hydrogen in the sintering furnaces is a potential cause of an explosion. To prevent this, one strategy is to stop oxygen from entering the furnace; a second method is to supply a quality controlled, premixed gas to the furnaces. Hydrogen should be diluted with an inert gas (e.g. argon) before it enters the sintering furnace to reduce the likelihood so that any postulated resulting of a hydrogen explosion would result in acceptable consequences for safety. The supply of premixed gas should be automatically stopped when the concentration of hydrogen in the quality controlled premixed gas exceeds a limit.

5.57. In addition, effective gas locks should be provided between rooms with a hydrogen atmosphere and other areas of the facility. Systems for detecting hydrogen leakages should be installed in such rooms.

4.49.5.58. The concentration of oxygen within gloveboxes should be monitored.

Flooding

4.50.5.59. Flooding in a MOX fuel fabrication facility may lead to the dispersion of radioactive material and to changes in the conditions for moderation.

4.51.5.60. Gloveboxes should not be connected to the water supply in normal operating conditions, unless the presence or leakage of water inside gloveboxes was taken into account in the criticality analysis.

4.52.5.61. For In facilities where vessels and/or pipes containing water are present, the criticality analysis should be evaluated assuming a fully flooded condition take into account the presence of the maximum amount of water that could be contained within the room under consideration, as well as the maximum amount of water in any connected rooms. Such rooms or premises should be clearly identified to personnelworkers.

4.53.5.62. Walls (and floors if necessary) of rooms where flooding could occur should be capable of withstanding the water load, and safety related equipment should not be affected by flooding.

Leaks and spills

4.54.5.63. The amount of liquid present in a MOX fuel fabrication facility is limited. Water is used for cooling sintering furnaces. Possible steam explosions resulting from water entry due to a potential leak in the cooling system should be evaluatedhave an acceptably low likelihood.

5.64. Spillages may occur outside gloveboxes from cans, drums and waste packages during transit within the MOX fuel fabrication facility and/or in storage. Appropriate mechanical protection and appropriate containment confinement should be provided for movements of radioactive material.

5.65. Where spillages in quantities that could be significant from the standpoint of criticality safety are possible (as for example ingress of water from condensed humidity through ventilation systems), consideration should be given to installing design features to prevent water or moderator intrusion. Installation of humidity detectors and drainage systems should also be considered.

Loss of support systems

4.55.5.66. To fulfil the requirement established in requirements 49 and 50, and para. 6.286.89 of SSR-4Ref. [1], electric power supplies and other support systems to in a MOX fuel fabrication facilities should be of high integrity. In the event of loss of normal power (see Section 2) and depending on the status of the facility, an emergency power supply should be provided to certain structures, systems and components important to safety, including the following:

- Ventilation fans and glovebox monitoring systems for the confinement of radioactive material;
- Heat removal systems;
- Emergency control systems;
- Fire detection and alarm suppression systems;
- Monitoring systems for radiation protection;
- Alarm systems for criticality accidents Criticality accident detection and alarm systems.

Use of mobile power sources for emergencies should be considered.

4.56.5.67. The loss of general suppliesitems such as gas for instrumentation and control, cooling water for process equipment and ventilation systems, heating water, breathing air and compressed air may also have consequences for safety. In the design of a MOX fuel fabrication facility, suitable measures to ensure safety should be provided. For example:

a) Loss of gas supply to gas actuated safety valves and dampers. In accordance with the safety analysis, valves should be used that are designed to fail to a safe position.

b) Loss of cooling ~~or heating~~ water. Adequate backup capacity or a redundant supply should be provided for in the design.

c) Loss of breathing air. Adequate backup capacity or a redundant supply should be provided to allow work in areas with airborne radioactive material to continue to be carried out.

Loss or excess of process media

~~4.57.~~5.68. Either the loss of process media such as process gas supplies (e.g. hydrogen, helium, nitrogen or argon) and additives, or any excess of these media may have consequences for safety. Some examples are the following:

a) Excess of additives in the powder preparation process should be considered in the criticality analysis.

b) Overpressure in the gloveboxes (containing, for example, nitrogen, argon or helium) may cause an increase in the levels of airborne radioactive contamination ~~and/or the concentration of hazardous material~~ in the work areas of the facility.

c) Releases of large amounts of nitrogen, argon or helium may result in a reduction in the oxygen concentration in breathing air in the work areas of the facility.

d) For reasons of fire protection, inert gas may be used for the atmosphere in some gloveboxes. Failure of the gas supply, therefore, would remove one protective barrier. Consideration should be given to the integrity of gas supply by providing a suitable backup supply or by ensuring diversity of supply.

Loss of means of heat removal ~~of decay heat~~

~~4.58.~~5.69. MOX materials generate heat due to presence of Pu-238, and storage rooms, storage gloveboxes and larger production units in MOX fuel fabrication facilities have potentially large heat loads. Overheating may challenge the safety functions.

~~4.59.~~5.70. Ventilation systems are designed to provide cooling and so to maintain temperatures below specified values. In a MOX fuel fabrication facility, in the event of a failure of the ventilation system, the time interval before ~~damage occurs~~ confinement is breached should be adequate for repairing the failure or for taking alternative actions. All systems, structures, components important to safety should be so designed that they can withstand heat load generated during the above interval.

~~Load drops~~Handling errors

~~4.60.~~5.71. ~~From para. II.22 of Appendix II of Ref. [1], "~~Handling systems [e.g. cranes] ~~shall~~ should be designed to reduce the frequency of occurrence of load drops. The consequences of possible load drops ~~shall~~ should be minimized~~"~~ e.g. by qualification of the containers for the drop, and by the design of floors and the provision of safe travel paths.

~~4.61.~~5.72. Mechanical or human failures during the handling of radioactive material may result in a degradation of criticality control, confinement or shielding. Mechanical or human failures during the handling of loads of non-radioactive material may also result in a degradation of the safety functions of the MOX fuel fabrication facility.

~~Mechanical~~Equipment failures

~~4.62.~~5.73. ~~From para. II.23 of Appendix II of Ref. [1], "~~Measures for the industrial safety of non-nuclear-designed equipment installed in gloveboxes (e.g. mechanical guards) ~~shall~~ should be adapted to the nuclear environment.~~"~~

~~4.63.~~5.74. Mechanical failures during the processing of nuclear material could result in damage to equipment (e.g. by crushing, bending or breakage) which may result in a degradation of criticality control, confinement or shielding. For complex or important systems (e.g. rod handling systems designed to avoid the risk of breaking a rod), a systematic method of failure analysis should be implemented.

Radiolysis

~~4.64.~~5.75. The irradiation of organic or hydrogenated substances by plutonium, ~~or~~ and the resulting decomposition of molecules, may lead to the generation of gas, especially the release of hydrogen. The risk of radiolysis should be taken into account in the safety analysis for:

a) Liquid effluents and organic solvents used in the laboratory;

b) Contaminated oils and inflammable waste;

c) Process scraps enclosing hydrogenated additives ~~(which should be calcinated before being placed in a sealed container)~~;

d) Boxes containing PuO_2.

In addition, pressurization caused by alpha decay generating helium in a sealed system and the potential for water evaporation due to radiolytic heat generation should be considered.

External ~~initiating events~~hazards

~~4.65.~~5.76. A MOX fuel fabrication facility should be designed in accordance with the nature and severity of the external hazards, either natural or human induced, identified and evaluated in accordance with the provisions of SSR-1 [12] and its associated Safety Guides. Examples of specific external hazards for a MOX fuel fabrication facility are provided in the following paragraphs under appropriate headings.

Earthquakes

4.66. A MOX fuel fabrication facility should be designed for the design basis earthquake to ensure that an earthquake motion at the site would not induce a loss of confinement of plutonium or a criticality accident (i.e. a seismically induced loss of criticality safety functions such as geometry and moderation) with significant consequences for site personnel or members of the public.

4.67. To define the design basis earthquake for the facility, the main characteristics of the disturbance (intensity, magnitude and focal distance) and the distinctive geological features of the local ground should be determined. The approach should ideally evaluate the seismological factors on the basis of historical data for the site. Where historical data are inadequate or yield large uncertainties, an attempt should be made to gather palaeoseismic data to facilitate determination of the most intense earthquake affecting the site to have occurred over the period of historical record. The different approaches can be combined since the regulatory body generally takes into account the results of scenarios based on historical data and those based on palaeoseismic data in the approval of the design.

4.68. One means of specifying the design basis earthquake is to consider the historically most intense earthquake, but increased in intensity and magnitude, for the purpose of obtaining the design response spectrum (i.e. the relationship between frequencies and ground accelerations) used in designing the facility. Another way of specifying the design basis earthquake is to perform a geological review, to determine the existence of capable faults and to estimate the ground motion that such faults might cause at the location of the facility.

4.69.5.77. An adequately conservative spectrum should be used for calculating the structural response to guarantee the stability of buildings and to ensure the integrity of the ultimate means of confinement in the event of an earthquake. Certain structures, systems and components important to safety will require seismic qualification. This will apply mainly to equipment used for storage and vessels that will contain significant amounts of fissile or toxic chemical materials. Design calculations for the buildings and equipment should be made to verify that, in the event of an earthquake, no unacceptable release of fissile material to the environment would occur and the risk of a criticality accident would be very low. To ensure that the design provides the required degree of robustness, a detailed seismic assessment (see SSR-1 [12] and IAEA Safety Standards Series No. SSG-9, Seismic Hazards in Site Evaluation for Nuclear Installations [14]) should be made of the MOX fuel fabrication facility design, including the following seismically induced events:

a) Loss of cooling;
b) Loss of support services, including utilities;
c) Loss of containment functions (static and dynamic);
d) Loss of safety functions for ensuring the return of the facility to a safe state and maintaining the facility in a safe state after an earthquake, including structural functions and functions for the prevention of other hazards (e.g. fire, explosion, load drop and flooding);
e) The effect on criticality safety functions such as geometry and/or moderation and reflection of the following:

— Deformation (geometry control);

— Displacement (geometry control, fixed neutron absorbers, neutron interaction);

— Loss of material (geometry control, soluble neutron absorbers).

~~4.70.~~5.78. Supplementary control rooms or emergency control panels should be accessible and operable by staff after a design basis earthquake. Equipment required to maintain the MOX fuel fabrication facility in a safe and stable state and to monitor the facility and environment should be tested (as far as practicable) and qualified using appropriate conservative methodologies, including the use of an earthquake simulation platform.

~~4.71.~~5.79. Depending on the MOX fuel fabrication facility's site characteristics and location, as evaluated in the site assessment (Section 4), the effect of a tsunami induced by an earthquake and other extreme flooding events should be addressed in the facility design.

External fires and explosions and external toxic hazards

5.80. Hazards from external fires and explosions could arise from various sources in the vicinity of a MOX fuel fabrication facility, such as petrochemical installations, forests, pipelines and road, rail or sea routes used for the transport of flammable material such as gas or oil, and volcanic hazards.

~~4.72.~~5.81. To demonstrate that the risks associated with such external hazards are below acceptable levels, the operating organization should first identify all potential sources of hazards and then estimate the associated event sequences affecting the facility. The radiological or associated chemical consequences of any damage should be evaluated, and it should be verified that they are within acceptance criteria. Toxic hazards should be assessed to verify that specific gas concentrations meet the acceptance criteria. It should be ensured that external toxic hazards would not adversely affect the control of the facility. The operating organization should carry out a survey of potentially hazardous installations and transport operations for hazardous material in the vicinity of the facility. In the case of explosions, risks should be assessed for compliance with overpressure criteria. To evaluate the possible effects of flammable liquids, toxic spills, ~~-~~volcanic ashes, falling objects (such as chimneys), air shock waves and missiles resulting from explosions, their possible distance from the facility and hence their potential for causing physical damage should be assessed.

Extreme weather conditions

~~4.73. Typically, the extreme weather conditions assumed in the design and and in evaluation of the response of a MOX fuel fabrication facility are wind loading, tornadoes, tsunamis, etc.~~

~~4.74. The general approach is to use a deterministic, design basis value for the extreme weather condition and to assess the effects of such an event on the safety of the facility. The rules for obtaining the design basis values for use in the assessment may be specified by local regulations.~~

~~4.75.~~5.82. A MOX fuel fabrication facility should be protected against extreme weather conditions as identified in the site evaluation (see Section 4) by means of appropriate design provisions. These should generally include the following:

a) The ability of structures important to safety to withstand extreme weather loads, with particular assessment of parts of the facility structure designed to provide confinement.
b) The ability to maintain the availability of cooling systems under extreme temperatures and other extreme conditions.
c) Prevention of flooding of the facility including adequate means to evacuate water from the roof in cases of extreme rainfall.
d) Safe shutdown of the facility in accordance with the operational limits and conditions, followed by maintaining the facility in a safe and stable state, where necessary.
e) Events consequential to extreme weather conditions should also be considered in the design.

Tornadoes

~~4.76.~~5.83. Measures for the protection of the facility against tornadoes will depend on the meteorological conditions for the area in which the facility is located. The design of buildings and ventilation systems should be in compliance with specific national regulations relating to hazards from tornadoes.

~~4.77.~~5.84. High winds are capable of lifting and propelling objects as large as automobiles or telephone poles. The possibility of impacts of tornado missiles such as these should be taken into consideration in the design stage for the facility, as regards both the initial impact and the effects of secondary fragments arising from collisions with and spallation of concrete walls or from other types of transfer of momentum.

Extreme temperatures

~~4.78.~~5.85. The potential duration of extreme low or high temperatures should be taken into account in the design of support system equipment to prevent unacceptable effects such as the freezing of cooling circuits or adverse effects on venting and cooling systems.

~~4.79.~~5.86. If safety limits for humidity and/or the temperature are specified in a building or a compartment, the air conditioning system should be designed to perform efficiently also under extreme hot or wet weather conditions. Structural components of buildings (as static containment) should also be designed for extreme temperature and humidity and its associated thermal stress effects such as shrinkage in concrete.

Snowfall and ice storms

~~4.80.~~5.87. The occurrence of snowfall and ice storm and its effects should be taken into account in the design and safety analysis. Snow and ice ~~is~~are generally taken into account as an additional load on the roofs of buildings. The neutron reflecting ~~effect~~effect, or the interspersed moderation effect of the snow should be considered if relevant.

FloodsFloodingFlooding should be taken into account in the design of a facility. Two approaches to dealing with flooding hazards have been put forward:

In some states the highest flood levels recorded over the period of historical record are taken into account and nuclear facilities are sited at specific locations above the flood level or at a sufficient elevation to avoid major damage from flooding.

In other states, in which the use of dams is widespread and where a dam has been built upstream of a potential or existing site for a nuclear facility, the hazard posed by a breach of the dam is taken into account. The buildings of the facility are designed to withstand the water wave arising from the breach of the dam. In such cases the equipment — especially that used for the storage of fissile material — should be designed to prevent any criticality accident.

5.88. For any flood events such as extreme rainfall (for inland site), storm surge (coastal site), extreme rainfall, attention should be focused on potential leak paths (containment breaks) into active cells and structures, systems and components important to safety at risk of damage. In all cases, equipment containing fissile material should be designed to prevent any criticality accident. Gloveboxes should be designed to be resistant (undamaged and static) to the dynamic effects of flooding and all glovebox penetrations should be above any potential flood levels. Electrical systems, instrumentation and control systems, emergency power systems (batteries and power generation systems) and control rooms should be protected by design.

4.81.5.89. For extreme rainfall, attention should be focused on the stability of buildings (e.g. hydrostatic and dynamic effects), the water level and, where relevant, the potential for mudslides. Consideration should be given to the highest flood level historically recorded and to siting the facility above this flood level, at sufficient elevation and with sufficient margin to account for uncertainties (e.g. in postulated effects of global warming), to avoid major damage from flooding.

Accidental aircraft crashes

4.82.5.90. The likelihood and possible consequences of impacts onto the facility should be calculated by assessing the number of aircraft that come close to the facility and their flight paths, and by evaluating the areas vulnerable to impacts, i.e. areas where hazardous material is processed or stored. If the risk is acceptably low no further evaluations are necessary. See also para. 5.5 (item (h)) of Ref. [1]. In accordance with the risks identified in the site evaluation (see Section 4), MOX fuel fabrication facility should be designed to withstand the design basis impact.

4.83.5.91. For evaluating the consequences of impacts or the adequacy of the design to resist aircraft impacts, only realistic crash scenarios should be considered, which may require the knowledge of such factors as the possible angle of impact, velocity or the potential for fire and explosion due to the aviation fuel load. In general, fire cannot be ruled out following an aircraft crash, and so the establishment of specific requirements for fire protection and for emergency preparedness and response will be necessary.

INSTRUMENTATION AND CONTROL (I&C)

Instrumentation

4.84.5.92. Instrumentation should be provided to monitor the relevant variables parameters (such as radiation doses due to external exposure, air quality of operational areas and building pressure), and systems (such as ventilation systems) and general conditions of the facility (such as temperature, contamination) over their respective ranges for: (1) normal operation; (2) anticipated operational occurrences; and (3) design basis accidentsaccident conditions, to ensure that adequate information can be obtained on the status of the operations and the facility and proper actions can be undertaken in accordance with operating procedures or in support of automatic systems.

5.93. Instrumentation should be provided for measuring all the main variables parameters whose variation may affect the safety of processes (such as pressure, temperature and flowrate). In addition, instrumentation should be provided, for monitoring for safety purposes general conditions at the facility (such as criticality safety related parameters, radiation levels doses due to internal and external exposure., releases of effluents and ventilation conditions), and for obtaining any other information about the facility necessary for its reliable and safe operation (such as presence of personnel and environmental conditions). Provision should be made for the automatic measurement and recording of values of parameters that are important to safety.

Control systems

4.85.5.94. Passive and active engineering controls are more reliable than administrative controls and should be preferred for control in operational states and in accident conditions. Automatic systems should be designed to maintain process parameters within the operational limits and conditions or to bring the process to a predetermined safe state, which is generally the shutdown state.

4.86.5.95. Appropriate information should be made available to the operator for monitoring the effects of automatic actions. The layout of instrumentation and the manner of presentation of information should provide the operating personnel with an adequate impression of the status and performance of the facility. Devices should be installed that provide in an efficient manner visual and, as appropriate, audible indications of operational states that have deviated from normal conditions and that could affect safety. Provision should be made for the automatic measurement and recording of values of parameters that are important to safety and where applicable, manual periodic testing should be used to complement automated continuous testing of conditions.

Control rooms and panels

5.96. Control rooms and Human-Machine-Interface panels should be provided to centralize the availability of information and monitoring of actions. Occupational exposure and safety of personnel should be considered in the location of control rooms in the facility. Where applicable, it may be useful to have dedicated control rooms to allow for the remote monitoring of operations, thereby reducing exposures and risks to personnel. Particular consideration should be paid to identifying those events, both internal and external to the control rooms, that may pose a direct threat to the operation of control rooms. Human ergonomic factors should be taken into account in the design of control rooms and the design of control room displays and systemsmain data displays, controls and alarms for general conditions at the facility. Occupational exposure should be minimized by locating the control rooms in parts of the facility where the levels of radiation are low. For specific processes, it may be useful to have dedicated control rooms to allow the remote monitoring of operations, thereby reducing exposures and risks to operators. Particular consideration should be paid to identifying those events, both internal and external to the control rooms that may pose a direct threat to the operators and to the operation of control rooms. Ergonomic factors should be taken into account in the design of control rooms.

Safety related I&C systems for normal operation

4.87.5.97. The safety related I&C systems for normal operation of a MOX fuel fabrication facility should include systems for the following:

(1) Criticality detection and controlalarm system and building evacuation systems.
- — Depending on the method of criticality control, the control parameters relating to para. II.24 of Appendix II of Ref. [1] should usually include mass, density, moisture content, isotopic contentcomposition, fissile content, moderation and reflection of additives, and spacing between items.
- — Radiation detectors (gamma and/or neutron detectors) with audible and, where necessary, visible alarms for initiating immediate evacuation from the affected area, should cover all the areas where a significant quantity of fissile material is present – see para. 6.173 of SSR-4 [1];

(2) Process control.
- — A key safety related control system is the means of confirming the correct concentration of hydrogen in the gas supply to the sintering furnaces.

(3) Glovebox control.
- — The requirements for glovebox control are established in para. II.25 of Appendix II of Ref. [1]. Gloveboxes should be equipped with I&C systems ensuring negative pressure.
- — For gloveboxes containing inert gas, the in-leakage gas concentration should be monitored for safety and, if necessary, to verify product quality. Temperature levels should also be monitored.

(4) Control of ventilation.
- — Monitoring and control of ventilation is needed to ensure that the airflows in all areas of the MOX fuel fabrication facility are flowing in the correct direction, i.e. towards areas that are

more contaminated. In working areas, the temperature and humidity levels and the level of pollutants should be controlled to ensure the comfort of personnel workers and good levels of hygiene. In some cases, local ventilation should be used, e.g. in rooms housing backup batteries.

— Monitoring and control of ventilation should be applied in particular in areas where sintering furnaces and pellet grinding equipment are located.

(5) Control of occupational radiation exposure.

— External exposure. Sensitive dosimeters with real-time displays and/or alarms should be used to monitor occupational radiation doses, in particular in areas in which inspection equipment such as X ray equipment and radioactive sources are located. Portable equipment and installed equipment should be used to monitor whole body exposures and exposures of the hands to gamma radiation and neutron emissions.

— Internal exposure. The requirements for monitoring of internal doses are established in para. II.26 of Appendix II of Ref. [1]Owing to the specific hazards of airborne plutonium, the following provisions should be considered:

- Continuous air monitors to detect plutonium should be installed as close as possible to the working areas to ensure the early detection of any dispersion of plutonium.
- Continuous air sampling devices should be installed in the breathing zone of personnel for the retrospective assessment of doses due to internal exposure.
- Devices for detecting alpha surface contamination should be installed close to the working areas and also close at least to the exits of rooms in which working areas are located.
- Devices for detecting and assessment of eye lens doses should be installed where appropriate.

(6) Control of liquid discharges.

— MOX fuel fabrication facilities have low volumes of liquid discharges that can usually be monitored for control purposes by sampling and analysis and by measuring the volumes of discharges. Special arrangements should be made for effluents from laboratories, which can differ from site to site. Liquid discharges should be measured continuously.

— The detection and alarm system of abnormal releases should be ensured.

(7) Control of gaseous effluents.

— From para. II.27. of Appendix II of Ref. [1], "Real time measurements shall should be made to confirm that filtration systems are working effectively. Discharges shall should be measured continuously."

— The detection and alarm system of abnormal releases should be ensured.

(8) System for the control of transfers of nuclear material

(8) Safety related I&C systems for anticipated operational occurrences

(9) In addition to the listing provided in para. 4.88, safety related I&C systems for use in

ANTICIPATED OPERATIONAL OCCURRENCES SHOULD INCLUDE THE FOLLOWING PROVISIONS:

(10)(9) Fire detection and extinguishing systems and building evacuation systems;
(10) Systems for the detection of surface contamination and airborne radioactive material and alarm systems;
(11) Gas detectors and alarm systems

— Gas detectors and alarm systems should be installed in areas where a leakage of gases such as hydrogen or oxygen could produce an explosive atmosphere.Fire detection and extinguishing systems and building evacuation systems;Systems for the detection of surface contamination and airborne radioactive material and alarm systems;

— Gas detectors and alarm systems in areas where a leakage of gases such as hydrogen could produce an explosive atmosphere.

Safety related i&c systems for design basis accident conditions

In addition to the previous listings, the safety related i&c systems for design basis accident conditions should include:

Criticality detection systems, alarm systems and building evacuation SYSTEMS;

Detection and alarm systems for abnormal releases of effluents.

HUMAN FACTOR CONSIDERATIONS

4.88.5.98. The requirements relating to consideration of human factors are established in paras 6.15 and 6.16requirement 27 of Ref.SSR-4 [1].

4.89.5.99. Human factors in operation, inspection, periodic testing, and maintenance should be considered at the design stage. Human factors for MOX fuel fabrication facilities to be considered should include:

— The ease of operator intervention in all facility states;
— Possible effects on safety of inappropriate or unauthorized human actions (with account taken of ease of intervention by the operator and tolerance of human error);
— The potential for occupational exposure.

4.90.5.100. Design of the facility to take account of human factors is a specialist area. Experts and experienced operators should be involved from the earliest stages of design. Areas that should be considered include:

a) Design of working conditions to ergonomic principles: — The operator–process interface, e.g. electronic control panels displaying all the necessary information and no more; — The working environment, e.g. good accessibility to, and adequate space around, equipment and suitable finishes to surfaces for ease of cleaning;

b) Choice of location and clear labelling of equipment so as to facilitate maintenance, testing, cleaning and replacement;

c) Provision of fail-safe equipment and automatic control systems for accident sequences for which reliable and rapid protection is required;

d) Good task design and ease for implementing operating proceduresjob organization, particularly during maintenance work, when automated control systems may be disabled;

e) Minimization of the need to use additional means of personal radiation protection.

f) The criticality mass limit and the actual mass of fissile material in a glovebox should be visible to the operator. The availability of this information should be considered in case of computer failure.

e)g) Operational experience feedback relevant to human factors.

4.91.5.101. In the design and operation of gloveboxes, the following specific considerations should be taken into account:

a) In the design of equipment inside gloveboxes, account should be taken of the potential for conventional industrial hazards that may result in in

b) juries to personnelworkers, including internal radiation exposure through cuts in the gloves and/or wounds on the operator's skin, and/or the possible failure of confinement;

c) Ease of physical access to gloveboxes and adequate space and good visibility in the areas in which gloveboxes are located;

d) The potential for damage to gloves. Sharp edges and corners on equipment and fittings and associated tools should be avoided to minimize risks of glove damage;

e) Training of operators on procedures to be followed for normal and abnormal conditions.

SAFETY ANALYSIS

4.92.5.102. Safety analysis forThe safety assessment of MOX fuel fabrication facilities should include the safety analysis of the variety of hazards for the whole facility and all activities. The IAEA Safety Standards Series No. GSR Part 4 (Rev. 1), Safety Assessment for Facilities and Activities [15] requires that all credible postulated initiating events shall be assessed.be performed in two major steps:

- The assessment of occupational exposure and public exposure for operational states of the facility and comparison with authorized limits for operational states;

- Determination of the radiological and associated chemical consequences of design basis accidents (or the equivalent) for the public and verification that they are within the acceptable limits specified for accident conditions.

5.103. The list of postulated initiating events identified should take into account all the internal and external hazards and the resulting event scenarios and should be carried out considering all the structures, systems and components important to safety that might be affectedThe results of these two steps should be reviewed for identification of the possible need for additional operational limits and conditions.

5.104. For MOX fuel fabrication facilities, the safety analysis should be performed iteratively with the development of the design with the objectives of achieving the following:

a) That doses to personnel and the public during operational states are within acceptable and operational limits for those states and consistent with the optimization of protection and safety (see IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [16], Requirements 11 and 12);
b) That the radiological and chemical consequences of design basis accidents (or equivalent) to the public are within the limits specified for accident conditions and consistent with the optimization of protection and safety (see GSR Part 3 [16]);
f)c) The development of appropriate operational limits and conditions.

Safety analysis for operational states

Occupational radiation exposure and exposure of the public

4.93.5.105. At the design stage of a new MOX fuel fabrication facility, an assessment should be made of the external exposure of personnel workers in all workplaces, on the basis of conservative assumptions for factors including the following:

a) Calculations of the envelope source term on the basis of: (i) reference isotopic compositions of plutonium and traces of associated transuranic elements and fission products; and (ii) the highest specific activities of these radioactive materials.
b) The licensed inventories of radioactive material present in each itempiece of equipment, and in each glovebox and storage area.
c) Calculations of the efficiency of shielding during normal operation on the basis of conservative assumptions regarding the performance of shielding.
d) The maximum cumulative annual working time at each workplace for operation and anticipated maintenance work.

4.94.5.106. A best estimate approach with the use of adequate margins may also be used in the safety analysis.

4.95.5.107. The design of equipment, the layout of equipment in, for example, gloveboxes, and the placement of shielding should be determined on the basis of adequate interaction and feedback between process and mechanical designs, safety assessment, and operational experience from similar facilities and/or facilities upstream in the process (spent fuel reprocessing or plutonium polishing facilities). Cleaning operations (e.g. elimination of heavy dust from gloveboxes) should be given special consideration in the design.

4.96.5.108. As soon as plutonium is introduced into the MOX fuel fabrication facility, the calculated doses should be compared with actual doses rates. If considered necessary, maximum permissible annual working times for specific workplaces may be included in the operational limits and conditions.

4.97.5.109. Calculations of estimated public doses should be made on the basis of maximum estimated releases of radioactive material to the air and to water and maximum depositions to the ground and the direct exposure. Conservative models and parameters should be used to calculate the estimated doses to the public.

Releases of hazardous chemical material

4.98. This Safety Guide deals only with those chemical hazards that can give rise to radiological hazards (see para. 2.2 of Ref. [1]). Facility specific, realistic, robust (i.e. conservative), estimations of chemical hazards to workers and releases of hazardous chemicals to the environment should be performed, in accordance with the standards applied in the chemical industry.

Safety analysis for accident conditions

Methods and assumptions for safety analysis for accident conditions

5.110. The acceptance criteria associated with the accident analysis should be defined in accordance with GSR Part 4 (Rev. 1) [15], Requirement 16, and with respect to any national regulations and relevant criteria.

4.99. There is no general agreement on the best approach to the safety analysis for design basis accidents, and the associated acceptance criteria, for MOX fuel fabrication facilities. However, there is a tendency for the following or similar criteria to be adopted for new advanced facility designs.

4.100.5.111. For a MOX fuel fabrication facility, the consequences of design basis accidents would could cause be limited to consequences for individuals on the site and close to the location of the accident. The consequences depend on various factors such as the amount and rate of the release of radioactive material or hazardous chemicals, the distance between the individuals exposed or affected and the source of the release, pathways for the transport of material to the individuals and the exposure times.

5.112. To estimate the on-site and off-site consequences of an accident, the wide entire range of physical processes that could lead to a release of radioactive material to the environment or to a loss of shielding should be modelled in the accident analysis and the enveloping cases encompassing the worst credible consequences should be determined.

4.101.5.113. Accident consequences should be assessed in accordance with the requirements established in GSR Part 4 (Rev. 1) [15] and with relevant parts of its supporting Safety Guides.

4.102. The following approaches should be considered in the assessment:

(1) An approach using the enveloping case (the worst case approach), with account taken only of those safety features that mitigate the consequences of accidents and/or that reduce their likelihood. If necessary, a more realistic case can be considered that includes the use of some safety features and some non-safety-related features beyond their originally intended range of functions to reduce the consequences of accidents (the best estimate approach).
(2) An approach using the enveloping case (the worst case approach), with no account taken of any safety feature that may reduce the consequences or the likelihood of accidents. This assessment is followed by an assessment of the possible accident sequences, with account taken of the emergency procedures and the means planned for mitigating the consequences of the accident.

Analysis of Design extension conditions

5.114. The safety analysis should also identify design extension conditions followed by an analysis of their progression and consequences in accordance with Requirement 21 of SSR-4 [1]. The objective is to analyse additional accident scenarios to be addressed in the design of a MOX fuel fabrication facility to ensure that the design is such that, for design extension conditions, off-site protective actions that are limited in terms of times and areas of application shall be sufficient for the protection of the public, and sufficient time shall be available to take such actions. Moreover, the possibility of conditions arising that could lead to early releases of radioactive material or to large releases of radioactive material is practically eliminated. Design extension conditions include events more severe than design basis accidents that originate from extreme events or combinations of events which could cause damage to structures, systems, and components important to safety or which could challenge the fulfilment of the main safety functions. The postulated initiating events provided in Appendix of SSR-4 [1] should be used including combinations of initiating events as well as events with additional failures. Accidents that have more severe consequences as well as progression of events that could potentially lead to radiological or chemical releases should also be analysed to support emergency preparedness and response and assist in the development of emergency plans to mitigate the consequences of an accident.

5.115. Additional safety features or increased capability of safety systems, identified during the analysis of design extension conditions, should be implemented in the facility where practicable.

5.116. For analysing design extension conditions, best estimate methods with realistic boundary conditions can be applied. Acceptance criteria for the analysis, in line with para 6.74 of SSR-4 [1], should be defined and reviewed by the national regulatory authority.

5.117. Examples of design extension conditions that are applicable to MOX fuel fabrication facilities can be found in the IAEA Safety Report Series No. 90, Safety Reassessment for Nuclear Fuel Cycle Facilities in Light of the Accident at the Fukushima Daiichi Nuclear Power Plant [17].

5.118. Analysis of design extension conditions should also demonstrate that the MOX fuel fabrication facility can be brought into the state where the confinement function and sub-criticality can be maintained in the long-term (see also SSG-27 [4]).

Assessment of possible radiological or associated chemical consequences

~~4.103.~~5.119.~~Safety assessments should address the consequences associated with possible accidents.~~ The main steps in ~~the development and~~safety analysis ~~of accident scenarios~~ should include the following:

a) Analysis of the actual site conditions (e.g. meteorological, geological and hydrogeological site conditions) and conditions expected in the future including internal and external initiating events with the potential for adverse effects.

b) Specification of facility design information and facility configurations, with the corresponding operating procedures and administrative controls for operations.

~~b)~~c) Identification of individuals and population groups (for facility personnel ~~workers~~ and members of the public) who could possibly be affected by radiation risks and associated chemical risks arising from the operation of the facility~~accidents; i.e. a 'critical group' of people living in the vicinity of the facility~~.

~~c) Specification of the accident configurations, with the corresponding operating procedures and administrative controls for operations.~~

d) Identification and analysis of conditions at the facility, including internal and external initiating events that could lead to a release of material or of energy with the potential for adverse effects, the time frame for emissions and the exposure time, in accordance with reasonable scenarios.

e) Quantification of the consequences for the individuals and population groups identified in the safety assessment.

~~e)~~f) Identification and ~~Specification~~ specification of the structures, systems and components important to safety that are credited to reduce the likelihood and/or to mitigate the consequences of accidents. These structures, systems and components that are credited in the safety assessment should be qualified to perform their functions in the accident conditions.

~~f)~~g) Characterization of the source term (material, mass, release rate, temperature, etc.).

~~g) Identification and analysis of intra-facility transport pathways for material that is released.~~

h) Identification and analysis of pathways by which material that is released could be dispersed in the environment.

i) ~~Quantification of the consequences for the individuals identified in the safety assessment.~~Considerations for interface between safety and security.

~~4.104.~~5.120. The ~~Analysis~~ analysis of the ~~actual~~ site conditions at the site and the conditions expected in the future involves a review of the meteorological, geological and hydrological conditions at the site that may influence facility operations or may play a part in transporting material or transferring energy that ~~is~~ might be released from the facility ~~(see Section 5 of Ref. [1])~~.

~~4.105.~~5.121. Environmental transport of material should be calculated with qualified computer codes or by using data derived from qualified codes, with account taken of the meteorological and hydrological conditions at the site that would result in the highest exposure of the public.

5.122. The identification of ~~workers~~ personnel and members of the public (the critical group ~~of maximally exposed off-site individuals~~) who may potentially be affected by an accident involves a review of descriptions of the facility and of demographic information.

5.123. In assessment of consequences of design extension conditions, less conservative assumptions compared to design basis analysis may be used (for example prevailing wind directions on the site).

4.106.5.124. The magnitude and severity of conditions considered in design extension conditions as well as the acceptance criteria used for acceptability of consequences of design extension conditions should be accepted by the national regulatory body.

Assessment of possible associated chemical consequences

4.107.5.125. Useful guideline for assessing the acute and chronic toxic effects of chemicals used in MOX fuel fabrication facilities is provided Ref. [18].

EMERGENCY PREPAREDNESS AND RESPONSE

5.126. A comprehensive hazard assessment should be performed in accordance with Requirement 4 of IAEA Safety Standards Series No. GSR Part 7, Preparedness and Response for a Nuclear or Radiological Emergency [19] prior to commissioning. The results of the hazard assessment should provide a basis for identifying the emergency preparedness category relevant to the facility and the on-site areas and, as relevant, off-site areas where protective actions and other response actions may be warranted in case of a nuclear or radiological emergency. See IAEA Safety Standards Series No. GS-G-2.1, Arrangements for Preparedness for a Nuclear or Radiological Emergency [20] for further guidance.

4.108.5.127. The operating organization of a facility is required to develop an emergency plan that takes into account the potential hazards at the facility (Requirement 47 72 of Ref. SSR-4 [1]). The emergency plan and the necessary equipment and provisions should be determined on the basis of selected scenarios for beyond design basis accidents (or the equivalent) and design extension conditions. The conditions under which an off-site emergency is required to be declared for a facility should include criticality accidents, widespread fires in the powder area, and earthquakes.

MANAGEMENT OF RADIOACTIVE WASTE

5.128. The general requirements for optimization of protection and safety for waste and effluent management and the formulation of a waste strategy are established in the IAEA Safety Standards Series No. GSR Part 5, Predisposal Management of Radioactive Waste [21] with additional guidance provided in the IAEA Safety Standards Series No. GSG-3, The Safety Case and Safety Assessment for the Predisposal Management of Radioactive Waste [22], IAEA Safety Standards Series No. GSG-1, Classification of Radioactive Waste [23], IAEA Safety Standards Series No. SSG-41, Predisposal Management of Radioactive Waste from Nuclear Fuel Cycle Facilities [24] and IAEA Safety Standards Series No. GS-G-3.3, The Management System for the Processing, Handling and Storage of Radioactive

Waste [25]. Recommendations are provided in the following paragraphs on aspects that are particularly relevant or specific to MOX fuel fabrication facilities.

4.109.5.129. For safety, economic and environmental and economic reasons, the aim of radioactive waste management is to minimize the generation of waste (see Requirement 24 of SSR-4 [1])[7, 8]. The main type of waste encountered in MOX fuel fabrication facilities is material contaminated with plutonium (from PuO_2 or MOX). The following aspects should be considered in the design:

a) Generation of waste.

— Paragraph II.29 of Appendix II of Ref. [1] establishes the requirement on the generation of radioactive waste for MOX fuel fabrication facilities. The waste generated in a MOX fuel fabrication facility is mainly solid waste (see para. 1.8). A record keeping system should be implemented to ensure the proper identification, traceability and record keepingdocumentation for of the radioactive waste generated.

— It is possible to reduce waste from gloveboxes by reducing the amount of material imported into the glovebox.

b) Removal of waste.

— Waste should 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 should be such as to accommodate the expected waste, which may include equipment that has been replaced.

— From para. II.30 of Appendix II of Ref. [1]: "Filters from the gloveboxes and the ventilation system shall should have engineered features" (e.g. containers)

c)

d)c) Collection of waste.

— Design features for the collection and transport of waste should be such as to reduce the risk of dropping bags of waste.

— An indicative measurement or qualified estimate of fissile material mass in a waste package should be made before moving the package to central waste management area to ensure criticality safety.

— For the assessment and management of waste contaminated with plutonium, provision should be made for a central waste management area. In this central area, waste should be monitored for its plutonium content and may be treated and placed in containers for interim storage.

— Design features should be provided for the collection and transport of waste in containers to provide an additional level of confinement.

— Consideration should be given to criticality control and radiation exposure of the personnel when a number of bags of waste are collected.

e)d) Interim storage of waste.

— Subsequent treatment outside the MOX fuel fabrication facility may include conditioning, compaction and washing of the waste before its longer term storage.

4.110.5.130. Quality control regimes should be applied to the treatment and disposal of waste from all streams to ensure compliance with authorizations for disposal.

MANAGEMENT OF GASEOUS AND LIQUID RELEASESEFFLUENTS

5.131. MOX fuel fabrication facilities should be designed so that effluent discharge limits can be met in normal operation and accidental releases to the environment are prevented.

5.132. MOX fuel fabrication facilities use dry processes and generate dust. , and tThe effluent discharges from MOX fuel fabrication facilities should be reduced by filtration, which normally consists of a number of high efficiency particulate air (HEPA) filters in series. The use of sand filters may also be considered [9].

OTHER DESIGN CONSIDERATIONS

Customer specifications on fuel characteristics

4.111.5.133. Customer specifications on fuel characteristics that have implications for safety in the design and operation of MOX fuel fabrication facilities (e.g. criticality, shielding, thermal effects) should be taken into account at an early stage in the design of the facility and equipment, especially the specifications for the plutonium content as input and the specifications for MOX fuel assemblies as output.

Gloveboxes

4.112.5.134. Gloveboxes should be designed to facilitate the use of dry methods of cleaning (e.g. with vacuum cleaners).

Radiation protection shielding

4.113.5.135. PuO_2 and MOX can generate significant dose rates depending on the isotopic composition of the material processed. MOX from higher burnup PuO_2 may give rise to significant neutron dose rates while the presence of ^{241}Am (a decay product of ^{241}Pu) may give rise to gamma radiation. UO_2 from reprocessing may also contain residual fission products and ^{232}U that give rise to beta and gamma radiation.

4.114.5.136. As there may be significant dose rates in areas of the MOX fuel fabrication facility occupied by personnelworkers, consideration should be given at the design stage to the need for neutron and gamma shielding.

4.115.5.137. Effective shielding from 60 keV gamma radiation from ^{241}Am and from neutron emissions may be applied to the faces of gloveboxes, but this can restrict visibility and thus lead to increased occupancy periods of personnel ~~workers~~ by the glovebox. The type of shielding should therefore be selected on the basis of the estimated total doses due to occupational exposure during normal operation and maintenance.

Intermediate storage of MOX and PuO_2

5.138. PuO_2 may be stored in MOX fuel fabrication facilities pending its processing. MOX may be stored at intermediate stages in the process as powder, pellets, rods and assemblies. The neccessary storage capacity ~~is~~ should be determined by process buffer quantities.

Modularization

5.139. To facilitate the construction and commissioning of a MOX facility in line with requirement 29 of SSR-4 [1], the modularization of structures, systems and components should be considered. Modularization enables manufacturers of structures, systems and components to pre-assemble parts of the production line out of the facility site in better space conditions and using specific tools and equipment and to perform initial tests of the structures, systems and components. This helps the installation on site and reduces manufacturing deficiencies of the structures, systems and components before their transport on facility site.

5.140. The design should consider using a limited number of types of components and combine them for different purposes to reduce the complexity of the structures, systems and components resulting in less maintenance having and reduced personal doses (requirement 36 of SSR-4 [1]).

Maintenance policy

~~4.116.~~5.141. The maintenance policy should cover the following aspects:

a) Consideration of whether maintenance should be carried out by remote operation or manually by using gloves. This may vary for different stages in the process.

b) Criticality safety conditions such as limitations on the introduction of liquids, solvents, plastics and other moderators.

c) Prevention of contamination when replacing equipment (e.g. motors and drives may be located outside gloveboxes).

d) Limitation and removal of dust. Gloveboxes may become dusty unless cleaned regularly. A dusty environment may reduce visibility and may increase the whole body exposure and the occupational hand exposure (when hands are placed in dusty gloves).

e) Loss of shielding material. Shielding on gloveboxes is often provided for normal process operations and may need to be removed for access for maintenance. Ideally, it should be possible to remove the source before removing the shielding.

f) The design should ~~minimize~~ avoid where possible sharp edges and the need for sharp equipment in gloveboxes to minimize the potential for causing wounds that could become contaminated.

Design provisions for on-site transfer of radioactive and hazardous materials

5.142. Requirements for control over the transfer of radioactive and hazardous materials are listed in requirement 28 and para. 6.111 – 6.112 in SSR-4 [1].

5.143. For incoming containers, containing radioactive material, sufficient technical provisions for checking the integrity should be considered during the design phase.

5.144. All containers used for transportation of radioactive material on site should be considered in the safety analysis.

5.145. For cases where misidentification of containers could impose hazard, provisions for easy identification of the content should be used, if possible (for example unique colors, shapes, valves).

5.146. Technical provisions for inspection and maintenance of containers as items important to safety should be available.

5.147. The analyses of handlings should cover:

(a) Transportation routes and intersections;
(b) Technical limits of the transportation vehicles;
(c) Handling failures during transportation.

5.148. The design of the facility and the production processes should take into account the number of onsite transfers of radioactive materials across different safety related zones (such as contamination and criticality control zones).

AGEING MANAGEMENT CONSIDERATIONS

5.149. The design of structures, systems and components important to safety should take into account the ageing effects to ensure reliability and availability of the structures, systems and components during the lifetime of the facility.

5.150. The design should allow all systems, structures and components important to safety to be easily inspected in order to detect their ageing (static containment deterioration, corrosion) and to allow their maintenance or replacement if needed.

5.151. An ageing management programme should be implemented at the design stage to allow anticipating equipment replacements.

Design provisions for ~~Decontamination~~ decontamination and decommissioning

5.152. To facilitate decontamination and the ~~eventual~~ decommissioning of the facility, surface areas of the MOX fuel fabrication facility where there may be contamination should be non-porous and easy to clean. This may be achieved by applying special coatings to surfaces and ensuring that no areas are difficult to access. In addition, all surfaces that could become contaminated should be made readily accessible to allow for periodic and incidental decontamination.

4.117.5.153. The design should allow dismantling of the equipment within gloveboxes rather than using destructive techniques during the decommissioning.

5.6. CONSTRUCTION

5.1.6.1. Requirements for construction of MOX fuel fabrication facility are listed in requirement 53 and para. 7.1 – 7.7 of SSR-4 [1]. General guidance on the construction and construction management of nuclear installations is provided in the IAEA Safety Standards Series No. SSG-38, Construction for Nuclear Installations, [26].

5.2.6.2. MOX fuel fabrication facilities are complex, and regulatory body authorization should be sought in several stages. Each stage may conclude with a hold point at which approval by the regulatory body is required before the subsequent stage may be commenced (para. 3.43.7 -of Ref.SSR-4 [1]).

6.3. MOX fuel fabrication facilities are complex mechanically and, as such, modularized components should be used in their construction. This enables equipment to be tested and proved at manufacturers' shops before its installation at the MOX fuel fabrication facility (see para. 5.133). In addition tThis will also aid in the commissioning, maintenance and decommissioning of the facility.

5.3.6.4. Components and cables in a MOX fuel fabrication facility should be clearly labelled, owing to the complexity of the control systems.

6.5. The construction and commissioning phases may overlap. Construction work in an environment in which radioactive material is present owing to commissioning may be significantly more difficult and time consuming than when no radioactive material is present.Preferably, construction work should be completed prior to commissioning of the facility or its parts. In cases when the construction and commissioning or operational phases overlap, the appropriate precautions should be considered to minimize potential adverse impact of construction activities on safety. Consideration should be also given to the protection of equipment which has been already installed.

6.6. All structures and components after their installation should be properly cleaned and painted with suitable primer followed by appropriate surface treatment. Effect of nearby activities handling corrosive substances should also be considered.

5.4.6.7. Contractors engaged in the construction work should be properly assessed for their integrity and competency in adhering strictly to design and quality requirements to ensure the future safety of the facility.

6.7. COMMISSIONING

6.1.7.1. The requirements for commissioning are established in Requirement 54 of SSR-4 [1] and subsequent paragraphs. The operating organization should make the best use of the commissioning stage to become completely familiar with the facility. It should also be an opportunity to promote and further enhance safety culture, including positive behaviors and attitudes, throughout the entire organization.

6.2.7.2. For a MOX fuel fabrication facility, the commissioning should be divided into three main phases: inactive or 'cold processing' commissioning, active uranium or 'hot uranium' commissioning, and active plutonium or 'hot processing' commissioning:.

(1) Inactive or 'cold processing' commissioning

In this phase, the facility's systems are systematically tested, both individual items of equipment and the systems in their entirety. Sufficient operating personnel should be available at this stage for qualification as operators for the uranium commissioning phase. Initial testing of normal operation should be conducted. This may require regulatory authorization to use radiation sources. As much verification and testing as possible should be carried out because of the relative ease of taking corrective actions in this phase. Any modifications to structures, systems and components SSC important to safety should be reported to the regulatory body. -Testing of the effectiveness of the static confinement and dynamic confinement should be undertaken and approved by the competent authority and baseline performance data recorded. In this phase, operators should take the opportunity to prepare the set of operational documents and to learn train personnel in the operating procedures (including those for maintenance) , safety requirements and emergency procedures the details of the systems. At the end of this phase, the operator should provide evidence of conformity of the facility to design and safety requirements and operational readiness for uranium commissioning to the regulatory body.

(2) Uranium commissioning

Natural or depleted uranium should be used in this phase, to avoid criticality risks, to minimize doses due to occupational exposure and to limit possible needs for decontamination. This phase also provides the opportunity to initiate the control regimes that will be necessary when plutonium is introduced. Testing of neutron monitors and other radiation detectors should be conducted (with sources, if necessary) at the beginning or before this stage.

Safety tests performed during this commissioning period should mainly coverbe devoted to confinement checking, control of movement of material and final balancing of dynamic confinement. This should include: (i) checking for airborne radioactive material; (ii) smear checks on surfaces; and (iii) checking for gaseous aerial and liquid discharges and liquid releases. Unexpected accumulations of material should also be checked for. At the end of this phase, the operator should provide evidence to the regulatory authority that the facility is ready to conduct safe commissioning with plutonium, ensuring required level of radiation protection and criticality safety.

(3) Plutonium or 'hot processing' commissioning

This phase enables the process to be progressively, and cautiously, brought into full operation by addition of plutonium to the process in stages. Additional checks of radiation exposure and heat loading should be made. The requirements for this phase are established in para. II.37 of Appendix II of Ref. [1]

6.3. The verification process, defined in para. 8.4 of Ref. [1], should be completed prior to the operation stage. The operating organization should use the commissioning stage to become familiar with the facility. The facilitymanagement should use the commissioning stage to develop a strong safety culture and good behavioural attitudes throughout the entire organization.

6.4.7.3. During commissioning and later during operation of the facility, the estimated doses to personnel workers that were calculated should be assessed against actual dose rates. If, in operation, the actual doses are higher than the calculated doses, corrective actions should be implemented, including making any necessary changes to the licensing documentation (i.e. the safety caseanalysis report) or adding or changing safety features or work practices (see also Section 78).

7.4. The licence to operate the MOX fuel fabrication facility is generally issued to the operating organization just before this third phase. In this case, 'hot' processing commissioning will be performed under the responsibility, safety procedures and organization of the operating organization. It may be considered part of the operational stage of the MOX fuel fabrication facility.

6.5.7.5. During inactive commissioning the operating organization should verify (by a 'smoke test' or other equivalent method) that the location of key radiological instruments is correctly designed, i.e. that the air flows within the plant are as estimated by the calculations during the design phase.

6.6.7.6. Lessons learned from similar plutonium processing facilities that are in operation should be used, especially for the commissioning of a new MOX fuel fabrication facility. Where possible, lessons from the commissioning and operation of similar MOX fuel fabrication facilities should be sought out and applied.

7.8. OPERATION

CHARACTERISTICS ORGANIZATION OF OPERATION OF MOX FUEL FABRICATION FACILITIES

7.1. The distinctive features of a MOX fuel fabrication facility described in para. 2.1 that should be taken into account in meeting the safety requirements established in Ref.SSR-4 [1] for operation. are: These features require high emphasis to be placed on administrative measures together with monitoring and preventive maintenance to ensure safe operation, in addition to the design.The large inventories of plutonium and MOX powder in solida finely divided forms (powder, pellets, rods and assemblies) and the associated radiological hazards, including criticality;

7.2.8.1. The high radiological toxicity of the radioactive plutonium and MOX.

7.3.8.2. Much of the processing performed in a MOX fuel fabrication facility is done automatically, which helps to reduce occupational exposures due to plutonium and MOX. However, some processes relating to glovebox operations involve manual intervention. In a MOX fuel fabrication facility, automation serves to improve productivity and to reduce occupational exposures due to plutonium and MOX.

7.4. Because of this, emphasis is placed on administrative measures, monitoring and preventative maintenance to ensure safe operation.

8.3. In this section, specific recommendations are presented on good operational practices and on additional considerations in meeting the safety requirements for a MOX fuel fabrication facility.

7.5.8.4. The safety committee in a MOX fuel fabrication facility, as defined in SSR-4 [1], para. 4.29, should be created from the safety committee established for commissioning. Its function should be specified in the management system, it should be adequately staffed, and it should include diverse expertise and have appropriate independence from the direct line management of the operating organization.

QUALIFICATION AND TRAINING OF PERSONNEL

8.5. The safety requirements relating to the qualification and training of facility personnel are established in Requirements 56 and 58 paras 9.8 9.13 and II.38 of Appendix II of Ref.SSR-4 [1]. Further recommendationsRecommendations are provided in para. 4.6–4.25 of GS-G-3.1Ref. [8].

8.6. In addition, pPersonnel should be provided periodically with basic training in criticality and radiation safety and emphasis should be made on protection from radiation exposure, criticality control and emergency preparedness and response. Much of the processing performed in a MOX fuel fabrication facility is done automatically, but some processes relating to glovebox operations involve manual intervention. For this reason, "special attention shall be paid to training workers in glovebox operations, including actions to be taken if contamination occurs" (para. II.38 of Appendix II of Ref. [1]).

8.7. The safety risks and hazards for operators, maintenance staff and other personnel, such as the decontamination team, should be carefully considered when establishing the training programme. In particular, all staff handling fissile material, should have a sound understanding of radiation protection, criticality safety and the relevant physical phenomena.

8.8. The need for training all levels of management should be considered. Personnel involved in the management and operation of the facility should understand the range of hazards present at the MOX fuel fabrication facility at a level of detail consistent with their level of responsibility.

8.9. Comprehensive training should cover both automatic operations and manual operations. Dedicated training facilities should be established as necessary, with the training emphasis on activities according to their potential safety consequences.

8.10. For manual activities, training should include, but not be limited to, the following:

a) Maintenance, cleaning activities and project activities that may involve intervention in the active parts of the facility and/or changes to the facility configuration;
b) Work within gloveboxes, glove changes and glovebox posting activities;
c) Decontamination, preparation of work areas, erection and dismantling of temporary enclosures and waste handling;
d) Procedures for breaching barriers, self-monitoring and the use of personal protective equipment;
e) Responses to be taken in situations that are outside normal operation (including emergency response actions).

7.6.8.11. For automatic modes of operation, training should include, but not be limited to, the following:

a) Comprehensive training for the control room;
b) The response to alarms;
c) Alertness to the possibility of failures, malfunctions and errors in automatic and remote systems;
d) Alertness to unexpected changes (or lack of changes) in key parameters;
e) Responses to be taken in situations that are outside normal operation (including emergency response actions).

7.7.8.12. Complementary training of safety and security personnel and their mutual participation in exercises of both types should be part of the training programme to effectively manage the interface between safety and security. In particular, personnel with responsibilities and expertise in safety analysis and safety assessment should be provided with a working knowledge of the security requirements of the facility and security experts should be provided with a working knowledge of the safety considerations of the facility, so that potential conflicts between safety and security can be resolved most effectively.

GENERAL RECOMMENDATIONS FOR FACILITY OPERATION

7.8.8.13. Requirement 57 of SSR-4 [1] and subsequent paragraphs require that operational limits and conditions are developed for a MOX fuel fabrication facility. The safety significance of the operational limits and conditions as well as of the action levels and conditions should be well understood by the personnel operating the facility. The set of action levels should be defined and maintained by the operator.To ensure that the MOX fuel fabrication facility operates well within the operational limits and conditions under normal circumstances, a set of lower level sublimits and conditions should be defined.

Such sublimits and conditions should be clear and should be made available to and well understood by the personnel operating the facility.

7.9.8.14. Since the number of operational limits and conditions may be large for a MOX fuel fabrication facility, these could be grouped by topic or activity. Examples of structures, systems and components that may be used when defining operational limits and conditions for each process area are presented in Annex II.

8.15. Close attention should be paid to the prevention of events during non-routine operations and secondary operations such as decontamination, washing and preparation for maintenance or testing.

7.10.8.16. Operating documents should be prepared that list all the operational limits and conditions under which the facility is operated. Annex III gives examples of parameters that can be used for defining the operational limits and conditions in the various processing areas of the facility.

7.11.8.17. Generic limits should also be set for the facility. Examples of limits on operating parameters for safe operation (SSR-4 [1], para. 9.31) for a MOX fuel fabrication facilitysuch limits are:

a) The allowed ranges of the isotopic composition of PuO_2 and the content of ^{241}Am especially at the plutonium receipt stage;
b) The maximum PuO_2 content allowed for the different steps in the process;
c) The maximum specific heat loads;
d) The specified limits for impurities and fission products in feedstock;
e)d) The maximum allowed throughputs and inventories for the facility;
f)e) The maximum quantities of additives allowed at different steps in the process;
f) The maximum quantities of liquid moderator allowed at different steps in the process;
g) The maximum concentration of hydrogen allowed in the atmosphere of sintering furnaces;
h) The maximum concentrations of oxygen and moisture in gloveboxes.

8.18. Examples of administrative controls for safe operation (SSR-4 [1], para. 9.36) for a MOX fuel fabrication facility are:

— Minimum staffing on shift;
— Availability of specific expertise at all times when the facility is in production (criticality expert, radiation protection expert, etc.);
— Minimum and maximum number of persons working in a glovebox.

7.12.8.19. Consideration should be given to ensuring that plutonium and uranium, especially in the form of powder or pellets, are present only in areas designed for the storage or handling of plutonium and uranium. Programmes should be put in place for routine monitoring for surface contamination and airborne radioactive material, and more generally for ensuring an adequate level of housekeeping. Areas with higher dose rates (as for example around gloveboxes) should be clearly signed and additional barriers where practicable should be provided when operations in these areas are not in progress.

7.13.8.20. In a MOX fuel fabrication facility, the safe operational state of the process attained after any anticipated operational occurrence is often the shutdown state. However, some systems, such as the criticality accident alarm system, radiation detection and alarm system, the ventilation system used for confinement, should continue to operate. Nevertheless, specific operating procedures should be used for the shutdown of certain equipment such as sintering furnaces.

7.14.8.21. Operating procedures to directly control process operations directly should be developed. The procedures should include directions for attaining a safe facility state from all anticipated operational occurrences and accident conditions. Procedures of this type should include the actions required to ensure criticality safety, fire protection, emergency preparedness and environmental protection.

8.22. The operating procedures for the ventilation system should be specified for fire conditions, and periodic testing of the ventilation system should be carried out and fire drills should be performed.

8.23. Procedures should be developed for planned outages of production needed for activities such as inventory checking, maintenance and other operational needs. These procedures should specify systems for ensuring fissile materials are returned to their safe locations. The duration of scheduled activities and relevant compensatory measures should be specified in the procedures.

8.24. In meeting requirement 64 of SSR-4 [1] the following practices should be followed to establish and maintain a high standard of housekeeping in a MOX fuel fabrication facility:

— Prevent the accumulation of materials and tools in gloveboxes;
— Prevent accumulation of nuclear materials in gloveboxes;
— Control amount of radioactive material in gloveboxes in accordance with the principle of optimization of protection;
— Prevent accumulation of flammable materials anywhere in the building (tissues, gloves, cloths, oils, general wastes)
— Prevent accumulation of wastes inside and outside of gloveboxes;
— Maintain notices and warning signs in good condition;
— Maintain high standards of cleanliness;
— To develop a baseline condition for each workplace by photographs (or equivalent) ensuring that its condition can be maintained.

MAINTENANCE, CALIBRATION AND PERIODIC TESTING AND INSPECTION

8.25. Maintenance activities in a MOX fuel fabrication facility should be pre-authorised on the basis of a safety assessment. When carrying out maintenance in a MOX fuel fabrication facility, particular consideration should be given to the potential for surface contamination or airborne radioactive material. The facility should not intentionally be placed in an abnormal condition to perform periodic testing.

8.26. Prior to any maintenance activities, consideration should be given to radiological checks of the work areas, the need for decontamination and the need for periodic surveys during the period of maintenance and before return to service.

~~7.15.~~8.27. Before a maintenance is performed in areas where fissile material is located, criticality safety staff should be consulted.

~~7.16.~~8.28. Maintenance should follow good practices, with particular consideration given to:

a) Work control, e.g. handover and handing back of documents, means of communication and visits to job sites, changes to the planned scope of work, suspension of work and ensuring safe access;
b) Equipment isolation, e.g. disconnection of electrical cabling and heat and pressure piping and venting and purging of equipment;
c) Testing and monitoring, e.g. checks before commencing work, monitoring during maintenance and checks for recommissioning;
d) Safety precautions for work, e.g. specification of safety precautions, ensuring the availability of personal protective equipment and ensuring its use, and emergency response procedures;
e) Reinstallation of equipment, e.g. reassembly, reconnection of pipes and cables, testing, cleaning the job site and monitoring after recommissioning.
~~e)~~f) Verifying that after maintenance is performed the work area and equipment have been placed back within normal safe condition.
~~f)~~g) ~~Regular flow checks should be carried out at ventilation hoods and entrances to containment areas. Also, pressure~~Pressure drops across banks of air filters should be checked and recorded on a routine basis. Particular attention should be paid to gloves to ensure the detection of any degradation of glove material.

8.29. Periodic testing of fire detection and ~~extinguishing~~ suppression systems for gloveboxes should be carried out.

~~7.17.~~8.30. All temporary changes to the facility configuration during maintenance activities should be coordinated between safety and security specialists to avoid potential conflicts (e.g. cut of electrical power supply on some safety systems, opening of barriers and doors). Compensatory measures should be implemented as necessary.

~~Compliance of the operational performance of the ventilation system with the fire protection requirements (see para. 4.44) should be verified on a regular basis.~~

~~7.18.~~8.31. The operating organization should have a system in place which ensures that the information and experience gained through maintenance activities is collected, recorded, analysed and utilized in operating experience feedback programme.

8.32. A programme of periodic inspections of the facility should be established, whose purpose is to verify that the facility is operating in accordance with the operational limits and conditions. Suitably qualified and experienced persons should carry out inspections. Particular consideration should be given to fatigue affecting equipment and to the ageing of structures.

7.19.8.33. Places in the process line, identified by the operating organization as those with potential for accumulation of uranium compounds, should be periodically inspected.

AGEING MANAGEMENT

8.34. The operating organization should take into account following issues in implementing a systematic ageing management programme in line with requirement 60 of SSR-4 [1]:

a) Support for the ageing management programme by the management of the operating organization;
b) Early implementation of an ageing management programme;
c) A proactive approach based on an adequate understanding of structures, systems and components ageing, rather than a reactive approach responding to structures, systems and components failures;
d) Optimal operation of structures, systems and components to slow down the rate of ageing degradation;
e) Proper implementation of maintenance and testing activities in accordance with operational limits and conditions, design requirements and manufacturers' recommendations, and following approved operating procedures;
f) Minimization of human performance factors that may lead to premature degradation, through enhancement of staff motivation, sense of ownership and awareness, and understanding of the basic concepts of ageing management;
g) Availability and use of correct operating procedures, tools and materials, and of a sufficient number of qualified staff for a given task;
h) Feedback of operating experience to learn from relevant ageing related events.

8.35. The aging management programme should consider the technical as well as the non-technical aspects of ageing.

8.36. The periodic tests and inspections should be completed by regular checks performed by operating personnel.

CONTROL OF MODIFICATIONS

7.20.8.37. A standard process for any modification should be applied in a MOX fuel fabrication facility. The management system for a MOX fuel fabrication facility should include a standard process for all modifications (see para. 3.15). The This process should use a modification control form or equivalent management tool.

8.38. The operating organization should prepare procedural guidelines and provide initial and periodic training to ensure that the responsible personnel have the necessary training and authority to ensure that modification projects are carefully considered. The safety of modifications should be assessed for potential hazards during installation, commissioning and operation. Decision making relating to modifications should be conservative.

7.21.8.39. The modification control form should contain a description of what the modification is and why it is being made. The main purpose of the modification control form is to provide the basis for a safety assessment of the modification, especially any changes that may affect criticality safety. The modification control form should be used to identify all the aspects of safety that may be affected by the modification and to demonstrate that adequate and sufficient safety provisions are in place to control the potential hazards both during and after the modification, with any temporary or transient stages being clearly identified and assessed. For example, changes to the materials and thickness of shielding, quantities of hydrogenated and non-hydrogenated materials, and locations of equipment may affect criticality safety analyses. The modification control form should also identify any (potential) need for the revision or renewal of a licence by the regulatory body

7.22.8.40. Modification control forms should be scrutinized by and be subject to approval by qualified and experienced persons to verify that the arguments used to demonstrate safety are suitably robust. This should be considered particularly important if the modification could have an effect on criticality safety. The depth of the safety arguments and the degree of scrutiny to which they are subjected should be commensurate with the safety significance of the modification (a graded approach). Review of modification control forms should be carried out by the safety committee (or an equivalent committee), which should have suitable expertise and should be able to independently examine the proposal. Suitable records should be kept of their recommendations. Senior management of the MOX fuel fabrication facility should grant specific personnel the responsibility for the approval and control of modifications. Such authorizations should be regularly reviewed and either withdrawn or confirmed as still valid, as appropriate.

7.23.8.41. The modification control form should also specify which documentation will need to be updated as a result of the modification (e.g. training plans, specifications, safety assessment, notes, drawings, engineering flow diagrams, process instrumentation diagrams and operating procedures). Procedures for the control of documentation should be put in place to ensure that documents are changed within a reasonable time period following the modification.

8.42. Procedures for the control of documentation and training should be put in place to ensure that, where necessary and as specified in the modification control form:

— Training has been given and assessed.
— Documentation has been changed before the modification is commissioned.
— All changes in (the remaining) documentation and training requirements are completed within a reasonable period following the modification.

7.24.8.43. The modification control form should specify the functional (commissioning) checks that are required before the modified system may be declared fully operational again.

8.44. Modifications performed on design, layout or procedures of the facility might negatively affect security equipment and vice versa. For example, malfunction of safety equipment may damage nearby security equipment. Therefore, changes to the facility or its documentation should be reviewed, assessed and endorsed from the safety and its interface with security perspective before approval and implementation.

8.45. The modifications made to a facility (including those to the operating organization) should be reviewed on a regular basis to ensure that the combined cumulative effects of a number of modifications with minor safety significance do not have hitherto unforeseen effects on the overall safety of the facility. This should be part of (or additional to) periodic safety review or an equivalent process.

7.25.8.46. The modification control documentation should be retained at the facility in accordance with national requirements.

CRITICALITY CONTROL

7.26.8.47. The requirements for criticality safety in In a MOX fuel fabrication facility are established in SSR-4 [1], para. 9.83 – 9.85 and 9.87, and general recommendations are provided in SSG-27 [4]. The procedures and measures for controlling criticality hazards should be strictly applied, it is particularly important that the procedures for controlling criticality hazards are strictly applied (paras 9.49 and 9.50 of Ref. [1]).

7.27.8.48. Operational aspects of the control of criticality hazards in MOX fuel fabrication facilities should include:

(a) Anticipation of unexpected changes in conditions that could increase the risk of a criticality accident; for example, unplanned accumulation of PuO_2 or MOX powder (e.g. in gloveboxes or ventilation ducts) or hydrogenated materials;

(b) Management of moderating materials, particularly hydrogenated materials such as those used for the decontamination of gloveboxes, and leakages of oils from gear boxes;

(b)(c) Management of mass in transfers of plutonium and uranium (procedures, mass measurement, systems and records) for which mass control is used;

(c)(d) Reliable methods for detecting the onset of any of the foregoing conditions;

(d)(e) Periodic calibration or testing of systems for the control of criticality hazards (e.g. control of movements of material, balances, scales, etc.);

(e)(f) Evacuation drills to prepare for the occurrence of a criticality and/or the actuation of an alarm.

7.28.8.49. The tools used for the purposes of accounting for and control of nuclear material, such as the instruments used to carry out measurements of mass, volume or isotopic compositions and software used for accounting these purposes, may also have application in the area of criticality safety. However, if there is any uncertainty about the characteristics of fissile material, conservative values should be used for parameters such as the plutonium content and the isotopic composition. This arises in particular in connection with floor sweepings and similar waste material.

8.50. Criticality hazards may be encountered when carrying out maintenance work. For example, "if PuO_2 or mixed oxide (MOX) powder has to be removed from equipment, only approved containers shall be used" (para. II.41 of Appendix II of Ref. [1]). Also, waste Waste and residues arising from decontamination and maintenance activities should be collected in containers with a favourable geometry approved for the work, and should be stored in dedicated criticality safe areas. Maintenance instructions and procedures for equipment that possibly contain fissile material should be reviewed and approved by criticality safety staff before the work starts. Special care including the effect of moderation by the human body should be taken to ensure the proper spacing of vessels or installation parts that may contain enriched material.

RADIATION PROTECTION

8.51. The requirements for radiation protection in operation are established in SSR-4 [1], para. 9.90-9.101 and in GSR Part 3 [16]; recommendations are provided in the IAEA Safety Standards Series No. GSG-7, Occupational Radiation Protection [27]. The operating organization should have a policy to optimize protection and safety and is required to ensure doses are below national dose limits and within any dose constraints set by the operating organization (SSR-4 [1], para. 9.91).

8.52. Workplace monitoring for purposes of radiation protection inside and outside the MOX fuel fabrication facility buildings should be complemented by regular, routine monitoring by trained personnel. This should be organized to provide, as far as practicable, regular workplace monitoring of the whole MOX fuel fabrication facility site. Particular attention should be paid to the recording, labelling or posting where necessary, evaluating and reporting of abnormal radiation levels or abnormal situations. The frequency of workplace monitoring should be related to the relative risk of radiation or contamination in the individual areas. Radiation protection personnel should consider assigning a frequency for monitoring of each facility area based upon easily identified boundaries. The use of photographs or drawings of the area or equipment should be considered for reporting the findings.

8.53. Radiation protection personnel should be part of the decision making processes associated with the application of the requirements for minimization of exposure (e.g. for the early detection and mitigation of hot spots) and proper housekeeping (e.g. waste segregation, packaging and removal).

7.29.8.54. In a MOX fuel fabrication facility, the main radiological hazard for both the workforce personnel and members of the public is from the inhalation of airborne PuO_2 or MOX powder. PuO_2 and MOX powders pose a particular hazard because of their long biological half-lives (and therefore effective half-lives)[2], and their typically relatively small particle size (typically a few micrometres in diameter) when encountered in MOX fuel fabrication facilities. Thus close attention should be paid to the containment of PuO_2 and mixed oxide (MOX) powders and the control of contamination in the workplace" (para. II.42 of Appendix II of Ref. [1]).

7.30.8.55. For MOX fuel fabrication facilities, in normal operation, the main characteristic that needs to be taken into account in the development of measures for radiation protection is that the external dose rate from beta and gamma radiation and neutron emission in the operational state is relatively low. It is required to put in place emergency arrangements for criticality incidents, which are the only events in which a high external dose rate would be encountered.

7.31.8.56. Interventions for maintenance and/or modifications are activities that require justification and optimization of protective actions as specified in GSR Part 3 Ref. [516]. The procedures for intervention should include:

a) Estimation of doses due to external exposure prior to the intervention.
b) Preparatory activities to minimize the doses due to occupational exposure, including.
   — Identifying specifically the risks associated with the intervention.
   — Specifying protective measures in the work permit the procedures for the intervention (such as for the individual and collective means of protection, e.g. use of masks, clothing and gloves, and time limitation).
c) Measurement of the doses due to occupational exposure during the intervention.
d) Implementation of feedback of information for identifying possible improvements.

8.57. The risks of exposure of members of the public should be minimized by ensuring that, as far as reasonably practicable, radioactive material is kept away and/or removed from ventilation exhaust gases to prevent its discharge to the atmosphere.

8.58. The monitoring results from the radiation protection programme should be compared with the operational limits and conditions. Furthermore, these monitoring results should be used to verify the dose calculations made in the initial environmental impact assessment.

7.32.8.59. The doses caused by plutonium are dependent on the proportion of ^{238}Pu and ^{241}Pu (^{238}Pu has a short half-life and ^{241}Pu decays to ^{241}Am). The doses should be controlled by integrity of the first containment barrier, which should be monitored close to the workplace of the operator, by means of continuous air-sampling and routine monitoring for surface contamination.

[2] The biological half-life is the time taken for the amount of a material in a specified tissue, organ or region of the body to halve as a result of biological processes. The effective half-life is the time taken for the activity of a radionuclide in a specified place to halve as a result of all relevant processes.

~~Control of internal exposure~~

~~7.33.~~8.60. Internal exposure should be controlled by the following means:

a) Performance targets should be set for all parameters relating to internal exposure, e.g. levels of contamination.

b) Enclosures and ventilation systems should be routinely inspected, tested and maintained to ensure that they continue to fulfil their design requirements. Regular flow checks should be carried out at ventilation hoods and entrances to containment areas. Pressure drops across air filter banks should be checked and recorded regularly.

c) Operators should be made aware of and specially trained in the immediate actions necessary in the event of the puncture of a glove and/or a breach of containment integrity.

d) A high standard of housekeeping should be maintained at the facility. Cleaning techniques should be used that do not give rise to airborne radioactive material, e.g. the use of vacuum cleaners with HEPA filters.

e) Regular contamination surveys of areas of the facility and equipment should be carried out to confirm the adequacy of cleaning programmes.

f) Contamination zones should be delineated and clearly indicated.

g) Continuous air monitoring should be carried out to alert facility operators if levels of airborne radioactive material exceed predetermined action levels.

h) Mobile air samplers should be used at possible sources of contamination as necessary.

i) An investigation should be carried out promptly in response to readings of high levels of airborne radioactive material.

j) Personnel and equipment should be checked for contamination and should undergo decontamination if necessary prior to their leaving contamination zones. Entry to and exit from the work area should be controlled to prevent the spread of contamination. In particular, changing rooms and decontamination facilities should be provided.

k) Temporary means of ventilation and means of confinement should be used when intrusive work increases the risk of causing contamination by airborne radioactive material (e.g. during periodic testing, inspection or maintenance).

l) Personal protective equipment (e.g. respirators, gloves and clothes) should be made available and should be used when dealing with possible releases of radioactive material from its normal means of confinement in specific operational circumstances (e.g. bag-out/bag-in operations, certain maintenance operations or changing of gloves of gloveboxes).

m) Personal protective equipment should be maintained in good condition, cleaned as necessary, and should be periodically inspected.

n) Any ~~staff~~ personnel having wounds should protect them with an impervious covering for work in contamination zones.

~~7.34.~~8.61. In vivo monitoring and biological sampling should be available as necessary as a complementary measure for monitoring doses due to occupational exposures. Whole body counts should also be performed periodically to check for internal exposure.

~~7.35.~~8.62. The extent and type of workplace monitoring should be commensurate with the expected level~~s~~ of airborne activity, ~~radioactive material and the~~ contamination levels and radiation type, and the potential for these to change~~of workplaces~~.

~~7.36.~~8.63. For exposures which are expected to be low, ~~The~~the method for assessing doses due to internal exposure should be based on the collection of data from air sampling in the workplace, in combination with personnel ~~worker~~ occupancy data. This method should be assessed, and should be reviewed as appropriate by the regulatory body.

~~7.37.~~8.64. In carrying out the activities for periodic testing, inspection and maintenance, precautions should be taken to limit, by the use of temporary enclosures and ventilation systems, the spread of radioactive material.

~~7.38.~~8.65. On completion of maintenance work, the area concerned should be decontaminated and air sampling and smear checks should be carried out to confirm that the area can be returned to normal use.

~~7.39.~~8.66. Estimates should be regularly made, by means of monitoring data on effluents, of doses due to internal exposure received by members of the public who live in the vicinity of the site.

~~Control of external exposure~~

~~7.40.~~8.67. ~~In all process areas of a MOX fuel fabrication facility, control of external exposure is required to ensure that doses are kept below authorized limits and are as low as reasonably achievable (ALARA).~~ External exposure due to gamma radiation from americium (and residual fission products from UO_2 where appropriate) and neutron radiation from PuO_2 ~~can~~ should be controlled by means of an appropriate combination of requirements on time, distance and shielding. Radioactive sources are used in a MOX fuel fabrication facility ~~to~~for scanning rods and in the laboratory.

~~7.41.~~8.68. Although most of the processes in a MOX fuel fabrication facility are automated, there are some actions that require manual work in gloveboxes. Owing to the proximity of the hands of operators to PuO_2 when work in gloveboxes is being carried out, the hands are more susceptible to exposure than other parts of the body.~~,~~ The dose to the hands should therefore be monitored (by extremity dosimetry) together with doses to eye lens.

~~7.42.~~8.69. External exposure should be controlled by:

a) Training of personnel in radiation hazards and the use of dose monitoring equipment;
b) Removing PuO_2 and the other radioactive materials from process areas in use for extended maintenance work;
c) Ensuring that radiation sources are changed by suitably qualified and experienced persons;
d) Avoiding unnecessary ~~stays~~ presence in the vicinity of gloveboxes;

e) Using individual and temporary shielding;

f) Performing routine surveys of radiation dose rates.

INDUSTRIAL AND CHEMICAL SAFETY

8.70. The requirements relating to industrial and chemical safety are established in Requirement 70 of SSR-4 [1].

7.43. See also para. 7.4.

7.44.8.71. The industrial and chemical hazards found present in MOX fuel fabrication facilities may be summarized as follows:

a) Asphyxiation hazards due to the presence of argon or hydrogen or mixtures thereof, or of nitrogen or carbon dioxide;

b) Explosion of hydrogen storage bottles outside the main MOX processing building;

c) Fire;

d) Gas storage bottles becoming missiles;

e) Chemical hazards in the laboratory;

e)f) Potential fire hazards including metallic fires involving zirconium metal shavings.

8.72. The occupational exposure to chemical hazards should be assessed similarly to the assessing of radiation doses and should be based upon the collection of data from air sampling in the workplace, in combination with personnel occupancy data. This method should be assessed and reviewed as appropriate by the regulatory body. The acceptable levels of occupational exposure for various chemical hazards in a fuel fabrication facility can be found in Ref. [18].

8.73. 7.46 The selection of personnel protective equipment should be commensurate to the hazard present (e.g. acid filters for protective equipment for acids, particulate filters for particulates and combination filters where both hazards are present).

7.45.8.74. A mixture of argon and hydrogen is generally used in the sintering furnaces in MOX fuel fabrication facilities. Nitrogen may be used in gloveboxes to ensure the quality of the product. Carbon dioxide may be used in automatic fire suppression systems except where it may cause a criticality risk. A leakage of any of these gases may cause asphyxiation. Additionally, there is a potential for explosion at the location outside the main processing building where the mixing of hydrogen with argon is carried out.

7.46.8.75. Gas storage bottles are used to store various gases such as carbon dioxide, hydrogen, and mixtures of argon and hydrogen. Procedures should be developed and used to ensure the proper storage and handling of gas storage bottles to prevent them from becoming missiles.

8.76. Chemicals are used mostly in the laboratory for performing product analyses. Personnel should be made aware of the potential chemical hazards. Written procedures should be developed and used to control the quantity and handling of chemicals in the laboratory to prevent explosion, fire, high toxicity, undesirable chemical interactions, etc. Chemicals should be stored in well aerated premises or in racks outside the process and laboratory area.

8.77. To minimize the fire hazard of pyrophoric metals (zirconium or uranium particles), shearing hot cells and other locations where such materials could accumulate should be monitored, periodically checked and cleaned in accordance with procedures. In some cases, routine flushing out (i.e. high flow rate washing) of equipment may be necessary.

8.78. The procedures and training for responses to fires in areas containing fissile material should pay particular attention to the prevention of a criticality and preventing any unacceptable reduction of criticality safety margins.

8.79. The work permit and facility procedures and instructions should include an adequate assessment of and, as necessary, a check-sheet on the potential radiological consequences of fires resulting from activities that involve potential ignition sources, e.g. welding, and should define the precautions necessary for performing such work.

8.80. The prevention and control of waste material accumulations (contaminated material and 'clean' material) should be rigorously enforced to minimize the fire load (fire potential) in all areas of the MOX fuel fabrication facility. Auditing for waste accumulations should be an important element in all routine inspection and surveillance activities by all levels of personnel. Periodic inspections by fire safety professionals should be part of the audit programme.

8.81. A health surveillance programme should be set up, in accordance with national regulations, for routinely monitoring the health of workers personnel who may be exposed to chemicals. Monitoring of the chemical effects of uranium and of the radiological effects of plutonium, as necessary, should be considered the core part of the health surveillance programme. The surveillance program should address short term effects (acute exposure) and long term effects (chronic exposure).

8.82. During emergencies, special considerations should be given to the presence of combination of both chemical and radiological hazards.

MANAGEMENT OF RADIOACTIVE WASTE AND EFFLUENTS

7.47.8.83. The requirements relating to the management of radioactive waste and effluents in operation are established in para. 9.102 – 9.1089.54–9.57 of SSR-4Ref. [1].

7.48.8.84. Gaseous radioactive discharges should be treated, where appropriate, by means of HEPA filters or equivalent (see para. 5.1254.122). Performance standards should be set that specify performance levels at which filters or scrubber media are to be changed. After filter changes, tests should be carried out to ensure that new filters are correctly seated and yield a removal efficiency as used in the analyses.

7.49. Chemicals should be recovered and reused where possible.

7.50.8.85. One easy way to minimize the generation of solid radioactive waste is to remove as much outer packing as possible before material is transferred to controlled areas. Processes such as incineration, metal melting and compaction may also be used to reduce the volume of waste, but such processes are beyond the scope of this publication. As far as reasonably practicable, and in accordance with national regulations, waste material should be treated to allow its further use. Cleaning methods should be adopted at the facility that minimize the generation of waste.

Information on the management of waste and effluents can also be found in refs [7, 8].

EMERGENCY PLANNING AND PREPAREDNESS AND RESPONSE

7.51.8.86. The requirements for emergency planning and preparedness and response specific to MOX fuel fabrication facilities are established in para. 9.120 – 9.1329.62–9.67 and paras II.44 and II.45 of Appendix II of SSR-4Ref. [1], in GSR Part 7 [19], and recommendations are provided in GS-G-2.1 [20] and in IAEA Safety Standards Series No. GSG-2, Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency [28]. The conditions for declaration of an off-site emergency at a MOX fuel fabrication facility may include releases of plutonium and also, depending on national requirements and facility specific considerations, criticality accidents, large fires or explosions.

8.87. The emergency preparedness should include how and when an interface with local and national emergency response organizations should be established. This arrangement should be tested periodically to ensure effective operation during an emergency. Clear communication and authorization protocols should be established with local authorities to ensure proper functioning of the emergency response organization.

8.88. The operator should ensure availability of personnel with specific expertise on the type of hazards present in facility as well as specific environmental sampling equipment for local authorities to support appropriate decision-making.

8.89. Emergency plans and contingency plans should be developed in a coordinated manner, considering all of the responsibilities of the facility personnel and security forces, to ensure that in the event of a simultaneous response of both groups to an event, all critical functions can be performed in a timely manner. Emergency response plans should consider nuclear security events as possible emergency initiators and their implications on emergency situations and be coordinated with the security response. Strategies for rapidly determining the origin of events and deploying appropriate first responders (safety personnel, security forces or a combination of both) should be developed including the roles and actions of security forces and emergency response personnel. These situations should be jointly exercised and evaluated. From this, lessons should be identified and recommendations should be made to improve the overall response.

8.90. For establishing access control procedures during emergencies, when there is a necessity for rapid access and egress of personnel, safety and security specialists should cooperate closely. Both safety and security objectives should be sought for during emergencies as much as possible, in accordance with regulatory requirements. When it is not possible, the best solution taking into account both objectives should be pursued.

FEEDBACK OF OPERATING EXPERIENCE

8.91. Requirements on feedback of operating experience are listed in SSR-4 [1], para. 9.133 – 9.137. Further guidance on operational experience program is provided in SSG-50 [11].

8.92. The programme for the feedback of operational experience at uranium fuel fabrication facilities should cover experience and lessons learnt from events and accidents at the nuclear facility as well as from other nuclear fuel cycle facilities worldwide and other relevant non-nuclear accidents. It should also include the evaluation of trends in operational disturbances, trends in malfunctions, near misses and other incidents that have occurred at the research reactor and, as far as applicable, at other nuclear installations. The programme should include consideration of technical, organizational and human factors. Useful information on the causes and consequences of many of the most important anomalies and accidents that have been observed in MOX fuel fabrication facilities and other nuclear fuel cycle facilities is provided in Ref. [29].

8.9. PREPARATION FOR DECOMMISSIONING

8.1.9.1. Requirements for the preparation of safe decommissioning of a MOX fuel fabrication facility are established in Section 10 and para. II.46 of Appendix II of Ref. SSR-4 [1] para. 10.1 – 10.13, and in the IAEA Safety Standards Series No. GSR Part 6, Decommissioning of Facilities [30], Sections 2 to 7. Recommendations on decommissioning of nuclear fuel cycle facilities, including MOX fuel fabrication facilities, are provided in Ref. [10].

8.2. The radiological hazard associated with the decommissioning of MOX fuel fabrication facilities is mostly due to potential exposure to alpha radiation, which can be controlled by means of appropriate clothing, containment and use of respirators. Since, during the lifetime of a MOX fuel fabrication facility, the processing of nuclear material is performed inside gloveboxes, there will normally be little contamination present in areas outside the gloveboxes.

9.2. To facilitate the decommissioningIn the operational stage ,the gloveboxes should be routinely cleaned in the operational stage, in accordance with the justification provided for the cleaning interventions (the balance of cost and benefit in respect of exposure and the generation of waste).

9.3. Special measures should be implemented during the preparatory works for decommissioning to ensure that criticality control is maintained when handling equipment containing nuclear material which criticality safety is controlled by geometry.

8.3.9.4. During the transition period between the shutdown and decommissioning, post-operational cleanout to remove all bulk amounts of PuO_2 and MOX powder in gloveboxes in order to reduce the residual inventory of plutonium should be performed. The plutonium inventory should be determined on the basis of accounting data for nuclear material.

PREPARATORY STEPS

8.4.9.5. The decommissioning plan for MOX fuel fabrication facilities should be developed following the guidance provided in SSG-47 [31]. Specific consideration should be given to the following elements The preparatory steps for decommissioning a MOX fuel fabrication facility should begin with the decontamination of the first containment barriers (mainly gloveboxes):

a) The description of facility status at the beginning of decommissioning including the list of systems that should be operational.

a)b)Post-operational cleanout to remove all bulk amounts of PuO2 and MOX material in gloveboxes in order to reduce the residual inventory of plutonium The plutonium inventory should be determined on the basis of accounting data for nuclear material.The decontamination of the first containment barriers should be done at the beginning of the decommissioning.

b)c)Identification of parts of buildings and items of equipment that are contaminated with plutonium and their levels of contamination.

c)d)Determination of decontamination methods Decontamination of the facility to reach the levels required by the regulatory body for cleanup operations or the lowest reasonably achievable level of residual contamination.

d)e)Preparation of risk assessments and method statements for the licensing of the decommissioning process.

e)f) Preparations for the dismantling of process equipment, gloveboxes and ducts upstream of the HEPA filters (or equivalent):

— Selection and justification of the dismantling methods and equipment (such as ventilated tents), with account taken of all the options for waste management (pretreatment, conditioning and disposal);

— Organization and planning of the dismantling interventions;

— Assessment of the risks associated with dismantling, including emergency planningpreparedness and response.

9.6. The developed decommissioning plan and the safety assessment should be periodically reviewed and updated throughout the MOX fuel fabrication facility's commissioning and operation stages (see GSR

Part 6 [30], Requirements 8 and 10) to take account of new information and emerging technologies to ensure that:

a) The (updated) decommissioning plan is realistic and can be carried out safely;

b) Updated provisions are made for adequate resources and their availability, when needed;

c) The radioactive waste anticipated remains compatible with available (or planned) interim storage capacities and disposal considering its transport and treatment.

DECOMMISSIONING PROCESS

8.1. In the decommissioning process, particular consideration should be given to preventing the spread of contamination by means of appropriate techniques such as:

- The systematic use of enclosures to recreate both static and dynamic containment;
- Proper bagging-out of materials from gloveboxes that are being dismantled.

8.2. In addition, particular consideration should be given to:

- The appropriate handling and packaging of waste as well as planning for the appropriate disposal of radioactive waste;
- The safe storage of contaminated material and radioactive waste that cannot be decontaminated or disposed of immediately.

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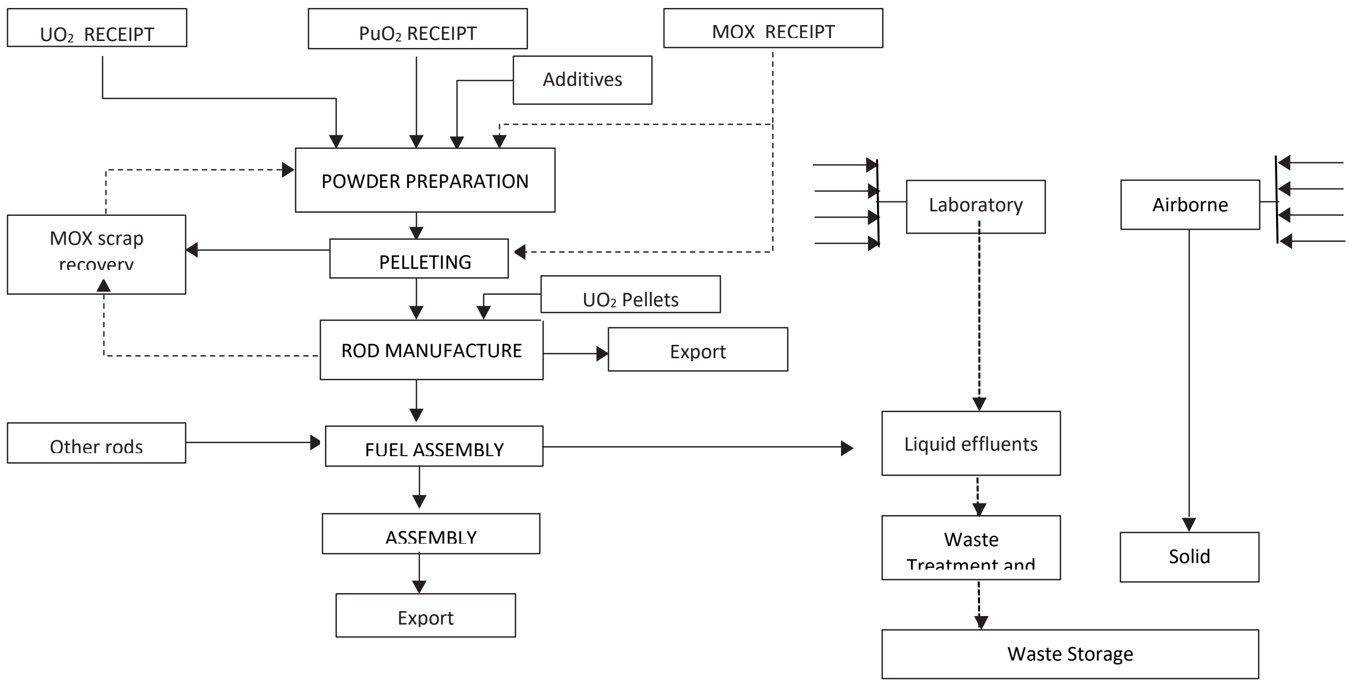
ANNEX I
TYPICAL PROCESS ROUTES IN A MOX FUEL FABRICATION FACILITY



ANNEX II
EXAMPLES OF STRUCTURES, SYSTEMS AND COMPONENTS IMPORTANT TO SAFETY AND POSSIBLE CHALLENGES TO SAFETY FUNCTIONS FOR MOX FUEL FABRICATION FACILITIES

Safety function:

(1) Criticality prevention;
(2) Confinement of radioactive material;
(3) Protection against external exposure.

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged
Receipt of PuO_2 and MOX	Equipment for non-destructive analysis or destructive analysis of PuO_2 for isotopic characterization[a]	Degradation of criticality safety margin (material out of specification)	(1)
Receipt of UO_2	Equipment for non-destructive analysis or destructive analysis of UO_2 for isotopic and stoichiometric characterization[a]	Degradation of criticality safety margin (material out of specification) Fire (spontaneous ignition of UO_2 in air owing to stoichiometry being out of specification)	(1), (2)
Powder preparation	Equipment for powder metering (dosing) and weighing	Degradation of criticality safety margin (mass)	(1)
	Additive metering device	Degradation of criticality safety margin (moderation)	(1)
	Homogenizer mixer	Degradation of criticality safety margin (mass) Radiolysis due to hydrogenated additives	(1) (2)

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged
	Gloveboxes	Release of radioactive material (glovebox leak, glove rupture)	(2)
	Shielding	Increase in dose rate to hands and body	(3)
Pellet manufacture	Pellet press design (oil volume limit)	Degradation of criticality safety margin (moderation — oil leak) Fire (oil leak)	(1), (2)
	Sintering furnace design (gas mixture control, leaktightness, airlocks)	Release of radioactive material (explosion in sintering furnace)	(2)
	Gloveboxes	Release of radioactive material (glovebox leak, glove rupture)	(2)
	Shielding	Increase in dose rate to hands and body	(3)
	Grinding dust cleaning system	Increase in dose rate (if system fails and dust accumulates in glovebox)	(3)
Pellet storage	Pellet storage rack structure	Degradation of criticality safety margin (geometry)	(1)
	Ventilation and air cooling device	Degradation of neutron absorber (due to heating of reprocessed plutonium)	(1)
Fuel rod manufacture	Gloveboxes	Release of radioactive material (glovebox leak, glove rupture)	(2)
	Glovebox fire protection systems	Fire (zirconium particles)	(2)

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged
	Shielding	Increase in dose rate to hands and body	(3)
Fuel rod inspection	Rod testing equipment for leaktightness	Release of radioactive material	(2)
	Shielding	Increase in dose rate to hands and body	(3)
	Rod X ray scanner	External exposure	(3)
	Rod transfer machines	Breakage	(2)
Fuel rod storage	Fuel rod structure	Degradation of criticality safety margin (geometry)	(1)
	Ventilation and air cooling devices	Degradation of neutron absorber (due to heating of plutonium)	(1)
Fuel rod assembly manufacture	Handling machines on assembly lines	Degradation of criticality safety margin (geometry, neutron absorber, moderation) Rod breakage (release of radioactive material) External hazard (time and/or proximity to rods)	(1) (2) (3)
	Fire protection systems	Fire (zirconium particles)	(2), (3)
	Cranes	Dropped assembly	(1), (2)
	Washing unit	Degradation of criticality safety margin (geometry, moderation, reflection)	(1)
Fuel assembly storage	Fuel assembly storage structure	Degradation of criticality safety margin (geometry)	(1)
	Ventilation and air cooling devices	Degradation of neutron absorber (due to heating of plutonium)	(1)
	Shielding	Increase in dose rate	(3)

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged
MOX scrap recovery	Gloveboxes	Release of radioactive material	(2)
	Shielding	Increase in dose rate to hands and body	(3)
	Characterizing devices for plutonium content and moderation	Degradation of criticality safety margin (mass, moderation) Radiolysis due to hydrogenated additives	(1) (2)
Laboratory	Gloveboxes Storage of samples Use of chemicals	Release of radioactive material Increase of dose rate Chemical reactions including fire Radiolysis	(2) (1) (2) (2)
Waste handling	Measuring devices for plutonium content	Degradation of criticality safety margin (mass)	(1)
	Fire protection systems in the radioactive waste storage area	Fire	(2)
All process areas	Building structure, including wall penetrations and doors between fire areas and between confinement areas	Loss of integrity	(2)
	Ventilation systems and controls	Loss of dynamic confinement with release of radioactive material into the work place	(2)
	Filters inside the process areas	Fire Degradation of criticality safety margin (mass)	(2) (1)

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged
	Process gas in ventilation ducts	Degradation of criticality safety margin (mass — accumulation of material)	(1)
	Measurement devices for activity in waste air	Release of radioactive material	(2)
	Emergency power supply system	Release of radioactive material (loss of dynamic confinement — ventilation system shutdown) Loss of instrumentation and control	(2) (2)
	Fire protection systems	Fire	(2)

[a] If the quality assurance by the supplier and the MOX fuel fabrication facility is considered adequate, the measurements carried out on PuO_2 or MOX before their transfer to the facility may be sufficient.

ANNEX III
EXAMPLES OF PARAMETERS FOR DEFINING OPERATIONAL LIMITS AND CONDITIONS FOR MOX FUEL FABRICATION FACILITIES

Safety function: (1) Criticality prevention;

(2) Confinement of radioactive material;

(3) Protection against external exposure.

21 Process area (including storage areas)	Safety function	Control parameter for operational limits and conditions
Area for receipt of PuO_2 and MOX	(1)	Isotopic composition (fissile isotopes and minimum value of ^{240}Pu)
	(1)	Limited moderation (moisture)
	(1)	PuO_2 content in MOX
	(2)	Specific heat of PuO_2
	(2)	Total amount of plutonium allowed on the site
	(3)	Isotopic composition, for neutron and gamma exposure (americium, etc.)
Area for receipt of UO_2	(1)	Enrichment in ^{235}U (if >1%, then criticality concern)
	(1)	Limited moderation
Intermediate storage of PuO_2 powder	(1)	Mass per container
Intermediate storage of UO_2 powder (only if ^{235}U >1%)	(1)	Total mass or mass per container
Powder preparation	(1)	Total mass of fissile material in each process unit to correspond with the criticality analysis
	(1)	Content of PuO_2 in each process unit to correspond with the criticality analysis
	(1)	Limited moderation (moisture, additives)

Process area (including storage areas)	Safety function	Control parameter for operational limits and conditions
	(1)	Operational controls to ensure homogeneity of MOX mixture before pellet manufacture
	(3)	Content of americium in the MOX
	(2)	Surface contamination of radioactive sources
Pellet manufacture	(1)	Total mass of fissile material in each process unit to correspond with the criticality analysis
	(1)	Limited moderation (moisture)
	(1)	Size of pellets is within the limits of the criticality analysis
	(1)	For pellets received from other facilities, enrichment of uranium in the uranium pellets is within the limits of the criticality analysis
	(2)	Composition of atmosphere in sintering furnace (gas mixture)
	(2)	Temperature of sintering furnace
	(2)	Surface contamination of radioactive sources
Fuel rod manufacturing and fuel rod inspection	(1)	Total mass of fissile material or number of rods in each process unit or manual rod transport container, to correspond with the criticality analysis
	(1)	Limited moderation (moisture)
	(1)	Fissile length of fuel pellets in rods and diameter of rods are within limits of criticality analysis
	(1)	For rods received from other facilities, isotopic content, PuO_2 content and enrichment of uranium in the uranium rods are within the limits of the criticality analysis
	(2), (3)	Surface contamination of rods
	(2)	Surface contamination of radioactive sources

Process area (including storage areas)	Safety function	Control parameter for operational limits and conditions
Fuel assembly manufacturing	(1)	Operational controls to ensure that the types of rods are correct and the rods are in the correct locations in the assembly
	(1)	Operational controls to ensure that all rods have been installed into the assembly
	(2)	Surface contamination of radioactive sources
MOX scrap recovery	(1)	Total mass of fissile material in each process unit to correspond with the criticality analysis
	(2)	Surface contamination of radioactive sources
Laboratory	(1)	Mass of plutonium
	(2)	Surface contamination of radioactive sources
Radioactive waste treatment	(1)	Mass of PuO_2 in containers and maximum number of containers in storage
	(2)	Surface contamination of radioactive sources
Ventilation system	(2)	Stages of pressure in the building
	(2)	Efficiency of last stage filters
	(2)	Minimum number of exhaust fans that are operational at any given time
	(2), (3)	Limits on radiation levels in flow going out to the environment
	(2)	Maximum pressure differential across filters
Gloveboxes	(1)	Total mass of fissile materials in each process unit (which can comprise one or more gloveboxes) to correspond with the criticality analysis
	(2)	Overpressure and underpressure values
	(2)	Detection limits or alarm level for detecting room contamination caused by glovebox leakage

CONTRIBUTORS TO DRAFTING AND REVIEW

Anderson, R.W.	British Nuclear Fuels, United Kingdom
Aono, S.	Japan Nuclear Cycle Development Institute, Japan
Bogdanova, T.	Federal Environmental, Industrial and Nuclear Supervision Service of Russia, Russian Federation
Gater, R.	International Atomic Energy Agency
Groche, K.	Germany
Kyriazidis, G.	Atomic Energy Commission, France
Lecarme, C.	Institute for Radiological Protection and Nuclear Safety, France
Michaelson, T.	International Atomic Energy Agency
Nocture, P.	International Atomic Energy Agency
Persinkon, A.	Nuclear Regulatory Commission, United States of America
Petrova, L.	Ministry for Atomic Energy of the Russian Federation, Russian Federation
Rovny, J.	International Atomic Energy Agency
Tiktinsky, D.	Nuclear Regulatory Commission, United States of America
Tshuchino, S.	Japan Nuclear Energy Safety Organization, Japan
Shokr, A.	International Atomic Energy Agency
Ueda, Y.	Japan Nuclear Energy Safety Organization, Japan
Voitellier, J.L.	Cogema, France