DS 381: Draft 1.1

13 June 2014

IAEA SAFETY STANDARDS

for protecting people and the environment

Status: Step 7

for submission to

NUSSC

Safety of Nuclear Fuel Cycle Research and Development Facilities

DRAFT SPECIFIC SAFETY GUIDE XXX (DS381)

IAEA

INTERNATIONAL ATOMIC ENERGY AGENCY

FOREWORD

by Yukiya Amano

Director General

EDITORIAL NOTE

An appendix, when included, is considered to form an integral part of the standard and to have the same status as the main text. Annexes, footnotes and bibliographies, if included, are used to provide additional information or practical examples that might be helpful to the user.

The safety standards use the form 'shall' in making statements about requirements, responsibilities and obligations. Use of the form 'should' denotes recommendations of a desired option.

CONTENTS

Field Code Changed
Field Code Changed
Field Code Changed
Field Code Changed
Field Code Changed
Field Code Changed
Field Code Changed
Field Code Changed
Field Code Changed
Field Code Changed
Field Code Changed
Field Code Changed

1. INTRODUCTION

BACKGROUND

1.1. This Safety Guide on the Safety of Nuclear Fuel Cycle Research and Development Facilities (R&D facilities) supplements the Safety Requirements publication on the Safety of Nuclear Fuel Cycle Facilities NS-R-5 Ref. [1] including Appendix V. It addresses all the stages in the lifecycle of R&D facilities whether at the laboratory, pilot and demonstration scales.

1.2. R&D facilities receive, handle, process and store a large variety of nuclear materials (e.g. uranium, thorium or plutonium), other actinides, and fission products or activated materials. This guide covers two types of R&D facility, described as Case 1 and Case 2 and illustrated in Annex I:

- Case 1: Experiments and fundamental research studies of chemical conducted on chemical, physical, mechanical~~, material~~ and radiological properties of specific ~~radioactive~~ nuclear materials like prototype nuclear fuels (before and after reactor irradiation) or experiments on nuclear material or ~~/~~wastes arising from ~~experimental~~ new processes. This guidance applies to the experiments as well as the facility that houses them, in accordance with the graded approach.
- Case 2 : Research and development ~~of~~ on processes and equipment ~~the~~ envisaged for use on ~~f which is envisaged later on~~ an industrial scale (e.g. pilot facilities for waste treatment).

1.3. R&D facilities can operate over extended periods of time to provide analytical services, materials or testing services and their inventories of radioactive and toxic materials can be significant. Consequently all of the IAEA requirements for production facilities such as requirements for the management of activities, learning from experience, inspection and maintenance should be applied to R&D facilities where similar operations are carried out.

1.4. R&D facilities include various facility types, from fundamental to applied research, covering all stages of the fuel cycle including research for fuel processing, material examination and fuel safety, chemical analysis and the development of instrumentation. A variety of physicochemical processes may be employed to study different types of fuels or materials that may also possess hazardous chemical, biological or physical properties.

OBJECTIVE

1.5. The objective of this Safety Guide is to provide guidance based on experience gained from member States and considering present state of technology to ensure safety at all stages of the lifecycle of R&D facilities. This guidance specifies actions, conditions, or procedures to meet the requirements established in Ref [1].~~The objective of this publication is to provide recommendations which, in the light of experience in States and the present state of technology, should be satisfied to ensure the safety for all stages in the lifetime of R&D facilities. These recommendations specify actions, conditions or procedures for meeting the requirements established in Ref. [1]~~. This Safety Guide is intended to be of use to researchers, designers, operating organizations, and regulators for ensuring the safety of R&D facilities.

1.6. In this document, the operating personnel, researchers, contractors and subcontractors working at the R&D facility are collectively referred to as "R&D facility personnel" or simply "personnel". More specific terms may be used where a distinction is necessary.

SCOPE

1.7. The safety requirements common to the whole range of nuclear fuel cycle facilities (i.e. milling, refining, conversion, enrichment, fabrication of fuel, reprocessing of spent fuel, waste treatment, storage and, associated analytical laboratories) are established in Ref. [1]. The specific requirements related to R&D facilities are established in Appendix V of Ref. [1]. This Safety Guide provides guidance on meeting the requirements in Sections 5 – 10 and Appendix V of Ref. [1].

1.8. This publication applies to the facilities defined in paragraph 1.2 with the exception of irradiators, accelerators and research reactors, including criticality mock-ups and radio-isotope producers. It specifically deals with the safe design, construction, commissioning, operation and decommissioning of R&D facilities. This guide is limited to the safety of the R&D facility, the protection of its workers and the public around it. It does not deal with the subsequent impact that the material produced by R&D facilities may have on end-users.

1.9. Full ~~recommendations~~ guidance on meeting the requirements for the management system and for the verification of safety established in Ref. [8] ~~are~~ is provided in Ref. [9]. ~~The implementation of other s~~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) are established in Ref. [10]~~, and those on the management system and the verification of safety (e.g. requirements for the management system and for safety culture) are established in Ref. [8]~~.

1.10 Safety ~~recommendations~~ guidance ~~and requirements~~ related to R&D facility Case 2 can also be found in the IAEA safety guides related to the ~~similar~~ corresponding type~~s~~ of nuclear fuel cycle facilities, e.g. ~~recommendations~~ guidance applicable to fuel fabrication pilot facilities will also be found in the safety guide for fuel fabrication facilities, Ref. [20].

1.11. Sections 3 to 8 of this publication include guidance on radiation protection measures to meet the safety requirements specified in the International Basic Safety Standards for Protection against Ionizing Radiation (Ref. [2]). This standard and the associated guide (Ref. [3]) also present measures for personnel dosimetry, protection optimization, measures to control and limit the discharge of radioactive materials to the environment and radiation monitoring of the workplace as well as contamination monitoring of the workers from design through to the decommissioning stage.

STRUCTURE

1.12. This document contains guidance specific to nuclear f~~F~~uel c~~C~~ycle R&D facilities. This Specific Safety Guide provides guidance on relevant IAEA safety requirements in standards listed at the end of this document. The recommendations in this guide have been referenced to their corresponding requirements in Ref. [1] and elsewhere, where this does not destroy the readability of the text. This Safety Guide covers all ~~the important~~ stages in the lifecycle of a R&D facility, including site evaluation, design, construction, commissioning, operation, and decommissioning. It also considers modifications, maintenance, calibration, testing and inspection as well as emergency preparedness where there is specific guidance. Reference is ~~should be~~ made to ~~the referenced documents and~~ other IAEA standards for requirements and guidance on generic topics (such as safety assessment, radioactive waste~~s~~ management, decommissioning or security) that are not specific to ~~Fuel Cycle~~ R&D facilities, in accordance with the structure of the publications for nuclear facilities and operations being prepared by the IAEA.

1.13. General safety ~~recommendations~~ guidance for a R&D facility ~~are~~ is described in section 2. The safety aspects to be considered during the process of evaluating the site of a facility are described in section 3. Section 4 deals with safety during the design stage and section 5 deals with safety aspects during the construction stage. Section 6 describes the safety considerations that arise during commissioning. Section 7 considers the operational stage and contains guidance on practices to ensure safety during facility operation. It includes also management of facility operation and emergency planning and preparedness. Section 8 deals with guidance on meeting safety requirements during the decommissioning of a R&D facility. Annex I shows the typical process route for a R&D facility. Annex II gives examples

of structures, systems and components important to safety (SSCs) in R&D facilities grouped by process areas. Annex III provides examples of operating limits and conditions (OLCs) for R&D facilities.

1.14. R&D facilities remain subject to the same international agreements and national laws as other types of nuclear facility.

2. GENERAL SAFETY CONSIDERATIONS FOR R&D FACILITIES

GENERAL

2.1. In R&D facilities, fissile and other radioactive materials can be present in different forms with diverse physical and chemical characteristics. The main hazards are criticality, loss of confinement, radiation exposure (both internal and external) and chemical or explosive hazards, from which workers, the public, and the environment need to be protected by adequate design, construction and safe operation.

2.2. ~~In R&D facilities a great variety of materials can be handled and processed, such as fissile, radioactive or toxic materials.~~ The factors affecting the safety of R&D facilities include the following:

- The radiological consequences caused by the release of radioactive materials under accident conditions can be significant~~high~~. While the radio-toxicity of uranium is relatively low, this is not the case for plutonium or other radionuclides~~, and thus the expected radiological consequences following potential accidents can be significant~~.
- Furthermore, fissile materials have the potential to achieve criticality under certain conditions. The subcriticality of a system depends on many parameters relating to the fissile material, including its mass, concentration, geometry, volume, enrichment and density~~Criticality is affected by the mass, geometry of the material and the existence of a reflecting/moderating environment~~.

- When irradiated fuel is used, the radiation levels and the risk of internal and external radiation exposures are significantly increased.
  - Depending on the kind of processes performed in the R&D facilities, chemical hazards as well as fire and explosion risks also need to be taken into account, see 6.54 in Ref. [1].
- The chemical toxicity of material used in R&D facilities has to be considered (e.g. uranium hexafluoride, which if released, reacts with the moisture in the air to form hydrogen fluoride and soluble uranyl fluoride). Therefore, the safety analysis of R&D facilities should also address impacts resulting from these chemicals and their potential mixing (e.g. in waste or liquid release).
- Products, sub-products, or waste arising from research and development programmes on exotic nuclear materials should be included in safety assessments. For example;

- Non-standard MOX or UO_2 fuel fabrication, or new fuel matrices, e.g. carbides, nitrides, metallic forms;
- Isotopes with particular constraints for disposal , e.g. long half-life transuranics (like curium), fission products (like ^{99}Tc), or activated materials such as trace materials in cladding;
- Materials without an agreed national disposal route, e.g. graphite or aluminum in waste.

R&D FACILITY LICENSING

2.3. The framework for licensing, inspection and enforcement regime is defined in Section 3 of Ref. [1]. Licensing documentation, including the safety case and the operational limits and conditions (OLCs), is defined in paragraphs 2.9-2.15 of Ref. [1]. Requirement 23 of Ref. [11] states that "The results of the safety assessment shall be used to specify the programme for maintenance, surveillance and inspection; to specify the procedures to be put in place for all operational activities significant to safety and for responding to anticipated operational occurrences and accidents; to specify the necessary competencies for the personnel involved in the facility or activity and to make decisions in an integrated, risk informed approach". In other words, licensed operations will be conducted as defined in the safety analysis report and the OLCs. The R&D facility management team should be trained on the content and use of the safety analysis report and OLCs, in accordance with Ref. [9].

2.4. Through the licensing approval, the operating organization is committed to involve the regulatory authority in the case of new research programmes which are outside of the scope of the existing R&D facility safety case (in accordance with national practices).

2.5. The Safety Case/Licensing Document should be sufficiently broad in scope to capture potential expansion of research and development programmes to take account of any consequential safety requirements.

2.6. The safety approach (as documented in the safety analysis report) for a R&D facility should provide the same level of safety assurance whether the R&D facility comprises a laboratory in a university, or a large established nuclear R&D center. This equivalence of standard is achieved by application of a graded approach.

2.7. When deactivating or reactivating parts of an existing R&D facility's nuclear facilities or equipment, the safety assessment of the ~~se existing~~ facility~~ies~~ should be reviewed and

updated and should cover potential legacy waste and decommissioning needs as far as achievable. Radioactive or hazardous materials should be relocated to safe storage before deactivating parts of a R&D facility.

2.8. According to paragraph 3.9 (e) of Ref. [2], a~~A~~n environmental impact assessment ~~of an existing R&D facility~~ should be carried out by the operating organization as part of the licensing process for the R&D Facility. The prospective assessment for radiological environmental impacts should be commensurate with the magnitude of the possible radiation risks arising from the R&D facility~~prepared according to Ref. [13] using actual, historical monitoring data so far as practicable~~.

2.9. R&D facilities are normally established for a variety of different R&D programmes. Before starting a new programme the operator should verify that the new programme is either covered by the existing facility safety case, or otherwise is subject to a suitable modification with an appropriate authorization, as described later in this Section.

2.10. Paragraph 9.35 of Ref. [1] states that "The operating organization shall establish a process whereby its proposals for changes ….. are subject to a degree of assessment and scrutiny…" and a R&D facility should be subject to a change management process like other nuclear facilities. When there is change of use of a R&D facility (or part of), an appropriate change modification process should be applied, with peer review by suitably qualified personnel. Moving from laboratory scale to pilot plant usage would be an example of this situation. Where the increase in scale is large, the operating organization should plan the increase in stages, in order to permit feedback and validation of each stage. ~~Recommendations~~ Guidance on ~~for~~ the configuration and audit of such changes are provided later in this publication.

2.11 According to the safety significance of the modification and in agreement with the national regulatory authority, modifications should be verified by the regulatory authority before implementation. The reassessment of the facility and the formal authorization by the national regulatory authority identified in paragraph 3.10 of Ref. [1] should consider, in particular, the need to assess human factors, e.g., the man/machine interface, alarm systems, procedures, and qualification or requalification of personnel. See paragraphs 7.29-7.33 Modification Control.

2.12 The licensing documentation should also take into account the aspects arising from the decommissioning and radioactive waste management at ~~of~~ the facility.

MANAGEMENT OF SAFETY

2.13. In accordance with the requirements of Paragraph 4.5 of Ref. [1], the overall responsibility for safety of R&D facilities rests with the operating organization. Paragraph 4.7 of Ref. [1] goes on to state that "The operating organization shall clearly specify the responsibilities and accountabilities of all personnel involved in the control or conduct of operations that affect safety. The person with the responsibility for overall safety management shall be clearly identified at all times and suitably appointed".

2.14. The management processes and organizational provisions should reflect the requirements of Ref. [1] and also those of Ref. [8]. The licensing of R&D facilities should be based on a complete and adequate safety case produced by suitably qualified personnel. This safety case should include OLCs and a listing of the procedures to be followed in accordance with Section 9 of Ref. [1].

2.15. These processes and provisions apply throughout the lifetime of the facility and/or experiment, from its siting to its decommissioning. Paragraph 9.29 of Ref. [1] provides additional requirements applying to the maintenance of SSCs. Systems that should continue to operate to maintain the R&D facility and/or experiment in a safe state include:

- Heat removal systems in storage areas to remove decay heat from heat producing materials, and in heat producing experimental apparatus;
- Dynamic containment ~~confinement~~ systems (i.e. ventilation) should continue to operate to prevent radioactive material leakage from the facility;
- Safety monitoring systems;
- Inert gas feed systems e.g.: to hot cells or glove boxes.

2.16. R&D facility personnel should always be aware of the fact that technical installations can fail, even if the design is robust. An attitude of technical inquisitiveness and conservatism (e.g. built in redundancy) is an important contribution to safety culture and should be maintained by adequate training.

2.17. Operating organizations and regulatory authorities should promote the sharing of operational experience feedback on safety with other R&D facilities worldwide. Whether full-scale plant or individual experiments, R&D facilities should use the safety experiences of existing facilities as far as practicable.

2.18. Self-assessment and challenge of the safety performance within the sub-organizations of R&D facility should be developed and promoted by the operating organization.

2.19. A safety analysis should be performed in which potential accidents are analyzed to assure that they are adequately prevented, detected and mitigated. A graded approach should be taken to the safety requirements as outlined in Paragraph 1.14 of Ref. [1]. However, all levels of Defense in Depth should be addressed as necessary, see paragraphs 2.4 – 2.8 of Ref. [1].

2.20. For the implementation of the defense-in-depth requirements (Section 2 of Ref. [1]), the first two levels are the most significant, as the risks are mainly eliminated by design and appropriate operating procedures (see Sections 4, 6 and 7 of Ref. [1]).

2.21 R&D facilities should take advantage of existing infrastructural support. Emergency Planning & Preparedness (EPP) should take into account all other facilities at the site, their interactions and ability to support the R&D facility.

2.22 A complete set of national safety regulations should be developed and implemented to assure that the safety of R&D facilities is maintained for the full lifecycle of the R&D facility, see paragraph 3.7 of Ref. [1]. The regulatory body should establish the basic requirements for protection of workers and members of the public against the R&D facilities hazards (e.g. based on a dose assessment). These requirements should be consistent with internationally agreed approaches to achieving this objective.

2.23. Due consideration should be given to the minimization, segregation and conditioning of radioactive wastes that will be produced during operation and decommissioning of the R&D facility, as well as any legacy material.

2.24. The safety of e~~E~~xisting R&D facilities should be assessed and, if necessary, the facilities modified to meet current (or updated) safety standards as far as reasonably achievable. As an alternative ~~ or provide~~ equivalent compensatory measures should be provided.

2.25. In a R&D facility, the use of remote handling operations should be considered ~~normally be used~~ to reduce occupational exposures from radioactive materials and to ensure safe operations, especially in experiments using highly toxic or radioactive materials.

3. SITE EVALUATION

3.1. Ref. [13] establishes generic requirements for the safety evaluation of sites for most land-based nuclear installations including fuel-cycle facilities. The site evaluation process for a R&D facility may depend upon a large number of criteria, some of which are specific to the site and others are related to the facility. At the earliest stage of planning a R&D facility, a list of these criteria should be prepared and considered in accordance with their safety significance and discussed with regulatory bodies. In most cases, it is unlikely that all the criteria can be met, and the risks posed by certain externally generated safety significant initiating events (e.g., earthquake, aircraft crash, fire, extreme weather conditions) and the resulting consequences will dominate the choice of a site. Ref. [18] and Ref. [19] provide guidance on safety criteria used in this process.

3.2. A R&D facility may be a stand-alone facility, in which case the site should be capable of supporting the necessary infrastructure (e.g., offsite emergency response organizations). However, many R&D facilities are a part of another site, for which siting criteria have already been determined. Interactions with facilities nearby should be considered;

- Existing nuclear facility: In this case, the siting criteria should be encompassed by the evaluation studies of the existing facilities.
- Non-nuclear site (e.g., hospitals, universities, or research centers): The main siting issue can be emergency response, especially the potential need for evacuation. This may require specific design provisions.

3.43. Requirements for the evaluation of a Fuel Cycle R&D Facility are provided in Ref. [13]. Where the facility is a pilot for a Fuel Cycle Facility of another type, reference should be made to the relevant Specific Safety Guide, e.g. Ref. [20].

~~The main external hazards should include:~~

~~Flooding, which may result in criticality issues, and;~~

~~Earthquake, which can result in fire, loss of containment, spread of contamination or potential criticality events due to geometry changes.~~

~~3.5 The density of population, and its proximity to the R&D facility, should be considered in the siting in order to minimize the impact on people in case of a radioactive material releases.~~

~~3.6 According to national practice, administrative restrictions for the use of land around a R&D facility should be defined which accord to the level of hazards that the R&D facility~~

~~may pose. Their implementation to manage human development around the site may become more important the longer the site has been in existence.~~

3.~~7~~4 The siting of the R&D facility should allow the implementation of physical security measures in accordance with the guidance provided in the IAEA Nuclear Security ~~Guidance~~ Series publications Ref. [17].

~~3.8 For high potential hazard facilities, ongoing site re-evaluation should be conducted during the life of the R&D facility. The evaluation should consider changes in the specific site characteristics like population density and man-made hazards etc.~~

4. DESIGN

GENERAL

4.1. The structures, systems, components, procedures and organizational processes of a R&D facility should be designed in a manner that ensures safe operation, prevents events that could compromise safety, and mitigates the consequences of such events were they to occur. This design process usually begins with an analysis of potential internal accidents (or faults) and external events. It should proceed to the identification of safety functions that provide defense-in-depth, usually within boundaries defined by OLCs or safety case limits.

Basic Safety functions for R&D facilities

4.2. The basic safety functions (see paragraphs 6.37 to 6.53 and paragraphs V.1 to V.10 in Appendix V of Ref. [1]), are those functions, the loss of which, may lead to radioactive releases or exposures having possible radiological consequences for workers, the public and/or the environment, namely:

(1) Prevention of criticality;

(2) Confinement of radioactive material, including removal of decay heat;

(3) Protection against external radiation exposure;

4.3. The safety functions identified in the design of the R&D facility should comprise those individual SSC and OLCs which, when taken as a whole, provide the basic safety functions above. The remainder of this section describes those accidents, events and particularly those safety functions which may be especially relevant to a R&D facility.

Specific engineering design requirements

4.4. The following requirements apply:

- The requirements on prevention of criticality as established in paragraphs 6.43–6.51 and V.4–V.6 of Appendix V of Ref. [1].
- The requirements on confinement of radioactive materials as established in paragraphs 6.37–6.39, 6.52 and V.7 of Appendix V of Ref. [1].
- The requirements on protection against exposure are established in paragraphs 6.40–6.42 and V.8 of Appendix V of Ref. [1].

4.5. The design should give consideration to the handling of various types of radioactive materials. Due to the nature of the work done in R&D facilities there are often design and engineering provisions for flexibility and adaptation against future requirements or

dismantling. These provisions should be a) designed to enhance safety and b) operated to ensure safety is maintained over the lifetime of the facility.

Design basis accidents and safety analysis

4.6. In the context of nuclear fuel cycle facilities, a design basis accident (DBA) or a design basis event (DBE) presents a challenge against which a facility is designed according to established design criteria such that the consequences are kept within defined limits. The definition and the specific safety requirements relating to design basis accidents are established in Ref. [1] at paragraphs 6.4–6.9, V.1 and III.10 to ensure that the design keeps radiation exposures from normal operation and accident conditions as low as reasonably achievable. Ref. [18] and Ref. [19] provide guidance on the relevant DBEs.

4.7. In addition with the radiological hazards outlined ~~in paragraph 4.1~~ above, particular consideration should be given to the following hazards:

(a) Fire or chemical explosion;

(b) Natural phenomena such as earthquakes, tsunami, flooding or tornadoes;

(c) Aircraft crash.

4.8. Some of the events listed in paragraph 4.~~4~~ 7 may occur as a consequence of a postulated initiating event (PIE) and a selection of PIEs is listed in Annex I of Ref. [1].

Structures, systems and components important to safety

4.9. The design measures identified by the safety analysis are intended to prevent an accident or to mitigate its consequences if one does occur. These are often implemented by means of structures, systems and components important to safety (see paragraphs 6.6 and 6.8–6.9 and Annex III of Ref. [1]). Annex II presents examples of structures, systems and components and representative events that may challenge the associated safety functions.

SAFETY FUNCTIONS

Prevention of criticality

4.10. For R&D facilities, criticality prevention should be strictly addressed according to paragraphs 6.45 and 6.49 of Ref. [1]. In addition, R&D facilities corresponding to a type of nuclear fuel cycle facility should fulfil the requirements specific to this facility type (e.g. where the R&D facility is a pilot MOX facility, the requirements in Appendix II of Ref. [1] apply). In many R&D facilities handling fissile materials, sub-critical mass control is used (as far as possible, independent of all other factors) as a ‘deterministic” safety measure not

usually available in full scale facilities. A number of such areas may coexist independently in a single facility. The rest of this section describes the basis of control by mass and other factors in more detail and concludes with ~~recommendations~~ guidance regarding criticality detection and emergencies.

4.11. Paragraph 6.45 in Ref. [1] establishes requirements for all fuel-cycle facilities where criticality is considered; "For the prevention of criticality by means of design, the double contingency principle shall be the preferred approach" and the subsequent paragraph states that a fundamental requirement of criticality management is a conservative approach. Specific requirements for the control of criticality in R&D facilities are stated in Appendix V.1, V.4 and V.5 of Ref. [1]. Where the R&D facility is a pilot for another type of fuel-cycle facility, Appendices I, II, III and IV of Ref. [1] also define requirements for specific facility types which are applicable to R&D facilities. Some examples of the parameters that should be controlled to prevent a criticality include the following:

1. Mass: In R&D facilities, mass margins[1] should be based on representative material with the lowest critical mass. The margin should be not less than 100% of the normal value in operation (unless the likelihood of double batching is demonstrated to be sufficiently remote), or a mass margin equal to the physical mass that can be accumulated in the equipment.
2. Geometry or Shape: The analysis should give consideration to the layout of the facility, the dimensions and locations of pipes, vessels, and other laboratory equipment. For example, control by geometry could be used in the design of furnaces, dissolvers, and other equipment or processes.
3. Density and forms of materials: The analysis will consider the range of densities for different forms of materials (e.g., powder, pellets or rods) used in a R&D facility.
4. Concentration and density in analytical laboratory and in liquid effluent units: The analysis will consider the range of fissile material in solution as well as any potential precipitates (e.g. recovery of Pu in waste streams).
5. Moderation: The analysis should consider a range of moderation to determine the most reactive conditions that could occur. Water, oil and similar hydrogenous substances are common moderators which are present in R&D facilities, or may be present under accident conditions (e.g. water from firefighting paragraph V.6 in Ref. [1]). Non

[1] Mass Margin: The difference between the safety limit (maximum amount allowed within OLCs) and the subcritical limit (K_{eff}<1, often taken as Keff<0.95)

homogenous distributions of moderators should be considered (e.g. organic binders and porosity enhancing agents used in pelletizing process).

6. Reflection: The most conservative margin should be retained out 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 to e.g. the presence of personnel, organic materials, shielding materials, concrete or steel of the containment in or around the processing unit.
7. Neutron absorbers: If claims are made for neutron absorbers in the safety analysis, their effectiveness should be verified depending on the relevant operating conditions identified in Appendices I – IV in Ref. [1]. Neutron absorbers such as cadmium and boron may be used in R&D facilities and the safety analysis should incorporate their effect as neutron absorbers; however, ignoring their effects would still yield conservative results. The use of mobile or easily displaced or removed solid absorbers should be avoided.
8. Neutron interaction: Consideration should be given to neutron interaction between all locations of fissile materials in the R&D facility and all potential locations that may be involved. Specific consideration should be given to the layout of the R&D facility and any possible changes. Physical locators are preferred to floor markings as a means of indicating the placement of equipment with potential neutron interactions.
9. Fissile content: For any fissile material (e.g. fresh or irradiated fuel), the maximum fissile content (e.g. level of enrichment) in any part of the facility should be used in all assessments unless the impossibility of having this level of enrichment in a particular area of the facility is demonstrated in accordance with the double contingency principle, See paragraph 6 of Appendix III in Ref. [1].

4.12. The criticality safety analysis should demonstrate that the design of equipment is such that the values of control parameters are always maintained in the subcritical range. This ~~is~~ should be achieved by determining the effective multiplication factor K_{eff}, which depends on the mass, the distribution and the nuclear properties of the fissionable material, and all other materials with which it is associated. The calculated value of K_{eff} is then compared with the value specified by the design limit.

4.13. A number of methods can be used to perform criticality safety analysis, e.g. the use of experimental data, reference books or recognized standards, hand calculations or calculation by means of deterministic or probabilistic computer codes. Any method used to carry out the

analysis should use conservative data and should be fully verified and validated for the application. For detailed guidance see Ref. [12].

4.14. The method employed should be appropriate to the type of material(s) being handled in the R&D facility. The general procedure to be followed in this analysis should include the use of:

- A conservative approach, taking into account:
    - Uncertainties in physical parameters, optimum moderation conditions potential non-homogenous distributions of moderators;
    - Potential operating abnormalities and their combinations, if they cannot be proven to be independent;
    - Facility states, e.g. resulting from external hazards.
- Appropriate computer codes that are verified & validated (i.e. compared with benchmarks to determine the effect of code uncertainties on calculated K_{eff}) within their applicable range and using appropriate cross section libraries.

4.15. For a process where fissile materials are handled in a discontinuous manner (including batch processing or waste packaging), the process and its installations should meet the safety requirements above for criticality management at all times. The R&D facility design, including any accountancy support systems should provide the necessary accountancy equipment and have clear and easily identifiable boundaries.

Mitigation of criticality event

4.16. Information regarding the need to install criticality accident alarm systems can be found in Ref. [16]. Where such systems are installed, the R&D facility should be designed to include safe evacuation routes to personnel regrouping areas. These routes should be clearly marked and personnel should be trained in evacuation procedures.

4.17. Consideration should be given to the provision of remote mitigation devices, e.g., to empty a vessel containing the solution initiating the event or to absorb the neutron flux.

Protection of people and the environment from radiation

4.18. Protection against radiation exposure relies on an appropriate combination~~s~~ of controls on source magnitude, time of exposure and the shielding or distance between the subject and the source. These should be used separately, or in combination.

4.19. Consideration should be given to maintenance, calibration, periodic testing and inspection, with the aim of minimizing dose to workers. There are specific requirement for the design of safety systems and components to reduce exposure during maintenance in paragraph 6.19 of Ref. [1]. Examples of such provisions include connection junctions at containment boundaries and easily cleanable surfaces.

4.20. The potential for accumulation of radioactive material in:

– Process equipment;

– Fume-hoods, glove-boxes and/or hot cells;

– Secondary systems (e.g. ventilation ductwork);

should be minimized and, where appropriate, provisions made for its removal or reduction.

4.21. Consideration should be given to the remote operation of services and experimental equipment where possible.

4.22. Paragraph 6.41 in Ref. [1] states "The designer shall classify areas by taking into consideration the magnitude of the expected normal exposures, the likelihood and magnitude of potential exposures, and the nature and extent of the required protection and safety procedures. Access to areas where radiation levels may cause exposures that give rise to high doses for workers shall be restricted and the level of control applied shall be commensurate with the hazards".

4.23. Background radiation levels in R&D facilities generally rely on analytical data from samples. If possible, an instrumental method of analysis that does not require sampling should be chosen. Where samples need to be taken, their number and sizes should be kept to a minimum. The requirements for housekeeping, waste management and dose control also apply to analytical facilities.

4.24. "Radiation levels shall be monitored so that any abnormal conditions would be detected and workers may be evacuated. Areas of potential exposure for workers shall be appropriately identified and marked", see paragraph 6.42 in Ref. [1]. Radiation protection monitoring should be provided consistent with national regulations and international practices including:

- Fixed gamma/neutron area monitors and stationary samplers for activity in air, (beta/gamma, alpha) for access and/or evacuation purposes.
- Mobile gamma/neutron area monitors and mobile sampler for activity in air, (beta/gamma, alpha) for evacuation purposes during maintenance.

- Personal monitoring consistent with the radiation type(s) present in the R&D facility,

4.25. All estimates of source terms should include allowance for the ingrowth of radioactive daughter products (such as ^{241}Am) over the lifetime of the facility.

Confinement of radioactive materials

4.26. In accordance with paragraphs 6.37-6.38, containment should be the primary method for protection against the escape of contamination. Containment should be provided (as required) by complementary containment systems (static, dynamic).

- The static containment system should consist of at least two independent static barriers between radioactive material and the environment;
- The dynamic containment system should be used to create airflow towards areas that are more contaminated.

4.27. Dynamic containment cannot be provided for systems such as closed items and waste containers or some maintenance operations in open areas. Task assessments should be performed to ensure the safety of the personnel and the public against unexpected leakage or release. Closed or sealed items should be treated as contaminated based upon their history and appropriate precautions specified in their handling, opening or unsealing. Consideration should be given in design to the provision of equipment capable of determining the radioactivity inside such items. Wastes and other potentially contaminated containers should be appropriately characterized and labelled at (and with) the time and place of origin to avoid unexpected contamination release.

4.28. In R&D facilities, the control of decay heat should normally rely on limiting the inventory of radioactive material in locations such as in hot cells and glove boxes. Where there is a potential for overheating, engineered cooling systems should be provided, e.g. for interim storage of waste.

4.29. The first static barrier should include hoods, hot cells, glove boxes, fuel cladding or material containers. The second static barrier should consist of rooms around the hoods, hot cells, and glove boxes and/or the building walls. The design of static containment ~~confinement~~ should take into account typical openings between different confinement zones (e.g. doors, penetrations).

4.30. The dynamic containment should create a gradient of reducing absolute pressures (i.e., creating negative pressure) between the environment outside the building and the radioactive or hazardous material inside the hood, hot cell, or glove box. Backflow of gaseous or particulate contamination should be prevented.

4.31. Specific attention should be paid (particularly at the design phase) to maintaining containment during operations that involve the transfer of radioactive materials outside of the static containment. Where appropriate, equipment should be designed to withstand radiation damage and contamination by alpha emitters.

4.32. The design of confinement areas should include contamination monitoring devices covering all locations inside the R&D facility and outside the primary containment boundary provided by vessels, glove-boxes, hoods, pipework (and closures such as valves or blanking plates), ventilation ducting and the primary filters.

4.33. The design of the R&D facility should facilitate operations such as maintenance and decontamination. Consequently, the design should employ compartmentalization as one of the means available for dose optimization.

4.34. Airborne contamination (from liquids or dispersible solids) should be prevented or minimized where possible. The ventilation system should include filters, in series, to protect the workers and the public/environment by filtering the air during normal operation and to assure the continuity of the static barriers ~~in case of loss of ventilation~~. Filters should also be used when airflow passes through containment barriers e.g. for cooling and when air exits the facility.

4.35. Where radioactive gases or particulates are generated, paragraph 6.38 in Ref. [1] states that "…the performance of air purification systems, shall be commensurate with the degree of the potential hazards…" The materials of the system should be resistant to any corrosive gases present. The ventilation system should include a final monitoring stage. The ventilation system should be designed according to accepted standards, e.g. those of the International Organization for Standardization (ISO) and the American Society of Mechanical Engineers (ASME).

4.36. The lifetime of filters and potential for failure of a fully loaded filter should be considered in the safety analysis. Additional standby fans and filters should be provided as specified in the safety analysis. These should be capable of maintaining ventilation during filter changing. ~~These f~~Fans should be supplied by emergency power such that, in the case of loss of electrical power, the standby ventilation system begins operation within an acceptable delay. The safety analysis should indicate what period of delay may exist between the loss of the primary ventilation system and initiation of the standby ventilation, and this may define an OLC. Local monitoring and alarm systems should be installed to alert operators to system malfunctions resulting in high or low flows or differential pressures.

4.37. To reduce risks related to transfer operations involving radioactive material, the number of transfer operations should be minimized in the design of the facility. To reduce the complexity of transfer operations, R&D facilities should be designed to accommodate standardized means of transportation of radioactive material, on-site and off-site.

Protection of the workers from contamination and internal exposure

4.38. The first static barrier normally protects the workers. Its design requirements should be specified to assure and to control the efficiency of this barrier. Its design specifications should include: welding specifications; choice of materials; leak-tightness (for hoods, glove boxes, and hot cells leak rate vs. flow rate); ability to withstand seismic loads; design of equipment (inside equipment for hoods, hot cells, and glove-boxes); specification of seals for electrical and mechanical penetrations; and the ability to perform maintenance.

4.39. The dynamic containment ~~confinement~~ system should also be designed to minimize the occupational exposure to hazardous material that may become airborne in the facility and inhaled by the workers.

4.40. At the design stage, provisions should be made for the installation of equipment to monitor airborne contamination. These should provide an immediate alarm on detection of airborne contamination with a low threshold. Monitoring points should be chosen which would best represent the exposure of facility operators. See paragraph. 6.39 in Ref. [1] and the section covering external radiation exposure in this document.

4.41. Where radioactive powders or liquids are handled in the R&D facility or experiment, the installation of collection equipment should be considered to prevent the accidental spreading of material.

4.42. For normal operation, the need for use of protective respiratory equipment should be minimized through careful design of static, dynamic containment systems.

~~*Environmental protection*~~

~~4.43. Paragraph V.7 in Ref. [1] requires that a graded approach is taken to the provision of barriers for the containment of radioactive materials, dependent on the magnitude of the radiological hazard. Uncontrolled dispersion of radioactive substances to the environment from accidents can occur if a containment barrier is impaired. The barriers that may provide environmental protection include rooms and the wider building structure. In addition, the ventilation components that scrubs or filter gases before discharge through a stack should reduce normal environmental discharges of radioactive materials to acceptable levels.~~

~~4.44. The design of a R&D facility should also provide measures for continuous monitoring and control of the stack exhaust and for the monitoring of the environment around the facility. Facility requirements that are also relevant to R&D facilities of specific types are also defined in paragraphs I.9, II.14, III.9, IV.7 and IV.8 of Ref. [1],~~

Protection against external radiation exposure

4.4~~3~~5. The design of any radiation shielding should ensure compliance with occupational exposure targets (see Section 6 and V.1 of Ref. [1]) based on assumptions regarding the movement of material, occupancy time and sources to be handled. Provision of shielding should also be considered in material storage areas. External radiation exposure can be controlled through a combination of source removal, reduction, shielding and administrative controls. The requirement for dose minimization should also take the maintenance personnel into account.

4.4~~4~~6. In high radiation areas (such as those handling commercial spent fuel), the design of shielding should consider both source term and location. In medium or low activity areas (such as a teaching laboratory), a combination of source term, shielding and administrative controls should be utilized for protection of workers for both whole body and extremity doses. A general design guide is to shield as close as practical to the source.

4.4~~5~~7. Source terms should take into account the potential for radiation from deposited radionuclides inside pipes, equipment, hoods, glove boxes and -hot cells. The interior surfaces of equipment such as glove-boxes can be covered or coated to prevent accumulation of deposits from processed materials or their daughter products.

-*Environmental protection*

4.46. Paragraph V.7 in Ref. [1] requires that a graded approach is taken to the provision of barriers for the containment of radioactive materials, dependent on the magnitude of the radiological hazard. Uncontrolled dispersion of radioactive substances to the environment from accidents can occur if a containment barrier is impaired. The barriers that may provide environmental protection include rooms and the wider building structure. In addition, the ventilation components that scrub or filter gases before discharge through a stack should reduce normal environmental discharges of radioactive materials to acceptable levels.

4.47. The design of a R&D facility should also provide measures for continuous monitoring and control of the stack exhaust and for the monitoring of the environment around the facility. Facility requirements that are also relevant to R&D facilities of specific types are also defined in paragraphs I.9, II.14, III.9, IV.7 and IV.8 of Ref. [1].

POSTULATED INITIATING EVENTS

4.48. Annex 1 of Ref. [1] lists a number of PIEs that could be applicable to a R&D facility and further guidance on some of these is provided below.

Internal initiating events

Fire ~~and~~ Hazard Analysis~~explosion~~

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4.49. R&D facilities should be designed to control fire hazards in order to protect R&D facility personnel, the public and the environment. Fire can lead to dispersion of radioactive and/or toxic materials by destroying the containment barriers (static and/or dynamic) or cause a criticality accident by modifying the safe conditions (geometry, moderation control system). Fire hazards are often associated with the presence of flammable or combustible materials such as chemical reagents, electrical cabling and shielding particularly associated with hoods, glove boxes, and hot cells. A fire hazard analysis should be performed in order to identify appropriate measures which should be taken to ensure that the fire is prevented; and if it occurs, it is mitigated with minimization of resulting contamination spread.

4.50. The fire hazard analysis should identify any areas that require special consideration in accordance with the graded approach. Locations subject to fire hazard analysis should include:

a) Areas where fissile material are processed and stored;

b) Those facilities processing nuclear and other materials as powder or producing powder;

c) Workshops, laboratories, and storage areas containing flammable and/or combustible liquids, solvents and resins and reactive chemicals, or involving mechanical treatment of pyrophoric metals or alloys (e.g. cuttings, shavings);

d) Areas with high combustible loadings, e.g. waste storage areas;

e) Waste treatment areas, especially if incineration is used;

f) Rooms housing safety-related equipment, i.e. items such as air filtering systems and electrical switch rooms, whose degradation might have radiological or criticality consequences;

g) Process control rooms and emergency control rooms;

h) Evacuation routes.

4.51. The fire hazard analysis should identify potential causes of fires i.e. any fuels or oxidizing agents present. The potential consequences of fires should be assessed with, where appropriate, an estimation of the frequency or probability of the occurrence. The fire hazard analysis should also assess the inventory of radioactive materials, ignition sources and combustible materials nearby, and determine the adequacy of protective features.

4.52. Modelling may be used to support the fire analysis. Requirement 18 in Ref. [11] states "Any calculational methods and computer codes used in the safety analysis shall undergo verification and validation". The results of the method can provide valuable information on which to base decisions or to identify weaknesses that might otherwise have gone undetected. Even if the frequency of a fire occurring may be low, it may have significant consequences with regard to nuclear safety and, as such, certain protective measures should be undertaken such as delineating fire compartment areas.

~~Fire prevention, detection and mitigation~~

4.53. Analysis of fire hazards should also include a review of the provisions made for preventing, detecting and fighting fires.

Fire prevention, detection and mitigation

4.54. Prevention is the most important aspect of fire protection. R&D facilities should be designed to limit fire risks by taking measures to ensure that fires do not break out. Should a fire break out despite the precautions taken, measures should be in place to minimize its consequences.

4.55. For limiting risks and consequences of a fire, a number of general and specific measures should be taken, including the following:

1. The amount of flammable and combustible material in individual rooms, hoods, glove boxes, and hot cells should be minimized to the extent practicable.
2. The storage of non-radioactive hazardous material should be separated from the process areas;
3. In glove boxes and hot cells, where there is a high likelihood of fire (e.g. cutting of metal clad fuel elements), inert atmospheres with oxygen monitoring alarms should be used to minimize the risk of spreading a fire;
4. Materials should be chosen according to functional criteria and fire-resistance ratings;
5. Compartmentalization of buildings and ventilation ducts as far as possible in order to prevent spreading of fires. Buildings should be divided into fire areas. If a fire starts

within a given ‘fire’ area, its capability to spread beyond the area boundary should be eliminated or curtailed. The higher the fire risk, the greater the number of such fire areas a building should have. Utility lines penetrating fire compartment boundaries (e.g. electricity, gases or process lines) should be designed to ensure that fire does not spread.

6. Ignition sources such as open flames or electrical sparks should be limited to the extent practicable (e.g., use of electrical earthing or grounding devices).

7. Fire extinguishing devices, automatically or manually operated, with the use of an appropriate extinguishing material should be installed in areas where a fire is possible and where the consequences of a fire could lead to the dispersion of contamination outside the first static barrier. Paragraph V.6 of Ref. [1] states that “the choice of fire extinguishing media (e.g. water, inert gas or powder) and the safety of their use shall be addressed.” The installation of automatic devices with water sprays should be carefully assessed for areas where fissile materials may be present, with account taken of the risk of criticality. Extinguishing gas may be preferable for hoods, glove boxes and hot cells.

8. Where extinguishing devices are installed inside hoods, glove-boxes or cells, the possible spread of contamination due to reversing dynamic containment or uncontrolled water flows should be assessed.

9. Where inert gas is used as a fire suppressant, consideration should be given to the integrity of the gas supply by providing suitable backup or diversity.

10. Where “active” firefighting systems are used in radioactive environments special consideration should be given during design to the requirements for their commissioning and subsequent examination, inspection, maintenance and testing.

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

12. Dynamic containment systems should continue operation (including filtration) during a fire to remove smoke, heat, and particulates and to compensate for potential over-pressure. This operation is maintained so long as temperatures at filters do not exceed the threshold at which containment would be lost, as determined by the safety analysis. Suitable monitoring equipment should be installed and the remote control of ventilation should be considered. Smoke particulates can lead to the rapid loading (blinding) of filters and consideration should be given to the need to reduce flows as above and other design means to reduce the challenge to filters in the event of a fire.

Explosions

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4.56. Paragraph 6.54 of Ref. [1] states "Chemical, toxic, flammable or explosive substances can affect nuclear safety. To prevent this from occurring, the following should be considered in the design of the R&D facility:

(a) Design requirements and guidance contained in international and national standards and guidance on chemical safety;
(b) The chemical compatibility of materials to be handled or processed in the R&D facility;
(c) The safe storage of hazardous process materials;
(d) The initial process configuration and/or credible changes to it that may lead to the release of chemical compounds or toxic materials (e.g. hydrogen, solvents), fires or explosions;
(e) The detection and alarm capability for chemical or toxic releases;
(f) The minimization of inventories."

4.57. Examples of such materials in R&D facilities include: extraction solvents, hydrogen, hydrogen peroxide, nitric acid, degradation products and pyrophoric materials (e.g. metallic fines). Additionally, consideration should be given to the following:

(a) Fault scenarios such as leakage leading to the contact of incompatible materials;
(b) Use of blow-out panels to mitigate the effects of explosions;
(c) Identification of parameters (e.g. concentration, temperature) to prevent situations leading to explosion;
(d) Use of inert atmospheres;
(e) Controlling levels of humidity.

4.58. In addition, effective air-locks should be provided between the flammable atmosphere and other areas, see paragraph 6.55 in Ref. [1].

Flooding

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4.59. Flooding ~~by moderating fluids~~ in R&D facilities can lead to the dispersion of radioactive materials and changes in the moderation of any fissile material present~~conditions~~. References to water in the following paragraphs should be read as any moderating fluid.

4.60. Where fissile material is present, criticality assessment should be undertaken to consider the risk of flooding. Equipment should not have water supply connections during normal conditions unless criticality assessments take into account the presence or leakage of water e.g. use of full disconnection or limited water volumes should be considered.

4.61. In R&D facilities where there are vessels and/or pipes with moderating fluids such as water, or where fissile materials are stored, the criticality safety analyses should consider the presence of the maximum amount of fluid within the considered location, as well as in connected locations (e.g. via transfer tunnels).

4.62. The walls (and floors if needed) of locations with potential for flooding should withstand the water load and other safety related equipment and should not be affected by flooding (e.g. installation of sumps or floor drain system to remove water).

Leaks and spills

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4.63. Leaks from equipment and components such as pumps, valves and pipes can lead to dispersion of radioactive and fissile materials, toxic chemicals and the creation of unnecessary waste. Leaks of hydrogenous fluids (water, oil, etc.) can change the neutron moderation in fissile material, and reduce criticality safety. Leaks of flammable gases (H_2, natural gas, propane) or liquids can lead to explosions and/or fire. Leak detection systems should be used in such cases.

4.64. Vessels containing significant quantities of nuclear materials in liquid form should be equipped with alarms to prevent overfilling and with drip trays of appropriate capacity (e.g. volume of the capacity greater than (or equal) than the volume of the vessel) and configuration to ensure criticality safety.

4.65. In-leakage of coolants should also be considered where there may be physical or chemical incompatibility with the materials or equipment present, including precipitation of fissile materials.

4.66. Spillage may occur from cans, drums and waste packages during transit within the R&D facilities and/or in stores. Appropriate mechanical protection and containment should be provided during material movements.

Loss of support systems

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4.67. To fulfil the requirement established in paragraph 6.28 of Ref. [1], electric power supplies to R&D facility facilities should be robust. In the event of loss of normal power ~~(see Section 2)~~ and depending on the status of the R&D facility, an emergency power supply should be provided to certain structures, systems and components important to R&D facility safety, including the following:

(a) Ventilation fans and monitoring systems for the confinement of radioactive material;

(b) Heat removal systems;

(c) Emergency control systems;

(d) Fire detection and alarm systems;

(e) Monitoring systems for radiation protection;

(f) Alarm systems for criticality accidents.

4.68. Electrical power supplies to R&D facilities should meet accepted industry codes and standards and the provision of diverse or remote electrical supplies should be considered.

4.69. The loss of general supplies such as gas for actuators of the 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 R&D 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 secondary 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

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4.70. Consideration should be given to the loss and excess of process media or additives, which may have safety consequences. Examples include:

a) Process gas supplies, e.g. hydrogen, nitrogen, helium or argon;

b) Overpressure in glove boxes may cause an increase of airborne contamination and/or concentration of hazardous materials;

c) Release of large amounts of nitrogen, helium or argon in working areas may result in reduction of oxygen concentration in breathing air.

Loss of ~~decay~~ heat removal

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4.71. Consideration should be given to ~~materials~~ processes that ~~may~~ generate heat; indeed large pilot plants ~~production units~~ have potentially significant heat loads. A pilot plant can often be shut-down easily if there is a loss of a service such as power. The provision of an alternative means of cooling should be considered for pilot plants with large heat sources.

4.72. Related functions of the v~~V~~entilation system~~s~~ should be considered in the safety analysis, such as the maintenance of cooling to prevent operator heat stress or the control of humidity in materials handling. These can have an indirect effect on the safety of operations.~~designed to provide cooling for maintaining temperatures at acceptable levels.~~

Load drops

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4.73. Ref. [11] requires an assessment that systems and components are sufficiently robust, and includes lifting equipment that should be assessed. The frequency of potentially damaging, dropped loads should be avoided by qualification of cranes, avoidance of clashes, provision of appropriate slings and grabs, handling at a low elevation and training/qualification of relevant operators.

4.74. Mechanical or human failures during the handling of radioactive material may result in degradation of criticality control, confinement or shielding. Dropped loads are ~~also listed~~included as postulated ~~possible~~ initiating events in Annex I of Ref. [1] and their possible consequences should be minimized. Mechanical or human failures during the handling of non-radioactive loads may result in degradation of R&D facilities safety functions. Safe travel paths should be provided and floors designed to withstand a dropped load. Containers should be designed and qualified to maintain containment and protect their contents wherever appropriate.

Mechanical failure

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4.75. Measures for the safety of commercially supplied equipment (e.g. mechanical guards) installed in nuclear facilities should be retained. If there is a need for adaption to their nuclear environment, this should be justified.

4.76. Mechanical failures could result in damage (e.g. crushing, bending, breakage), which may result in degradation of criticality control, confinement or shielding. For complex or critical systems (e.g. rod handling systems designed to avoid the risk of breaking the rod), a systematic failure analysis method should be applied.

Radiolysis hazard

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4.77. A number of chemical processes can be affected by radiolysis potentially generating secondary hazards, such as uranium hydride from the radiolysis of water. Irradiation of organic or hydrated substances by radioactive materials can lead to gas generation, especially hydrogen. Radiolysis risks 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;

And, where necessary, the design should prevent or mitigate radiolysis hazards.

External initiating events

4.78. As stated in Paragraph 6.21 of Ref. [1], "SSCs important to safety shall be designed to withstand the effects of extreme loadings and environmental conditions (e.g. extremes of temperature, humidity, pressure, radiation levels) arising in operational states and in relevant design basis accident (or equivalent) conditions". The R&D facility design should take account of operational experience regarding the effects of extreme loadings due to these events individually and in combination, e.g. earthquake and tsunami.

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Earthquake

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4.79. R&D facilities should be designed for the design basis earthquake so as to ensure that an earthquake does not induce a loss of containment or criticality accident (e.g. seismically induced failures of criticality safety parameters, such as geometry and moderation) with significant consequences to the R&D facility/site personnel or members of the public.

4.80. To determine the design basis earthquake, the main characteristics of the disturbance (e.g. intensity, magnitude, and focal distance), based on historic data and the distinctive geological features of the 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 paleoseismic data to facilitate determination of the most intense earthquake for the R&D facility location. These

different approaches can be combined since the regulatory body generally takes both into account in the approval of the design.

4.81. 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 R&D 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 R&D facility.

4.82. An adequately conservative spectrum should be used for calculating the structural response to guarantee the stability of buildings and to assure the integrity of the ultimate means of confinement in case of 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 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 radioactive material to the environment would occur and the risk of a criticality accident would be very low.

External fire and explosions

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4.83. Hazards from external fires and explosions could arise from various sources in the vicinity of R&D facilities, such as petrochemical installations, forests, pipelines and road, rail or sea routes used for transport of flammable material such as gas or oil.

4.84. To demonstrate that the risks associated with such external hazards are within acceptable levels, the operating organization should first identify all potential sources of hazards and then estimate the associated event sequences affecting the R&D facility. The radiological and associated chemical consequences of any damage should be evaluated and it should be verified that they are within acceptance criteria. The operating organization should carry out a survey of potentially hazardous installations and transport operations for hazardous material in the vicinity of the R&D facility. In the case of explosions, risks should be assessed for compliance with overpressure criteria.

4.85. To evaluate the possible effects of flammable liquids, falling objects (such as chimneys) and missiles resulting from explosions, their possible distance from the R&D facility and hence their potential for causing physical damage should be assessed. Toxic hazards should be assessed to verify that specific gas concentrations to meet the acceptance criteria and do not affect the controllability of the R&D facility.

Extreme weather conditions

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4.86. Typically, the extreme weather conditions used to design and/or evaluate the response of a R&D facility are wind loading, tornadoes, rainfall, snowfall, ice storm, extreme temperatures, tsunami and flooding.

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

4.88. The design provisions will vary according to the type of hazard and its effects on the safety of the R&D facility. For example, extreme wind loading is associated with rapid structural loading and thus design provisions for this event should be the same as those for other potentially rapid loading events such as earthquakes. However, the effects of extreme precipitation or extreme temperatures would take time to develop and hence there is time for operational actions to be taken to limit the consequences of such events.

4.89. A R&D facility should be protected against extreme weather conditions by means of appropriate design provisions. These should generally include:

- The ability of structures important to safety to withstand extreme weather loads;
- Prevention of flooding of the R&D facility;
- The safe shutdown of experiments in the R&D facility in accordance with the operational limits and conditions.

Tornadoes

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4.90. Measures for protection against tornadoes will depend on the meteorological conditions for the area where the R&D facility is located. The design of buildings and ventilation systems should comply with specific regulations relating to hazards from tornadoes.

4.91. High winds are capable of lifting and propelling objects such as automobiles or telephone poles. The possibility of impacts by missiles such as these should be considered in the design stage for the R&D facility; by their initial impacts and by possible secondary fragments arising from collisions with, and spallation from, concrete walls or by other momentum transfer mechanisms.

Extreme temperatures

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4.92. The possible 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 ventilation and cooling systems.

4.93. If safety limits for humidity and/or the temperature are specified in a building or a compartment, the air conditioning system should also be designed to perform efficiently under extreme hot or wet weather conditions.

4.94. Human access may be essential for safety and under such circumstances the combined effects of low temperatures and ventilation on operators should be considered.

Snow and Ice

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4.95. The occurrence of snowfall and its effects should be taken into account in the design of the R&D facility and its safety analysis. Snow is generally taken into account as an additional load on the roofs of buildings. Snow can also block the inlets of ventilation systems and outlets of drains. The neutron reflecting effect or the interspersed moderation effect of the snow should be considered if relevant. The effect of ice on wall loadings should also be considered where this is a possibility.

Flooding

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4.96. Flooding should be taken into account in the design of a R&D facility. Two approaches to cope with flooding hazards are:

- In some States the highest flood levels historically recorded are taken into account and the nuclear facilities are sited at specific locations above the flood level, or at 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 of 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.

Accidental aircraft crash hazards

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4.97. The likelihood and possible consequences of impacts onto the R&D facility should be calculated by assessing the number of aircraft that come close to the R&D 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 item (h) in paragraph 5.5 of Ref. [1].

4.98. For evaluating the consequences of impacts or the adequacy of the design to resist aircraft impacts, only credible crash scenarios should be considered, which may require the knowledge of such factors as the possible angle of impact, 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

4.99. Instrumentation should be provided to monitor facility parameters and systems over their respective ranges for: (1) normal operation; (2) anticipated operational occurrences; (3) design basis accidents; and (4) ~~extended~~ design extension conditions, to ensure that adequate information can be obtained on the status of the facility and proper actions can be undertaken in accordance with operating procedures or in support of automatic systems.

4.100. Instrumentation should be provided for measuring all the main variables that may affect the processes and for monitoring the general safety conditions of the R&D facility (such as radiation doses due to internal and external exposure, releases of effluents and ventilation conditions) and for obtaining any information on the facility necessary for its reliable and safe operation. Provision should be made for automatic measurement and recording of parameters that are important to safety, allowing remote viewing if necessary.

Control systems

4.101. Passive and active engineering controls are more reliable than administrative controls, and should be preferred for control in normal operational states and in accident conditions. When used, automatic systems should be designed to maintain process parameters of the R&D facility or experimental apparatus within operational limits and conditions or to bring the process to its safe stable state, which is generally the shutdown state.

4.102. Appropriate information should be available to the R&D facility operators for monitoring the effects of automatic actions. The layout of the instrumentation and the mode of presentation of information should provide the operating personnel with an adequate overall picture of the status and performance of the R&D 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.

Control systems should be provided to ensure compliance with regulatory limits e.g. on discharges.

Control rooms

4.103. Control rooms should be provided to centralize the main (e.g. surveillance and overview monitoring) data displays, controls and alarms for general conditions at the R&D facility. For specific experiments, it may be useful to have local control areas where relevant information can be gathered together and monitored. These controls should be located in parts of the R&D facility where risks to operators and occupational exposure can be minimized. Special attention should be given to identifying events, both internal and external to the control rooms, which 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 the control room.

Safety related instrumentation and control systems for normal operations

4.104. During normal operation, the safety related I&C systems should be separated from the experimental instrumentation and should include where appropriate:

(a) Criticality control

Where there is a risk of criticality and depending on the method of criticality control, monitoring and control parameters should include mass, density, moisture content, isotopic content, fissile content, reflection and moderation by additives and the location of materials.

(b) Monitor and control of equipment and supplies

For the safety of R&D equipment, it may be necessary to monitor and control a number of safety parameters; e.g. temperature, gas flow, compositions/flow rates, pressure. A key safety control measure is the means of confirming correct concentrations of reactive media in supplies to hot equipment.

(c) Glove box control

Paragraph 9.60 of Ref. [1] contains requirements for fire safety controls in a R&D facility~~, see paragraph 9.60~~. For glove boxes under inert atmosphere, the gas concentration should be monitored and controlled for safety and possibly product quality purposes. Temperatures should also be monitored.

(d) Monitor of external occupational radiation exposure

Sensitive dosimeters with real-time display and/or alarm should be used to monitor and control occupational radiation exposures, especially in areas with inspection

equipment like X-rays and radiation sources. Installed equipment should be used where possible to control gamma and neutron whole body exposures.

(e) Monitor of internal occupational radiation exposure

In R&D facilities with the potential for airborne contamination, the following provisions should be considered in order to ensure early detection of radioactive particulate:

- Installation of continuous air monitors to detect contamination as close as possible of the working areas;

- Installation of detectors for alpha surface contamination close to working areas and self-monitoring at the exits of rooms.

(f) Monitor and control of liquid discharges

The liquid discharges of R&D facilities should be appropriately monitored and controlled. This can be done ~~are usually monitored and controlled~~ by sampling and analysis; and measuring the volume of discharge.

(g) Control of gaseous effluents:

Generic requirements for control of atmospheres and pressures are given in paragraphs 6.37 to 6.39 of Ref. [1], which states that "the nature and number of the barriers and their performance, as well as the performance of the air purification systems, shall be commensurate with the degree of the potential hazards with special attention paid to the potential dispersion of alpha emitters means of monitoring and appropriate alarm systems for atmospheric contamination shall be installed". These may include real time measurements such as differential pressure to confirm that the filtration systems are working effectively, and continuous monitoring of discharges.

Monitoring and control is needed to ensure that the airflows in all areas of the R&D facilities are flowing in the correct directions i.e., from less to more active areas. In work areas, the temperature, humidity and pollutants should be controlled to ensure worker comfort and hygiene. In some cases local ventilation should be used e.g., in rooms housing back up batteries.

Safety related instrumentation and control systems for operational occurrences

4.105. In addition to the listing above, safety related I&C systems for use in anticipated operational occurrences should include the following provisions:

- Fire detection and extinguishing systems and building evacuation systems;
- Radiation, airborne activity detection and alarm systems;
- Gas detectors and alarm systems, where leakage of gases such as hydrogen could produce an explosive atmosphere.
- Diluting gas flows for vessels where hydrogen accumulation is an issue

Safety related instrumentation and control systems for design basis accidents

4.106. In addition to the previous listings, the safety related I&C systems for design basis accident conditions should include:

- Where there is potential for criticality; criticality detection systems, alarm systems and building evacuation systems;
- Detection and alarm systems for abnormal releases of effluents.

HUMAN FACTOR CONSIDERATIONS

4.107. The requirements relating to consideration of human factors are established in paragraphs 6.15 and 6.16 of Ref. [1].

4.108. Human factors in operation, inspection, periodic testing, and maintenance should be considered at the design stage. Human factors to be considered include:

– Possible effects on safety of ~~unauthorized~~ human ~~actions~~ errors (with account taken of ease of intervention by the operator and tolerance of human error);

– The potential for occupational exposure.

4.109. The design of a R&D facility ~~(both at plant and experimental equipment level)~~ to take into account 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 requirements:

- 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, adequate space around, equipment and suitable finishes to surfaces for ease of cleaning;
- Commercial equipment that has been adapted for nuclear use (e.g. in a glove-box) should maintain original safety functions;

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 job organization, particularly during maintenance work, when automated control systems may be disabled;

e) Minimization of the need to use personal radiation protection (such as tabards).

4.110. In the design and operation of fume-hoods, glove boxes and (where appropriate) hot cells, the following specific considerations should be taken into account:

a) The design of equipment to avoid conventional laboratory hazards that may result in worker injuries, including internal radiation exposure through cuts in the gloves and/or wounds on the operator's skin and/or ~~possible~~ the possible failure of confinement;

b) Ease of physical access, work space and visibility in and around these installations;

c) The potential for loss of containment, including glove damage;

d) Training of operators on procedures to be followed in normal and abnormal situations.

SAFETY ANALYSIS

4.111. The safety analysis for a R&D facility should be performed in two major steps:

- The assessment of occupational exposure and public exposure for operational states of the R&D 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.

4.112. The results of these two steps should be reviewed for identification of the possible need for additional operational limits and conditions.

Safety analysis during operational states

Occupational radiation exposure and exposure of the public

4.113. At the design stage of a new R&D facility, an assessment should be made of the external radiation exposure to the workers in all workplaces, on the basis of conservative assumptions for factors including the following:

- Licensed inventories of radioactive materials in each part of the R&D facility;

- Calculated radiation levels should use the enveloping R&D facility source term;
- The maximum cumulative annual working time at each workplace for both normal operation and anticipated maintenance work;
- Calculations of the efficiency of shielding during normal operation based on conservative assumptions regarding its performance.

4.114. The design of equipment, layout of equipment in the R&D facility, shielding, etc., should be based on adequate interaction and feedback between process and mechanical designs, safety assessment, operational experience from similar and/or upstream facilities.

4.115. Cleaning operations (e.g. dust elimination from hoods, glove boxes and hot cells) should be given special consideration in the design.

4.116. The calculated exposure should be compared with actual exposure during subsequent R&D facility operation. If considered necessary, maximum permissible annual working times for specific workplaces may be included in the operational limits and conditions.

4.117. Calculations of estimated public doses should be made on the basis of maximum estimated releases of radioactive material and maximum deposition on the ground. Conservative models and parameters should be used to calculate the estimated doses to the public.

Release of non-radioactive hazardous materials

4.118. This Safety Guide deals only with those material hazards that can give rise to radiological hazards (see paragraph 2.2 of Ref. [1]). R&D facility specific, realistic and robust (i.e. conservative) estimations ~~should be made~~ of material toxicity to R&D facility personnel should be made. Releases of hazardous chemicals or biological materials affecting the public or the environment should be evaluated using conservative models and parameters, in accordance with the standards used in relevant industries.

Safety analysis for accident conditions

Methods and assumptions for safety analysis for accident conditions

4.119. For R&D facilities, the consequences of accidents are not necessarily limited to individuals located on site and in close proximity to the location of the accident. The consequences depend on various factors such as the release rate and quantity, distance between receptor and source of release, material transport to the receptor and exposure time.

4.120. The acceptance criteria associated with the accident analysis should be defined in accordance with paragraph 6.5 of Ref. [1] and with respect to any national regulations and

emergency criteria. To estimate the on-site and off-site consequences of an accident, the wide range of physical processes that could lead to a release of radioactive material to the environment should be modelled in the accident analysis and the enveloping cases encompassing the worst consequences should be determined (see paragraphs 2.6, 2.10-2.12 and 4.24 of Ref. [1]).

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

1) An approach using the bounding case (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 and some non-safety features beyond their originally intended range of functions to reduce the consequences of accidents (the best estimate approach).

2) An approach using the bounding case (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.

   The second case is generally used when the first one cannot be applied to justify the safety of an accident condition.

Assessment of possible radiological and other consequences

4.122. Safety assessments should address consequences associated with possible accidents. The main steps in the development and analysis of an accident scenario should include:

a) Analysis of the actual site conditions and conditions expected in the future;

b) Identification of workers and members of the public (representative persons or the ~~i.e.~~ 'critical group(s)' ~~of people~~ living in the vicinity of the R&D facility) who could possibly be affected by accidents, allowing for demographic variations;

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

d) Identification and analysis of R&D facility conditions, 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 of emission and the exposure time, in accordance with reasonable scenarios;

e) Specification of the structures, systems and components important to safety that are credited to reduce the likelihood of 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) 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.

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

4.124. Environmental transport of material should be calculated with qualified models/codes or 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.

Emergency preparedness

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

4.125a. The operating organization of a R&D facility should develop an emergency plan that takes into account the potential hazards at the facility using a graded approach~~(plant and experimental)~~, see paragraph 9.62 of Ref. [1]. R&D facility management should be informed of the hazards and shutdown arrangements for all experimental equipment. The emergency plan and the necessary equipment and provisions should be determined on the basis of selected scenarios for design extension [2] conditions ~~accidents~~ (or the equivalent). The

[2] Design extension conditions are ~~used to identify addition accident scenarios to be addressed in the design and to plan practicable provisions for the prevention of such accidents or their mitigation.~~ postulated accident conditions that are not considered for design basis accidents, but that are considered in the design process of the facility in accordance with best estimate methodology, and for which releases of radioactive material are kept within acceptable limits.

conditions under which an off-site emergency is required to be declared for a R&D facility should include criticality accidents, widespread fires, earthquakes and tsunamis, and their combinations where appropriate.

MANAGEMENT OF RADIOACTIVE WASTE

4.126. Requirements for managing radioactive wastes from R&D facilities are established in paragraphs 9.54 to 9.57 in Ref. [1]. Detailed guidance on predisposal management of radioactive waste is set out in other relevant Safety Guides, Ref. [14] and Ref. [21]. Paragraphs 6.31 and 9.34 in Ref. [1] require the generation of radioactive waste to be minimized, as far as practicable. ~~For both economic and environmental reasons, it is preferable to minimize the quantity of waste generated in R&D facilities~~ Ref. [4] and Ref.~~,~~ [5] provide further information on waste minimization. The following aspects should be considered in design:

a) Generation:

Paragraphs 6.31 and 9.54 in Ref. [1] define general requirements for waste control. At the generation step, wastes should be properly characterized in activity concentrations of relevant radionuclides and other hazards. A record keeping system should be implemented to ensure the proper identification, traceability and record keeping for the radioactive waste generated, and the avoidance of criticality conditions when fissile material becomes waste and during its subsequent processing. In fume-hoods, glove boxes and hot cells it is possible to reduce waste by reducing the materials ~~imported~~ introduced into these installations;

b) Removal:

Requirement 10 in Ref. [14] states that adequate containers should be provided for radioactive wastes removed from R&D facilities. It is good practice to minimize contamination spread by control at the point of origin. Guidance on the handling of fissile wastes is provided in Ref. [12] including mass control. Special requirements apply to fissile wastes, as stated in V.15 of Ref. [1], here the engineered features should provide containment and ~~geometric~~ control of geometry. Examples include; filters from hoods, glove boxes, hot cells and ventilation systems;

c) Collection:

Design features should reduce the risk of damage to waste containers which can potentially lead to loss of containment.

For the assessment and the management of radioactive waste, provision should be made for a central waste management area. In this central area, radionuclides in the waste should characterized and quantified ~~be monitored for activity~~ (including any ~~and~~ fissile content) and may be treated and placed in containers for interim storage;

d) ~~Interim s~~Storage:

The design of storage should take account of the radioactivity and other hazards of the waste, even if the storage is intended to be interim. Requirement 11 of Ref. [14] states that adequate storage conditions should be foreseen and maintained with regard to subsequent management of the waste. This includes the provision of suitable measures for inspection, monitoring and retrieval at the end of the anticipated storage period. Measures to guarantee the integrity of the facility and the containers considering low probability events should be taken even for interim storage.

~~d)~~e) Treatment:

Subsequent treatment outside R&D facilities can include conditioning, immobilization and decontamination before longer term storage. Subsequent treatment outside R&D facilities can include conditioning, volume reduction, encapsulation, immobilization, and decontamination before longer term storage. Techniques and procedures for treatment are preferred that provide waste forms and/or waste packages in line with the available waste acceptance requirements for storage and future disposal;

MANAGEMENT OF GASEOUS AND LIQUID RELEASES

4.127. The gaseous effluent discharge from a R&D facility should be reduced by filtration, which normally consists of a number of high efficiency particulate air (HEPA) filters in series.

4.128. Monitoring equipment such as the following should be installed and used:

(1) Differential pressure gauges to identify the requirement for filter changes; ~~and~~

(2) Activity or gas concentration measurement devices and discharge flow measuring devices with continuous sampling; and

(3) Injection and sampling equipment to test filter performance ~~should be installed and used~~.

4.129. Liquid effluents to be discharged to the environment should be treated to reduce the discharge of radioactive materials and hazardous chemicals to levels required by regulatory authorities. The use of filters, ion-exchange beds or other technology should be considered where appropriate.

OTHER DESIGN CONSIDERATIONS

Glove boxes and hot cells

4.130. Fume-hoods, glove boxes and hot cells should be designed to facilitate the use of dry cleaning methods (e.g. criticality safe filtered vacuum cleaners). Features such as easily cleaned surfaces, strippable coatings, rounded corners etc. should be considered.

Radiation protection shielding

4.131. The materials handled in a R&D facility can generate significant dose rates (neutron, beta/gamma) depending on the isotopic composition of the material processed. Therefore consideration should be given at the design stage for the need for neutron and gamma shielding.

4.132. Effective gamma and neutron shielding can be applied to hot cell and glove box faces but this can restrict visibility and increase occupancy. The choice and type of shielding should therefore be based on a prediction of the total occupational exposure during normal operation and maintenance.

Design for maintenance

4.133. Design for maintenance should include following aspects:

a) Consideration of whether maintenance can be carried out remotely if possible or carried out using personal protective equipment.

b) Criticality safety conditions such as limiting the introduction of liquids, solvents, plastics and other moderators;

c) Prevention of contamination spread when maintaining or replacing equipment (e.g. motors, drives can be located outside glove boxes);

d) The R&D facility design should aid good-housekeeping; Glove boxes and hot cells can become dusty unless cleaned regularly. Tools should be stored in designated locations. Waste accumulation should be avoided;

e) Removal of shielding material. Shielding on glove boxes is often provided for normal process operations and may need to be removed for maintenance access. Consideration should be given to the removing all radioactive sources before removing any shielding;

f) The facility design should minimize sharp edges and the need for sharp equipment in glove boxes to minimize the potential for contaminated wounds.

~~f~~)g) The design should include segregation and handling of mixed and hazardous waste.

Decontamination and ~~decommissioning~~ dismantling

4.134. Floor, wall and ceiling surfaces should be chosen, particularly in wet chemical areas, to facilitate decontamination and future decommissioning. Surfaces in areas where contamination may exist should be made nonporous and easy to clean. Appropriate methods include ~~This should be done by applying~~the application of coverings or coatings to such surfaces, for instance by using paint, resins or stainless steel liners. They should be designed without corners or crevices that may be difficult to access. In addition, all potentially contaminated surfaces should be made readily accessible for allow for periodic and eventual decontamination (e.g. by stripping of paint or coating).

4.136. The level of decontamination to release building or facility should be in accordance with the required criteria by the regulatory authority.

4.137. Before release of equipment for recycling or clearance for reuse, it should be decontaminated to the level required by the regulatory authority, See Ref. [2].

5. CONSTRUCTION

5.1. Para 7.1 of Ref. [1] states “Before the construction of a fuel cycle facility begins, the operating organization shall satisfy the regulatory requirements regarding the safety of the facility design” and the construction of a R&D facility will require authorization from the regulatory body.

5.2 For a complex R&D facility, 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 commence. The extent of regulatory involvement during construction should be commensurate with the hazards posed by the R&D facility during its expected life cycle.

5.3. Current good practices should be used for building construction, fabrication and installation of facility equipment.

5.4. Modularized components (e.g., glove boxes, hot cells, hoods, monitoring systems) should be used in the construction of complex R&D facilities. This enables equipment to be tested and proven at manufacturers' premises before installation in the R&D facility. In addition, this approach also aids commissioning, maintenance and decommissioning.

5.5. The construction of parts of the R&D facility and commissioning or operation of other parts of the R&D facility can overlap. Construction in a radioactive environment can be significantly more difficult and time consuming than when no active material is present. When this occurs, the R&D facility organization should take measures to prevent:

- Construction personnel from receiving unnecessary exposure to radiation;
- Damage to structures, systems and components necessary for operating the R&D facility by construction activities;
- Transfer of radioactive materials to the part of the facility under construction.

5.6. When radiation is present, training of construction personnel should be conducted on simulated installations prior to performing actual construction in order to reduce their exposure to radiation and to reduce the potential for harm to personnel in the operating part of the R&D facility.

5.7. Consideration should be given to the quality assurance programme during construction of a R&D facility. The programme should be prepared early in the construction stage and include:

- Applicable codes and standards;
- Organizational structure;
- Design change programme (configuration control);
- Procurement control;
- Records maintenance;
- Equipment testing;
- Coding and labelling of safety relevant components, cables, piping, and other pieces of equipment.

6. COMMISSIONING

6.1. Section 8 of Ref. [1] sets out the requirements applicable to commissioning of a R&D facility. A commissioning programme should be prepared and implemented to demonstrate that the R&D facility conforms to its designed objectives and safety performance criteria as well as to familiarize the operating personnel with particular characteristics of research and development facility. The establishment of a good safety culture should start at earliest possible stage in commissioning.

6.2. Paragraph 8.9 of Ref. [1] establishes the requirement for commissioning to be divided into 3 main stages, which is also applicable to a R&D facility at the plant or experimental level;

(1) Inactive or 'cold' commissioning

6.3. In this phase, the facility's systems are systematically tested, both individual items of equipment and the systems in their entirety. As it is relatively easy to take corrective actions, as much verification and testing as possible should be carried out in this phase. Operators should take the opportunity to prepare the set of operational documents and to learn the details of systems. Leak-tightness and the stability of control systems are best tested at this stage;

(2) Uranium or 'warm' commissioning

6.4. 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 higher activity materials are introduced, such as plutonium, other actinides or fission products.

6.5. Safety tests performed during this commissioning stage should mainly be devoted to confinement checking. This should include (i) checking for airborne radioactive material; (ii) smear checks on surfaces; and (iii) checking for gaseous discharges and liquid releases. There should also be checks for unexpected accumulations of hazardous material;

(3) Active or 'hot' commissioning

6.6. This stage enables administrative and engineered systems to be progressively and cautiously brought into full operation. Paragraphs 8.5 and 8.10 in Ref. [1] state requirements to fully exercise radioactive systems and reinforce safety culture ensuring that operating personnel are trained.

6.7. The licence to operate the R&D 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. The 'hot' commissioning may be considered part of operational stage of the R&D facility.

6.8. Lessons learned from similar facilities should be implemented especially for the commissioning of a new R&D facility.

6.9. During commissioning and later during operation of the R&D facility, predicted estimates of worker doses should be assessed against actual dose rates. If in operations, the actual doses are higher than the predicted doses, corrective actions should be implemented including making any changes to the licensing documentation (e.g. the safety case) or adding or changing safety features or work practices (see also Sections 6 and 7). The fundamental principles 4, 5 and 6 of Ref. [15] apply.

7. OPERATION

CHARACTERISTICS OF A R&D FACILITY

7.1. In this section, specific guidance on good practices and additional considerations in meeting the safety requirements for a R&D facility are presented, further guidance can be found in Ref. [9].

7.2. The distinctive features of a R&D facility that should be taken into account in meeting these safety requirements established in Ref. [1] are:

- The diversity of inventories of fissionable, radioactive, toxic, reactive or bioactive materials in different physical forms such as powders, liquids and solids;
- Their associated radiological hazards including criticality, alone or in combination with the following;
    - Toxic hazards from bioactive or chemical materials (e.g. HF, UF_6 or ammonia);
    - Explosive or flammable properties of reactive substances in different forms (e.g. hydrogen, nitric acid, ammonia, metallic powders).

7.3. There are requirements in Paragraphs 4.7 to 4.9 of Ref. [1] and Req. 23 of Ref. [11] concerning management responsibilities for safety throughout the lifetime of a facility. For a R&D facility, the management should take into account the potential diversity of research and operational personnel who may be organized in different teams.

7.4. Para 9.3 of Ref. [1] states "The operating organization shall have the overall responsibility for the safety of the facility during operation. The operating organization shall establish an appropriate management structure for the facility and shall provide the necessary infrastructure for operations to be conducted safely". Subsequent paragraphs in Ref. [1] detail responsibilities for operations, maintenance and ~~change~~ control of modifications. All these requirements are relevant to R&D facilities. The R&D facility Safety Committee should comprise representatives of both operations and research functions.

7.5. Research programmes should be compliant with the existing safety case or a modification generated to envelope the research to be carried out. The modification should be reviewed and approved by the appropriate authority, in accordance with regulatory requirements.

7.6. The activities performed in a R&D facility can be grouped into two categories: experiments for fundamental research (Case 1) and pilot processing (Case 2). The process routes of these two categories are illustrated in Annex I, Case 1 and Case 2.

QUALIFICATION AND TRAINING OF PERSONNEL

7.7. The general safety requirements related to qualification and training of R&D facility personnel are defined in the paragraphs 4.10, 4.24, 8.4 and 9.8 to 9.13 of Ref. [1].

7.8. The diversity of R&D facility personnel should be reflected in training programmes on safety. All training programmes linked with the R&D facility should aim to establish a common safety culture.

7.9. In these training courses, emphasis should be given to individual responsibility for safe operation, organization, human factors, lessons learned from events (both inside and outside the facility), defense in depth and assessment of the safety of specific R&D facility programmes or operations.

7.10. The operating organization should consider the effect of changes in research and operating personnel and work programmes when planning training programmes.

7.11. Many processes related to glove box and hot cell operations involve manual intervention. Therefore, special attention should be paid to training R&D facility personnel operating glove boxes and hot cells, including reaction to anticipated operational occurrences (e.g., punctured glove in glove box and loss of ventilation in hot cell).

FACILITY OPERATION

7.12. Just as Para 9.6 of Ref. [1] contains requirements related to interdependencies and communication between facilities on the same site, different organizational units within a R&D facility should hold regular work planning meetings to achieve a common work plan and to coordinate activities. Clear definitions of individual assignments should be documented and approved at a suitable level of authorization.

7.13. To ensure that the R&D facility operates well within the operating limits and conditions under normal circumstances, a set of lower level sub-limits and conditions should be defined. Such sub-limits and conditions should be clear and should be made available to and well understood by personnel operating the facility.

7.14. Operating documents should be prepared that list all the limits and conditions under which the R&D facility is operated. Annex III gives examples of parameters for both categories: experiments for fundamental research (Case 1) and pilot processing (Case 2).

~~which~~ These examples can be used for defining operating limits and conditions in the various R&D facility areas.

7.15. Generic limits should also be set for the facility. Examples are:

- Ranges of mass control of fissile material, during operation, transfer, and storage to avoid criticality, e.g., inventory limit of fissile material in glove boxes;
- Limits on concentrations, geometry and moderators in solutions containing fissile materials;
- Inventory limits of radioactive materials and isotopic compositions in glove boxes or interim storage areas.
- The maximum specific heat loads in locations such as hot cells or glove boxes;
- The maximum quantity of additives at different steps in R&D facility processes;
- Combustible material limits, types and inventory, in gloves boxes and hot cells;
- Limits of flammable atmospheres in enclosed equipment, e.g., hydrogen in a furnace.

7.16. Programmes should be prepared for the routine surveillance of airborne and surface contamination, radiological protection and, more generally, for ensuring an adequate level of housekeeping.

7.17. The values of the key safety variables in operating limits and conditions should be recorded at all times for auditing purposes and to support periodic safety reviews. There should be an investigation and learning process triggered by non-compliances with the operating limits. The findings of such investigation should be recorded and learning disseminated (operational experience feedback).

7.18. The operating organization should define procedures to assure a proper level of safety when phases of R&D facility operation are limited and are followed by long periods of shutdown. Training programmes should cope with these situations and reflect these procedures.

7.19. Procedures should also include actions required to ensure criticality safety, chemical safety, fire safety, emergency response, and environmental protection. Operating procedures should be defined for the ventilation system in fire conditions. Periodic testing and drills should be performed. Operating instructions and procedures should be reviewed periodically and updated and authorized as appropriate.

7.20. In a R&D facility measures should be taken to ensure that experiments and processes can be placed in a safe shutdown condition. However, some systems, such as ventilation used for confinement, continue to operate. Specific operating procedures should be used for the

shutdown of particular processes to prevent for example, exothermic reactions, hydrogen explosion, criticality, etc.

7.21. An inspection programme for the facility should be established, the purpose of which is to periodically confirm that the R&D facility ~~(plant or experimental)~~ is operating in accordance with prescribed operating limits and conditions.

7.22 The R&D facility management should organize pre-job "tool-box" briefings at the start of each day and before undertaking new operations or experiments, to identify potential safety issues and define the best options for safety, as well as to review and assess procedures. See paragraph 2.37 in Ref. [9]. All R&D facility personnel should participate in such meetings.

MAINTENANCE AND PERIODIC TESTING

7.23. The safety requirements related to maintenance, calibration, periodic testing and inspection of nuclear fuel cycle facilities are defined in Ref. [1], para 9.28 to 9.34.

7.24. When carrying out maintenance in a R&D facility, particular consideration should be given to the potential for surface contamination or airborne radioactive material, as well as to any chemical or biological exposure. The R&D facility should not intentionally be placed in an unsafe or unanalyzed condition in order to perform periodic testing or routine maintenance.

7.25. Maintenance should follow good practices with particular consideration given to:

– A suitable maintenance programme should be developed and implemented for all equipment and devices used in work control: e.g. handover and handing back of approved documents, means of communication and visits to job sites, changes to the planned scope of work, suspension of work and ensuring safe access;

– Equipment isolation: de-energizing and disconnecting electrical cabling, hot or pressurized piping and draining, venting and purging of equipment;

– Testing and monitoring: checks of workplace and tools before commencing work (see para 5.67 in Ref. [9]), monitoring during maintenance and checks for re-commissioning;

– Safety precautions during work, e.g. specification of safety precautions, ensuring the availability of personal protective equipment and ensuring its use;

– Continued monitoring systems for control of criticality and radiation protection;

– Reinstallation of equipment, e.g. reassembly, reconnection of pipes and cables, testing, cleaning the job site and monitoring should be performed after maintenance and before re-commissioning.

7.26. A programme of periodic inspections of the R&D facility should be established, at least at fume-hoods, hot cells, glove boxes, and entrances to containment areas. The pressure drop across filter banks should be checked on a regular basis. Particular attention should also be paid to glove material to detect degradation/failure and to maintenance of master slave manipulators and their sleeves in hot cells to avoid spread of contamination or release.

7.27. Periodic testing of fire detection and suppression systems for the R&D facility should be carried out. The operational compliance of ventilation systems with fire protection requirements should also be verified on a regular basis.

7.28. Regular verification of the availability of materials needed for maintenance should be conducted. For continuity of safe operations of the R&D facility, a programme for provision of spare parts for safety features including radiation monitoring equipment should be established and implemented.

MODIFICATION CONTROL

7.29. As part of the management system, a ~~A~~ standard process for any modification should be applied in a R&D facility, in accordance with Para 9.35 of Ref. [1]. The process should use a modification control form or equivalent management tool to control modifications to R&D facility experiments (and processes) and their impact on the safety of the facility.

7.30. The modification control form should contain a description of the change 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 or radiation safety. The modification control form should identify all aspects of safety that may be affected by the modification and demonstrate that adequate and sufficient safety provisions are in place to control the potential hazards. For example, changes to the materials and thickness of shielding, quantities of hydrogenated and non-hydrogenated materials, and locations of equipment that may affect criticality safety analyses.

7.31. Modification control forms should be scrutinized, and be subject to approval, by qualified and experienced persons to verify that the arguments used to demonstrate safety are suitably robust and meet the requirements of the regulatory body. 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.

7.32. The modification control form should also specify which documentation will need to be updated as a result of the modification. Procedures for the control of documentation should be put in place to ensure that documents are changed and distributed within a reasonable time, allowing operating personnel to review, adopt and implement modified procedures when modifications are commissioned. The modification control form should also specify the functional checks that are required before the modified system may be declared fully operational again.

7.33. The modifications made in a R&D facility should be reviewed by the operating organization on a regular basis. This is to ensure that the combined effect of a number of minor modifications do not have hitherto unforeseen effects on the overall safety of the facility. Depending upon the national regulatory practices, the assessment may also be reported to the regulatory authority. See section 2 of this publication.

CRITICALITY CONTROL

7.34. Where there is fissile material in a R&D facility, it is particularly important that procedures for controlling criticality hazards are strictly applied (paragraphs 9.49 and 9.50 of Ref. [1]).

7.35. Operational aspects of criticality control in a R&D facility should include:

– Consideration of an unexpected change in conditions which could increase the risk of a criticality accident, e.g., unplanned accumulation of fissile material (e.g. in glove boxes or ventilation ducts) or hydrogenated materials);
– Unexpected water accumulation e.g. due to water pipes leaks;
– Management of moderating materials, particularly hydrogenated materials such as those used for decontamination of glove boxes and leakages of oils from gear boxes;
– Management of the fissile material transfer (procedures, mass measurement, systems and records) where mass control is used;
– Reliable methods for detecting the onset of unsafe conditions with respect to criticality control;
– Evacuation drills and/or exercises assuming that a criticality occurs and/or alarm is activated;
– Periodic calibration or testing of criticality control and monitoring systems (e.g., material movement control, balances, scales, etc.).

7.36. The tools used for purposes of nuclear material control and accountability, like mass, volume or isotope measurements and accounting software may also have some use in the field of criticality safety. However, where there is any uncertainty about the characteristics of fissile material, conservative values should be used for parameters such as fissile material content and isotopic composition. This arises particularly when handling cell floor or glove box sweepings and similar waste material.

7.37. Additional criticality hazards may be encountered when carrying out maintenance work. For example, "if fissile material has to be removed from equipment only approved containers approved for criticality purposes shall be used", see paragraph V.14 in Ref. [1]. Also, wastes and residues arising from experiments or pilot processes, decontamination, and maintenance activities should be collected in containers with a favorable geometry approved for the work, and stored in dedicated criticality safe areas.

RADIATION PROTECTION

7.38. Paras 9.36 and 9.37 of Ref. [1] states "The measures for protection against radiation exposure of operating personnel, including contractors, and members of the public shall comply with the requirements of the regulatory body and with the requirements established in Ref. [2]. For all operational states the radiation protection measures should be such as:

(a) To ensure that exposures are kept below regulatory limits;

(b) To optimize radiation protection."

In a R&D facility, the radiological hazards to both ~~R&D facility personnel~~ workers and members of the public include intakes (inhalation/ingestion of particulates, aerosols and gases) and external exposure."

7.39. Paragraphs 9.38 to 9.43 of Ref. [1] require the establishment of an appropriate radiation protection programme. For a R&D facility, account should be taken of its complexity and size, as well as the diversity of inventories ~~and the complexity and size of the R&D facility~~. In addition, the physical and chemical properties of the inventory may change inadvertently and result in unforeseen consequences.

7.40. Any deviation of the radiation levels above the normal operational ranges (e.g. hot spots or slow incremental increases of radiation level) for equipment (outside of hot cells or glove boxes), in rooms, or environmental monitoring should be detected, have its origin identified, and result in prompt corrective and/or mitigating actions.

7.41. Radiation protection personnel should be part of the decision-making process in an operating R&D facility so that dose minimization requirements can be applied. These requirements include the early detection and mitigation of hot spots and proper housekeeping for materials storage and waste segregation. Any zones of high contamination or dose should be recorded and marked.

7.42. Interventions for maintenance and modifications should be major activities requiring 'justification' and 'optimization of protective actions' specified in Ref. [2]. The procedures for intervention should include:

– Estimation of doses (external doses) prior to the intervention;

– Preparatory activities to minimize the dose, including:

  - Identification of specific risks due to intervention;
  - Requirement for use of additional shielding, remote devices or mock-ups;
  - Definition of intervention procedures within the work permit (individual and collective protections requirements such as masks, clothing, gloves and time limitation);

– Measurement of the doses during the intervention;

– Implementation of feedback to derive possible improvements.

Control of internal dose

7.43. During R&D facility operation (including interventions for maintenance and modifications) the prevention of internal dose should be controlled by ensuring that:

– Performance standards are set for all parameters potentially affecting internal doses, e.g. contamination levels;

– Regular contamination surveys of facility areas and equipment are carried out to confirm the adequacy of cleaning programmes;

– To aid personnel in considering the level of risk involved in any task and assigning Radiological Protection personnel to routine surveys (rounds), the facility areas are assigned a radiological and contamination classification. These boundaries between the areas are regularly checked and adjusted to match current conditions;

– Contamination and radiation zones are delineated with proper signage;

– Continuous air monitoring is carried out to alert facility operators if airborne contamination is present;

– Contamination levels do not exceed predetermined action levels;

– Mobile air samplers are used at contamination sources, as necessary;

– Prompt investigation is carried out following high airborne contamination readings;

– Personnel are trained in dressing, using, and undressing from protective equipment with the assistance of Radiological Protection personnel;

– Radiation monitors are installed for airborne contamination (i.e., permanent or mobile);

– Personal protective equipment is maintained in good condition and is regularly inspected;

– A high standard of housekeeping is maintained within the facility. Cleaning techniques are used which do not give rise to airborne contamination;

– The effectiveness of the ventilation system should be checked regularly and rebalanced if necessary, following the isolation or de-isolation of boxes and hoods.

– Waste arising from maintenance or similar interventions are segregated by type (i.e. by treatment and disposal route), collected, and directed to the appropriate waste route;

– Careful consideration is given to the combination of radiological and industrial hazards (e.g., oxygen deficiency, heat stress) with particular attention paid to the risk/benefit analysis of the use of personnel protective equipment especially for air-fed systems;

– Personnel and equipment are checked for contamination and decontaminated, if necessary, prior to crossing contamination area boundaries.

7.44. The methodology for assessing internal exposure may be based on collection of air sampling data. The in-vivo (whole-body) monitoring and biological sampling (for example, nose-blow, faecal and periodic urine samples) should also be available, as necessary for normal and accident conditions, as complementary measures to monitor workers' exposure.

7.45. Monitoring efforts should be commensurate with the objective of having no airborne activity or contamination of work places.

7.46. Entry into and exit from the work area should be controlled to prevent the spread of contamination. In particular, clothing changing and decontamination stations should be available.

7.47. During periodic testing, inspections and maintenance of R&D facilities, precautions should be taken to limit the spread of radioactive contamination by means of temporary enclosures and additional ventilation systems.

7.48. On completion of maintenance work, areas should be decontaminated and air sample and smear checks carried out to confirm that the area can be returned to normal use.

7.49. In addition to industrial safety requirements for confined space entries, if entry is required into hot cells or maintenance glove boxes which have contained radioactive materials, radiation exposure rates and non-fixed contamination levels should be measured inside the hot cell or maintenance glove box to determine if working time restrictions are required before entry. These operations need appropriate authorizations, depending on local rules.

7.50. Access to areas designated 'controlled areas' should be avoided for R&D facility personnel with skin wounds.

7.51. On the basis of effluent monitoring data, regular estimates of exposure to the representative person or "critical group" ~~of population~~ living in the vicinity of the facility should be made.

Control of external radiation exposure

7.52. There are dedicated areas in a R&D facility ~~(e.g., pilot processing)~~ where specific arrangements are required to control external radiation exposure. Typically these will be areas in pilot processing facilities where bulk quantities of radioactive materials and source materials are stored and handled.

7.53. Radiation levels should be controlled at the worksite by:

– Ensuring areas of high occupancy are remote or appropriately shielded from significant quantities of radioactive materials;

– Removing radioactive materials from areas adjacent to the work area for extended maintenance work;

– Handling and operating instrumentation with enclosed radiation sources only by suitably qualified and experienced persons;

– Performing routine radiation dose rate surveys.

7.54. External radiation exposure should be controlled or limited by:

– Training of personnel about radiation hazards and use of dose measuring equipment;

– Avoiding unnecessary stay in radiation protection graded areas, e.g. limiting working-time near radiation sources;

– Using individual and temporary shielding;

7.55. Because of the proximity of hands to radioactive materials when doing work in glove boxes, hands are susceptible to receiving a higher exposure than other parts of the body. Therefore, exposure to extremities should be monitored closely (e.g. use of finger films).

7.56. Additional controls may be needed if higher specific activity materials are used. This could also introduce additional radionuclides into waste streams. A comprehensive assessment of occupational and public exposure should be carried out before the introduction of this type of material.

INDUSTRIAL AND CHEMICAL SAFETY

7.57. Paragraph 6.54 of Ref. [1] lists conventional hazards considered in the design of a facility. The conventional chemical hazards found in R&D facilities and experiments that should be considered include;

– Chemical hazards from compounds, such as acids, bases, toxic organic or metallic compounds;

– Explosion and fire hazards from flammable organics, pyrophoric metals, hydrogen, ammonium nitrate, and ammonia;

– Asphyxiation hazard from the presence of nitrogen, carbon dioxide, noble gases;

Requirements and guidance for these are contained in international and national standards on chemical safety.

7.58 Fire hazards analysis should be conducted at periodic intervals to incorporate changes that may affect the fire potential. Sometimes computer fire modelling is used to support the fire hazards analysis.

7.59. As required by the national regulations, a health surveillance programme should be set up which routinely monitors the health of R&D facility workers. It should be noted that such programmes will exist for exposure to the radioactive properties of any chemicals, see paragraph 3.76(f) in Ref. [2]. Therefore both the radiological and chemical effects of materials should be considered as part of the surveillance programme as necessary.

7.59. The national and international standards that apply to non-nuclear chemical laboratories also apply to nuclear chemical laboratories. Guidelines should be developed for scientific staff, covering the types of chemical hazards to be expected and their prevention. Much of the guidance may overlap with standard practice for radiological protection and there will be areas where there should be guidance specific to chemical hazards. These may cover topics such as; eye protection, reaction hazards and toxicity and may refer to documentation

provided by chemical and equipment suppliers or contained in the relevant international and national standards.

WASTE AND EFFLUENT MANAGEMENT

7.60. The requirements related to the management of radioactive waste and effluent during operation are defined in ~~the~~ paragraphs 9.54 to 9.57 of Ref. [1]. General requirements on predisposal management of radioactive waste are provided in Ref [14] and guidance in Ref. [21].

7.61. Radioactive and chemical gaseous discharges potentially containing particulates should be treated where appropriate, by a scrubbing system and/or by high efficiency particulate air (HEPA) filters. Performance standards should be set, specifying the levels at which filter or scrubber medium changes are required. Following filter changes, tests should be carried out to ensure that filters are not damaged and correctly seated, particulate efficiency tests may be used.

7.62. One easy way to reduce and/or minimize the generation of solid radioactive wastes is to minimize packaging before transfer to contamination areas. Processes like incineration, metal melting, and compaction can also be used to reduce the volume of wastes. According to the national regulations and as far as reasonably practicable, waste material resulting from processing should be recycled or re-used or cleared from regulatory control where possible. Facility cleaning methods should be adopted which reduce and/or minimize waste generation, for instance reuse of washings from clean areas for more contaminated areas.

7.63. As part of the management system, measures for q~~Q~~uality assurance and control ~~regimes~~ should be implemented ~~applied to~~ for the ~~treatment and disposal~~processing of all waste streams to ensure, as far as achievable, compliance with the waste acceptance requirements for the selected or anticipated disposal ~~authorizations~~option.

7.63. Mixing waste streams should be limited to those streams that are radiologically and chemically compatible. If the mixing of chemically different waste streams is considered, the chemical reactions that could occur should be evaluated in order to avoid uncontrolled or unexpected reactions.

7.64. The operating organization should characterize waste as it is produced. Relevant records and reports should be created and managed according to the proper safety management system, Ref. [21].

7.65. When legacy materials exist without chemical and radiological analyses, reports on the research and development programmes that produced these wastes should be collected or

prepared ~~(from historical information, if necessary)~~ and stored, to be used in subsequent safety assessments. Where necessary to fill gaps in historical information, former employees should be interviewed and published scientific and annual reports on legacy materials should be evaluated.

EMERGENCY PLANNING AND PREPAREDNESS

7.66. The requirements on emergency planning and preparedness (EPP) are defined in Para 9.62 to 9.67 of Ref. [1], and Paragraphs V.17 and V.18 in the same reference list aspects for immediate consideration.

7.67. For R&D facilities belonging to Case 2, an expanded list of hazards is defined in the ~~corresponding chapters of the related FCF~~ IAEA S~~s~~afety ~~g~~Guides related to the corresponding type of nuclear fuel cycle facilities e.g. Ref. [20], Ref. [23] and Ref. [24];

7.68. The EPP programme should reflect the level of the potential hazards and the layout of the R&D facility site (i.e., the site may be composed of a great number of buildings and facilities).

7.69. Firefighters should be trained on intervention in radioactive environments (i.e., the risk of the spread of contamination, criticality and chemical hazards from firefighting media (e.g., fissile, explosive, and/or reactive materials)). The fire brigade should be aware of the specific R&D facility hazards when fighting a fire.

7.70. General safety requirements for emergency preparedness and response are established~~Additional guidance on EPP can be found~~ in Ref. [7].

8. PREPARATION FOR DECOMMISSIONING

8.1. Decommissioning activities are performed with an optimized approach to achieving a progressive and systematic reduction in radiological hazards, and are undertaken on the basis of planning and assessment to ensure the safety of workers and the public and protection of the environment, both during and after decommissioning operations, see Ref. [22] which establishes general safety requirements for the decommissioning of facilities. ~~Decommissioning guidance for fuel cycle facilities is provided in Ref. [].~~

8.2. The following measures should be taken during the design, construction and operational stages of R&D facility life to facilitate eventual decommissioning:

- Design measures to minimize contamination penetrating structures;
- Physical and procedural methods to prevent the spread of contamination;

- Design features to facilitate decommissioning;
- Consideration of the implications for decommissioning resulting from modifications and experiments in the facility, when they are proposed;
- Identification of reasonably practicable changes to the facility design to facilitate or accelerate decommissioning;
- Comprehensive record preparation for significant activities and events at all stages of the facility's life, archived in a secure and readily retrievable form, indexed in a documented, logical and consistent manner;
- Minimizing the eventual generation of radioactive waste during decommissioning.

8.3 The radiological hazard associated with decommissioning R&D facilities depends upon the type of work performed: Either the decommissioning work should fall inside the existing safety case decommissioning plan or be subject to an appropriate modification before the decommissioning begins.

1. In High Activity cells/units, deposits of gamma-beta activity exist and may require prior decontamination by chemical or mechanical means (such as chemical rinses, sand-blasting or specialized tools). The objective is to remove contamination where possible in order to reduce dose levels to as low as possible in order to allow direct access to the equipment. If after decontamination dose rates remain high, remote handling should be used.
2. In alpha liquid units, deposits of alpha activity may exist and require adequate rinsing with chemical materials other than those used during operation.
3. In alpha powder units deposits of alpha activity may exist and can be managed with appropriate personal protective equipment.

8.4~~2~~. Where there may be fissile material, the criticality requirements on paragraphs V.19 and V.20 of Ref. [1] should apply.

PREPARATORY STEPS

8.5 The preparatory steps for the decommissioning process should include:

– Post-operational clean-out to remove all bulk quantities of radioactive and other hazardous materials;

– Identification of contaminated parts of buildings and equipment and radionuclides and levels of contamination;

– Decontamination of the facility to reach the required regulatory clean-up levels, or lowest reasonably achievable level of residual contamination;

– Preparation of risk assessments and method statements for the licensing of the decommissioning process, see Ref. [26] which contains guidance on safety assessment for decommissioning.

8.6. In the event of decommissioning being significantly delayed after a R&D facility has shut down for decommissioning, safety measures should be implemented to maintain the R&D facility in safe and stable state, including measures to prevent criticality, spread of contamination, fire, and to maintain appropriate radiological monitoring. Consideration should be given for the need for a revised safety assessment for the 'shut down' facility state and to using 'knowledge management' methods to retain the knowledge and experience of operators in a durable and retrievable form.

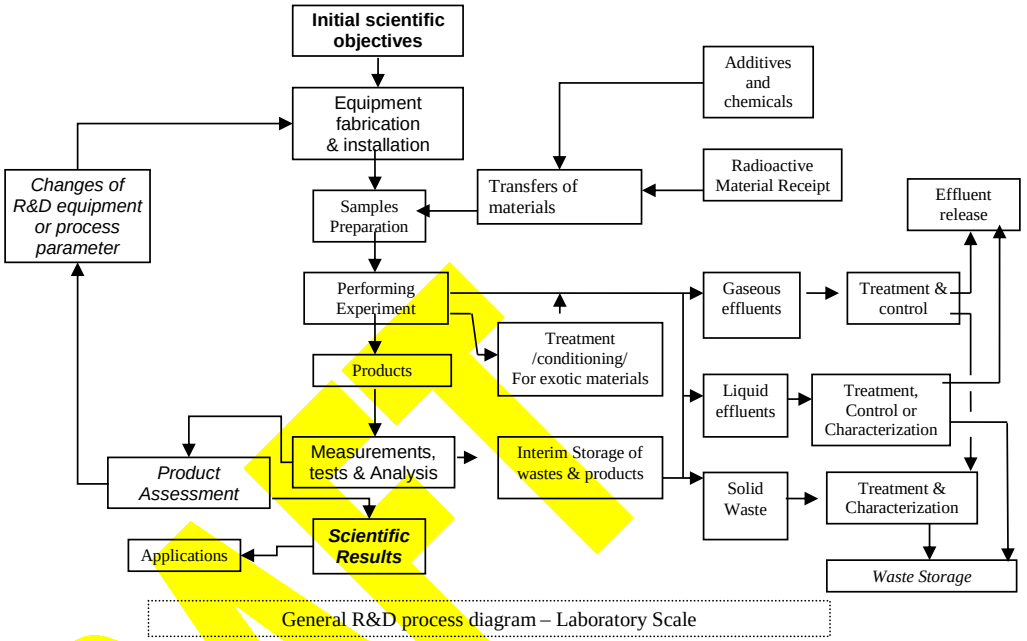
DECOMMISSIONING PROCESS

8.~~3~~7. Specific guidance on the decommissioning process for nuclear fuel cycle laboratories is provided in Ref. [25], guidance which may relevant to pilot plants can be found in Ref. [6]. It should be ensured that personnel deployed for R&D facility (plant or experimental equipment) decommissioning are suitably experienced and qualified for such work. They should clearly understand the control regime under which they are working in order to maintain acceptable environmental conditions and to implement applicable health and safety standards.

8.~~4~~8. During the decommissioning of radioactive areas, particular attention should be paid to:

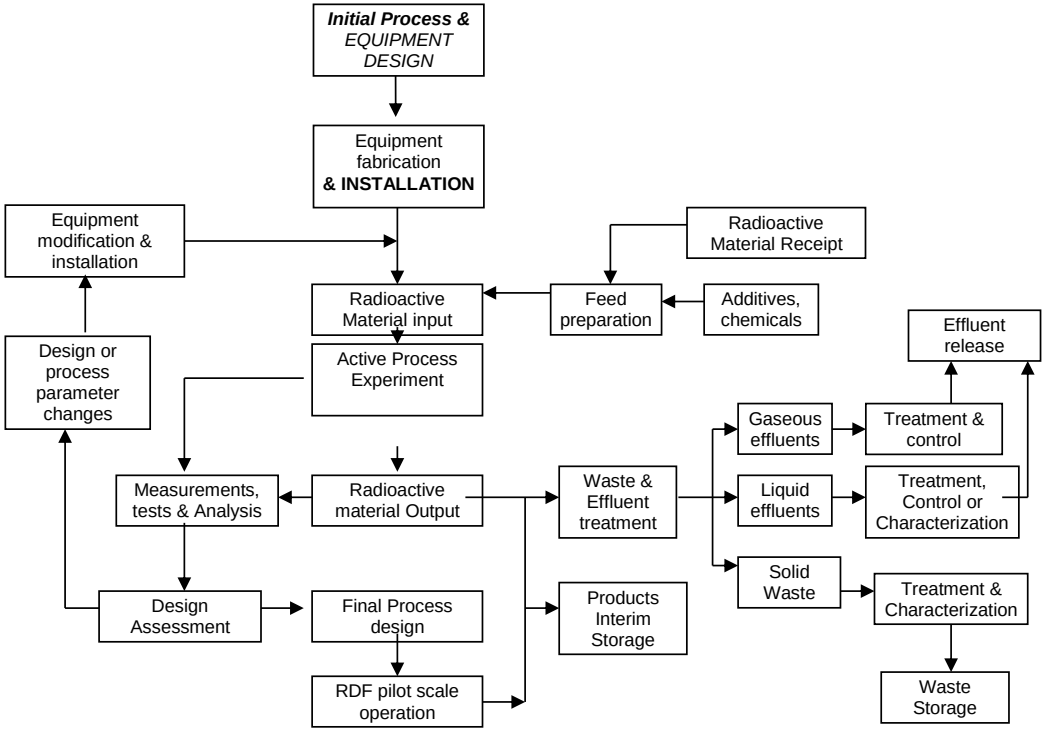
- Avoiding the spread of contamination through the use of appropriate techniques and procedures. In particular, the amounts of liquids (such as water and chemicals) used for decontamination should be minimized to reduce the generation of waste.
- Appropriate waste handling and packaging as well as planning for appropriate disposal of radioactive waste.
- The safe storage of contaminated waste material that cannot be disposed of immediately.
- Minimizing the creation of airborne contamination, rather than simply relying on personal protective equipment.

ANNEX I-A: R&D FACILITY PROCESS ROUTE LABORATORY SCALE (CASE 1)



General R&D process diagram – Laboratory Scale

ANNEX I-B: R&D FACILITY PROCESS ROUTE PILOT SCALE (CASE 2)



General R&D process diagram - Pilot Scale

ANNEX II: SAFETY FUNCTION IMPLEMENTATION BY PROCESS AREA

Safety Function (SF): (1) Criticality prevention
(2) Confinement of radioactive materials
(3) Protection against external radiation exposure

Examples of R&D facility Structures, Systems and Components (SSCs important to safety) implementing each of the above Safety Functions are listed below by process area, together with corresponding Operating Limits and Conditions, mitigations and other comments.

Process Area	**Example SSC**	**Events**	**Safety Function**	**OLCs/Comments/other mitigation**
Initial scientific objectives			1,2,3	Implementation of the IAEA safety principles # 4 to 9 (Ref. SF-1) Safety assessment of the R&D programmes and activities
Equipment fabrication & installation	Equipment ensuring geometry & moderation control. Reflectors Neutron absorbers Detection and alarm systems	Criticality accident	1	Quality of the design and construction Installation according to the safety case and set procedures Accessibility/visibility to allow periodic maintenance and checks
	Equipment ensuring mass, and concentration	Criticality accident	1	Quality of the design and construction with diverse and robust control of key parameters Installation according to the safety case and set procedures with realistic commissioning tests

	– Building, hoods, glove boxes, hot cells and interim storage – Ventilation, filters	Contamination. Loss of integrity	2	Quality of the design and construction Use of fail-safe designs where possible Installation according to safety case and set procedures Realistic commissioning tests. Measurement points for airflow/pressure Accessibility/visibility to allow periodic checks of structural integrity
	Hot cells or shielded glove boxes	Insufficient shielding	3	Quality of the design and construction OLCs on radiation protection Validation of the shielding suitability during commissioning
Radioactive material receipt	Transportation means	Degradation of criticality safety margin	1 (fissile only)	Transport rules, regulations and procedures Verification by recipient in accordance with OLCs
	Measurement devices for isotopic and chemical composition	Violation of acceptance criteria Unexpected or "exotic" material		Transport rules, regulations and procedures Suitably Qualified and Experienced Personnel Non Destructive Analysis or sampling of imported fissile material for isotopic or chemical characterization Calibration of the measurement devices
	Transportation means	Leakage Exposure Overpressure or explosion. For example, hydrogen due to radiolysis effect	2	Transport rules, regulations and procedures On-site transportation rules Suitably Qualified and Experienced Personnel Visual inspection of container and its seals Smear tests, pressure-tests

	Licensed container			Transport rules, regulations and procedures On site transportation rules Suitably Qualified and Experienced Personnel Verification of use of right container Correct labelling
	Shielding Licensed container	Increase dose to R&D facility personnel	3	Transport rules, regulations and procedures On-site transportation rules Suitably Qualified and Experienced Personnel Verification of use of right container Verification by recipient Visual inspection and radiation monitoring
Additives , chemicals including gases	Engineering fittings e.g. gas bottles Standardized containers	Fire, explosion and toxicity	2 (industrial safety)	Positive identification of supplies Checks of Material Safety Data Sheets (MSDS) Suitably Qualified and Experienced Personnel for receipt, storage, use and disposal of chemicals
Transfers of nuclear and non-nuclear materials	For nuclear materials; Hoods or coupling device to hot cell or glove box For chemicals – as defined by the MSDS	Breach of the continuity of containment leading inadvertent release	2, 3	For nuclear materials – R&D facility safety case limits Operating procedures consistent with safety analysis For chemicals, conformation to MSDS Radiation protection controls Chemical hazard controls
Sample/feed preparation	Chemical analysis, weighing devices	Non acceptable K_{eff}	1	Procedures, criticality control measures, moderator limits etc. Calibration of SSCs
	Criticality accident alarm system	Unavailability of alarm	1	Procedures controlling fissile transfers, personnel access and egress

	Hoods, hot cells or glove boxes	Breach of containment	2	Maintenance and periodic testing Permissible pressure
	Hoods, hot cells or shielded glove boxes	Insufficient shielding	3	Maintenance and periodic RP checks
Performing experiments /Equipment	Calibrated equipment. Diverse equipment ensuring mass, geometry, moderation control. Reflectors Neutron absorbers Detection and alarm systems	Non acceptable K_{eff} Double-batching Inadvertent accumulation of fissile material	1	OLCs where necessary Independent double check by ~~SQEP~~suitably qualified and experienced persons especially for mass and concentration of fissile materials Stringent implementation of Quality Assurance (QA) including maintenance and periodic inspection e.g.: of reflectors Questioning attitude
	Hoods, hot cells or glove boxes Pressure monitoring/recording	Breach of containment	2	Effective isolation procedures Maintenance and periodic testing
	Emergency power supply	Loss of power	2	System dependent procedures e.g. for battery low Volts Maintenance and periodic testing
	Fire protection system	Uncontrolled fire Accumulations of flammable materials, blocked exits	2	Note potential pyrophoric materials Maintenance and periodic testing Good house-keeping
	Hoods, hot cells or shielded glove boxes	Insufficient shielding Build-up of radioactive materials	3	Maintenance and periodic radiological checks Good house-keeping
Products	Criticality detection and alarm system or neutron measurement device Criticality accident alarm system	Non acceptable K_{eff}	1	Anticipation and verification of characteristics of products in line with OLCs - assessment if significant change in density, chemical and physical form e.g. precipitation Maintenance and periodic testing of the equipment

	Control of discharge of powders or fluids from the equipment to hot cell, glove box or waste. Containers, cabinet, well, wet storage.	Fire and explosion Breach of the containment	2	OLCs. Implementation of conservative procedures RP checks; smear tests, pool water activity etc. Put the R&D facilities in a safe state Maintenance and periodic testing Potential bio-hazards
Measurements, tests & analysis	Safety-related instruments and controllers	Unexpected outcome. Non-acceptable K_{eff}	1	Criticality assessment defining OLCs Double contingency principle Calibration
	Safety-related instruments and controllers e.g. pressure, radiation	Unexpected outcome.	2	Adequacy of the material with the safety case. Hazard assessment defining OLCs Calibration, regular inspections Maintenance and periodic testing
Application	None	Hazard transferred to a third party (customer of the facility)	1,2 and 3	QA applied to work conducted by the R&D facility with some transfer of knowledge and safety information to the user; • Product identified (labelled) and capable of safe handling • Documentation and training of third parties and customers • Checks on export packages prior to use Responsibility for the subsequent safety of product and its application transferred from the R&D facility to user or third party
Gaseous effluents	Off gas treatment units, iodine filters and HEPA filters Differential pressure measurements and controls	Breach of containment Fan malfunction	2	Periodic monitoring and testing as defined by procedures and regulatory limits

	Scrubbers, HEPA filters, connections and casings	Contact dose on filter casing Deposition of radioactive particulate	3	Periodic radiological checks as defined by procedures and regulatory limits
Liquid effluents	Ion exchange resins and extraction	Abnormal presence of fissile material	1	Periodic testing by gamma/neutron counting Accountability. Smear tests Criticality controls
	Connections, equipment for retention of filtering medium or resin e.g. prevention of backflow	Presence of leak	2	Measurements, periodic testing as defined by procedures and regulatory limits Tightness, fail-safe design Radiological checks
	Filters, Ion exchangers resins, extraction evaporation	Build-up of dose on media and increasing risk to R&D facility operators	3	Good planning, periodic radiological checks as defined by procedures and regulatory limits
	Containers	Contact dose on containers Breach of containment	2	Measurements e.g. smear test, periodic testing as defined by procedures and regulatory limits
	Shielding on containers	Build-up of radiation in packaging and increasing risk to R&D facility operators	3	Periodic radiological checks as defined by procedures, accountancy and regulatory limits for discharges

Definition of exotic materials:

- Non-standard ~~fuel fabrication~~ MO_X or UO_2 fuel, or new fuel matrix, e.g. carbides, nitrides,
- Isotopes with particular constraints for disposal acceptance criteria, e.g. long lived~~fe~~ transuranics, e.g. curium, or fission products, and activated materials, e.g. traces in cladding
- Chemical elements not allowed in radioactive wastes, e.g. graphite

Annex III

Example Operating Limits or Conditions

Area or Operation	**Example Operating Limit or Condition**
Radiation protection in hot cells or shielded glove boxes	No more than 100 millilitres of radioactive product or 1 TBq iodine-131 equivalent allowed in cell XYZ at any one time.
Verification of receipt for fissile material	The consignment number, weight and enrichment on the label are recorded in the "Samples-In" system and its as-received weight measured and recorded. Enrichments over 4.0% or discrepancies in the weight greater than 100mg should be reported to the supervisor.
Criticality control of process	The H/U atomic ratio should not exceed 8.4 at any time
Criticality control of process product	No more than 10mg/litre solids in daily product sample as measured by analytical service department
Individual experiment	No more than 10 litres of hydrogen shall be used in the glovebox in any one experiment.
X-Ray machines	The X-ray machine shall not be energized unless the door to the x-ray cell is closed and the interlock is functional

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Field Code Changed

CONTRIBUTORS TO THE DRAFTING AND REVIEW

Bardelle, P.	Commissariat à l'énergie atomique et aux énergies alternatives (CEA), Centre de Cadarache , France
Carr, V.M.	International Atomic Energy Agency
Gater, R.	International Atomic Energy Agency
Kotzalas, M.	U.S. Nuclear Regulatory Commission, United States of America
Mester, W.	GRS, Köln, Germany
Nocture, P.	International Atomic Energy Agency
Orabi, G.	National Centre of Nuclear Safety and Radiation Control, Egypt
Sigit	National Nuclear Energy Agency (BATAN), Indonesia
Williamson, R.	National Nuclear Laboratory, Sellafield, United Kingdom
Uchiyama, G.	Japan Atomic Energy Agency (JAEA), Japan
Anderson, R.W	British Nuclear Fuels, United Kingdom
Aono, S	Japan Nuclear Cycle Development Institute (JNC), Japan
Persinkon, A.	U.S. Nuclear Regulatory Commission, United States of America
Petrova, L	Ministry for Atomic Energy of the Russian Federation (MINATOM)
Tshuchino, S.	Japan Nuclear Energy Safety Organization (JNES), Japan
Voitellier, J.L.	COGEMA, France