

IAEA Safety Standards

for protecting people and the environment

Radiation Protection and Radioactive Waste Management in the Design and Operation of Research Reactors

Safety Guide

No. NS-G-4.6



IAEA
International Atomic Energy Agency

AVA Documents
Document Sharing Hub

**RADIATION PROTECTION AND
RADIOACTIVE WASTE
MANAGEMENT IN THE
DESIGN AND OPERATION OF
RESEARCH REACTORS**

Safety standards survey

The IAEA welcomes your response. Please see:
<http://www-ns.iaea.org/standards/feedback.htm>

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

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

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

IAEA SAFETY STANDARDS SERIES No. NS-G-4.6

RADIATION PROTECTION AND RADIOACTIVE WASTE MANAGEMENT IN THE DESIGN AND OPERATION OF RESEARCH REACTORS

SAFETY GUIDE

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2008

COPYRIGHT NOTICE

All IAEA scientific and technical publications are protected by the terms of the Universal Copyright Convention as adopted in 1952 (Berne) and as revised in 1972 (Paris). The copyright has since been extended by the World Intellectual Property Organization (Geneva) to include electronic and virtual intellectual property. Permission to use whole or parts of texts contained in IAEA publications in printed or electronic form must be obtained and is usually subject to royalty agreements. Proposals for non-commercial reproductions and translations are welcomed and considered on a case-by-case basis. Enquiries should be addressed to the IAEA Publishing Section at:

Sales and Promotion, Publishing Section
International Atomic Energy Agency
Wagramer Strasse 5
P.O. Box 100
1400 Vienna, Austria
fax: +43 1 2600 29302
tel.: +43 1 2600 22417
email: sales.publications@iaea.org
<http://www.iaea.org/books>

© IAEA, 2008

Printed by the IAEA in Austria
December 2008
STI/PUB/1369

IAEA Library Cataloguing in Publication Data

Radiation protection and radioactive waste management in the design and operation of research reactors : safety guide. — Vienna : International Atomic Energy Agency, 2008.
p. ; 24 cm. — (IAEA safety standards series, ISSN 1020-525X ; no. NS-G-4.6)
STI/PUB/1369
ISBN 978-92-0-111608-6
Includes bibliographical references.

1. Radiation — Safety measures. 2. Radioactive waste disposal — Safety measures. 3. Nuclear reactors — Safety measures. 4. Nuclear reactors — Design and construction. I. International Atomic Energy Agency. II. Series.

IAEAL

08-00554

FOREWORD

by Mohamed ElBaradei
Director General

The IAEA's Statute authorizes the Agency to establish safety standards to protect health and minimize danger to life and property — standards which the IAEA must use in its own operations, and which a State can apply by means of its regulatory provisions for nuclear and radiation safety. A comprehensive body of safety standards under regular review, together with the IAEA's assistance in their application, has become a key element in a global safety regime.

In the mid-1990s, a major overhaul of the IAEA's safety standards programme was initiated, with a revised oversight committee structure and a systematic approach to updating the entire corpus of standards. The new standards that have resulted are of a high calibre and reflect best practices in Member States. With the assistance of the Commission on Safety Standards, the IAEA is working to promote the global acceptance and use of its safety standards.

Safety standards are only effective, however, if they are properly applied in practice. The IAEA's safety services — which range in scope from engineering safety, operational safety, and radiation, transport and waste safety to regulatory matters and safety culture in organizations — assist Member States in applying the standards and appraise their effectiveness. These safety services enable valuable insights to be shared and I continue to urge all Member States to make use of them.

Regulating nuclear and radiation safety is a national responsibility, and many Member States have decided to adopt the IAEA's safety standards for use in their national regulations. For the contracting parties to the various international safety conventions, IAEA standards provide a consistent, reliable means of ensuring the effective fulfilment of obligations under the conventions. The standards are also applied by designers, manufacturers and operators around the world to enhance nuclear and radiation safety in power generation, medicine, industry, agriculture, research and education.

The IAEA takes seriously the enduring challenge for users and regulators everywhere: that of ensuring a high level of safety in the use of nuclear materials and radiation sources around the world. Their continuing utilization for the benefit of humankind must be managed in a safe manner, and the IAEA safety standards are designed to facilitate the achievement of that goal.

THE IAEA SAFETY STANDARDS

BACKGROUND

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

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

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

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

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

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

THE IAEA SAFETY STANDARDS

The status of the IAEA safety standards derives from the IAEA's Statute, which authorizes the IAEA to establish or adopt, in consultation and, where appropriate, in collaboration with the competent organs of the United Nations and with the specialized agencies concerned, standards of safety for protection

of health and minimization of danger to life and property, and to provide for their application.

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

Safety measures and security measures¹ have in common the aim of protecting human life and health and the environment. Safety measures and security measures must be designed and implemented in an integrated manner so that security measures do not compromise safety and safety measures do not compromise security.

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

Safety Fundamentals

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

Safety Requirements

An integrated and consistent set of Safety Requirements establishes the requirements that must be met to ensure the protection of people and the environment, both now and in the future. The requirements are governed by the objective and principles of the Safety Fundamentals. If the requirements are not met, measures must be taken to reach or restore the required level of safety. The format and style of the requirements facilitate their use for the establishment, in a harmonized manner, of a national regulatory framework. The safety requirements use 'shall' statements together with statements of

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

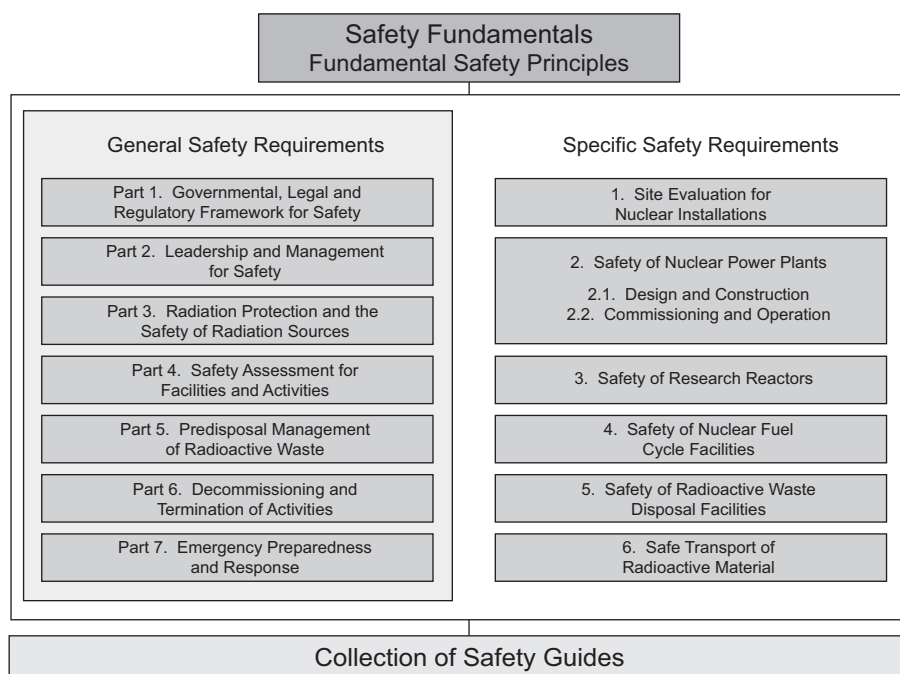


FIG. 1. The long term structure of the IAEA Safety Standards Series.

associated conditions to be met. Many requirements are not addressed to a specific party, the implication being that the appropriate parties are responsible for fulfilling them.

Safety Guides

Safety Guides provide recommendations and guidance on how to comply with the safety requirements, indicating an international consensus that it is necessary to take the measures recommended (or equivalent alternative measures). The Safety Guides present international good practices, and increasingly they reflect best practices, to help users striving to achieve high levels of safety. The recommendations provided in Safety Guides are expressed as ‘should’ statements.

APPLICATION OF THE IAEA SAFETY STANDARDS

The principal users of safety standards in IAEA Member States are regulatory bodies and other relevant national authorities. The IAEA safety

standards are also used by co-sponsoring organizations and by many organizations that design, construct and operate nuclear facilities, as well as organizations involved in the use of radiation and radioactive sources.

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

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

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

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

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

DEVELOPMENT PROCESS FOR THE IAEA SAFETY STANDARDS

The preparation and review of the safety standards involves the IAEA Secretariat and four safety standards committees, for nuclear safety (NUSSC), radiation safety (RASSC), the safety of radioactive waste (WASSC) and the safe transport of radioactive material (TRANSSC), and a Commission on

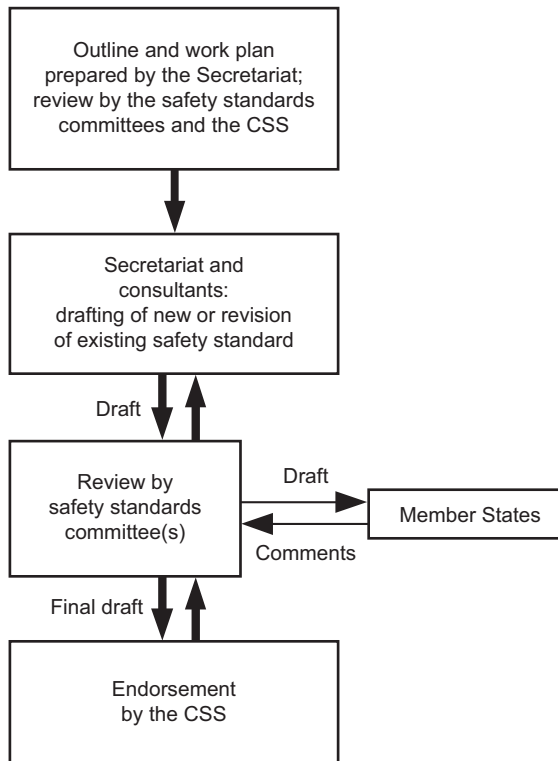


FIG. 2. The process for developing a new safety standard or revising an existing standard.

Safety Standards (CSS) which oversees the IAEA safety standards programme (see Fig. 2).

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

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

INTERACTION WITH OTHER INTERNATIONAL ORGANIZATIONS

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

INTERPRETATION OF THE TEXT

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

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

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

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

CONTENTS

1.	INTRODUCTION	1
	Background (1.1–1.2).....	1
	Objective (1.3)	1
	Scope (1.4–1.9)	2
	Structure (1.10).....	3
2.	APPLICABLE REQUIREMENTS, OBJECTIVES AND CONCEPTS	4
	Safety objective (2.1–2.2)	4
	Dose limits and constraints (2.3–2.4).....	4
	Application of the principle of optimization (2.5–2.7)	5
	Design target doses (2.8–2.9)	6
	Design target doses for accidents (2.10–2.11).....	7
3.	RESEARCH REACTORS AND ASSOCIATED RADIOLOGICAL HAZARDS	8
	Introduction (3.1).....	8
	Radiological hazard according to reactor type and utilization (3.2–3.15)	8
	Sources of radiation (3.16–3.18).....	11
4.	ASPECTS OF RADIATION PROTECTION AND RADIOACTIVE WASTE MANAGEMENT IN DESIGN	12
	Approach to design for operational states and decommissioning (4.1–4.22)	12
	Design features for radioactive waste management (4.23–4.34)	19
	Lifetime management and decommissioning of the facility (4.35–4.36)	22
	Design approaches for dealing with accident conditions (4.37–4.41)	23
	Design of structures, systems and components (4.42–4.50)	24
	Decontamination (4.51–4.54)	25
	Design of shielding (4.55–4.60).....	26
	Ventilation (4.61–4.65)	27

5.	RADIATION PROTECTION IN OPERATION	28
	Introduction (5.1–5.5)	28
	Dose limitation (5.6–5.12)	29
	Reference levels (5.13–5.15)	30
	Dose control on the site (5.16–5.57)	31
	Off-site (public) dose control by minimization of releases (5.58–5.61)	40
6.	OPERATIONAL RADIOACTIVE WASTE MANAGEMENT ..	40
	General (6.1–6.2)	40
	Generation of radioactive waste (6.3–6.8)	42
	Optimizing exposure associated with the management of radioactive waste (6.9–6.10)	44
	Packaging and confinement of radioactive waste (6.11–6.13)	45
	Storage of radioactive waste (6.14–6.24)	46
	Documentation relating to the management of radioactive waste (6.25–6.30)	48
	Classification and characterization of radioactive waste (6.31–6.39) ..	49
	Processing of radioactive waste (6.40–6.55)	51
	Transport of radioactive waste (6.56–6.57)	54
	Discharge control and compliance monitoring (6.58–6.63)	54
7.	MONITORING	56
	Introduction (7.1–7.9)	56
	Facility monitoring (7.10–7.17)	58
	Individual monitoring (7.18–7.32)	60
	Effluent monitoring (7.33–7.40)	63
	Environmental monitoring (7.41–7.42)	65
8.	INSTRUMENTATION	66
	Introduction (8.1)	66
	Requirements for instruments (8.2–8.4)	66
	Maintenance and calibration of instruments (8.5–8.7)	68
9.	ORGANIZATIONAL ASPECTS	68
	Introduction (9.1)	68

Organizational structure (9.2–9.3)	69
Responsibilities (9.4–9.19)	69
Qualification and training of personnel (9.20–9.35)	73
Documentation (9.36–9.41)	76
 10. RADIOLOGICAL ASPECTS OF EMERGENCIES	 78
Introduction (10.1–10.3)	78
Radiological assessment (10.4–10.7)	79
Protective actions (10.8)	80
Corrective actions (10.9)	80
 REFERENCES	 81
 ANNEX I: EXAMPLES OF POSSIBLE SOURCES OF RADIATION IN A RESEARCH REACTOR	 83
 ANNEX II: PERSONAL PROTECTIVE EQUIPMENT	 89
 ANNEX III: DESIGN CONSIDERATIONS FOR COLLECTION OR HOLDING (DELAY) TANKS FOR LIQUID RADIOACTIVE WASTE	 97
 CONTRIBUTORS TO DRAFTING AND REVIEW	 99
BODIES FOR THE ENDORSEMENT OF IAEA SAFETY STANDARDS	 101

1. INTRODUCTION

BACKGROUND

1.1. This Safety Guide was developed under the IAEA programme for safety standards for research reactors, which covers all the important areas of research reactor safety. It supplements and elaborates upon the Safety Requirements publication on Safety of Research Reactors [1] by presenting recommendations on the best practices, based on international experience, to meet the safety requirements of Ref. [1] and those of the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources [2].

1.2. Research reactors vary greatly in their structure, power levels and applications. They are usually flexible in their modes of operation and allow ready access to the reactor core. Additionally, some research reactors may have in-core experimental devices, which may include fissile materials, while others may have individual high pressure liquid or gas loops leading from the core region to an external cooler or measurement station. Appropriate radiation protection programmes and radioactive waste management programmes have to be established, therefore, with special attention to experimental facilities and experiments.

OBJECTIVE

1.3. The purpose of this Safety Guide is to provide guidance on radiation protection programmes and radioactive waste management programmes for research reactor facilities, consistent with the principles and requirements established in Refs [1–3]. This Safety Guide identifies important components that should be considered at the design stage with regard to facilitating radiation protection and radioactive waste management. It also recommends good practices in implementing operational radiation protection programmes and radioactive waste management programmes and in their optimization. This Safety Guide is directed at designers, operating organizations, managers and regulatory bodies of research reactors.

SCOPE

1.4. This Safety Guide covers all aspects of operational radiation protection and radioactive waste management. However, certain topics are not dealt with in detail here, owing to their specialized nature, such as environmental monitoring, disposal of radioactive waste, management of spent fuel and off-site emergency response. These topics are covered in other IAEA publications [4–6] and this Safety Guide should be used in conjunction with them.

1.5. This Safety Guide is applicable to research reactors. However, some flexibility in its application is warranted on the basis of the specific characteristics of each research reactor, as mentioned in paras 1.7–1.10 (on the graded approach), or the relevant national regulations. The extent to which the recommendations provided in this Safety Guide are to be applied should be agreed upon between the operating organization and the regulatory body.

1.6. This Safety Guide does not provide guidance on radiation protection and radioactive waste management in the decommissioning of research reactors.

1.7. Research reactors are used for a variety of purposes, leading to different design features and operational regimes. Design and operating characteristics may vary significantly since experimental devices may affect the performance of reactors. In addition, the need for greater flexibility in their use requires a different approach to achieving or managing safety in comparison with the approach used for nuclear power reactors.

1.8. The potential hazard to the public from research reactors is generally small compared with that from power reactors [7]. However, this may not be the case for workers.

1.9. The factors to be considered in deciding whether certain guidelines provided here may be waived in applying a graded approach include:

- (a) The power level of the reactor;
- (b) The radiological source term;
- (c) The amount and enrichment of fissile material and fissionable material present;
- (d) Spent fuel storage areas, high pressure systems, heating systems, fuel accumulators, etc., which may affect the safety of the reactor;
- (e) The type of fuel elements;
- (f) The type and mass of moderator, reflector and coolant;

- (g) The amount of reactivity that can be introduced and its rate of introduction, reactivity control, and inherent and engineered safety features;
- (h) The presence of a containment structure or other means of confinement;
- (i) The utilization of the reactor (experimental devices, tests, reactor physics experiments, etc.);
- (j) Site evaluation;
- (k) The reactor's proximity to people.

STRUCTURE

1.10. This Safety Guide consists of ten sections and three annexes. Section 2 presents the applicable requirements, objectives and concepts. Section 3 deals with the radiological hazard of different types of research reactors and identifies possible sources of radiation in the reactor facility. Section 4 provides recommendations on design aspects to be considered in order to facilitate radiation protection and radioactive waste management, including design approaches for operation, decommissioning and managing accident conditions. Section 5 deals with physical and administrative control of the radiological hazards identified in Section 3. Section 6 describes the issues to be considered in the operation of research reactors pertaining to radioactive waste management. Section 7 provides recommendations on monitoring for facilities and personnel, and for the possible releases associated with research reactors. Section 8 provides recommendations on instrumentation and its required characteristics for radiation protection purposes. Section 9 discusses organizational aspects that could affect the meeting of the requirements on radiation protection at research reactor facilities, including the responsibilities of the operating organization, the safety committee and the regulatory body, as well as recommendations on staffing, qualification and training. Section 10 provides an outline of the radiological aspects of emergencies at research reactors. Annex I provides examples of radiation sources in research reactors to be considered in the design and operation programmes for radiation protection and radioactive waste management. Annex II provides an overview of personal protective clothing and equipment, and Annex III gives some considerations with respect to the design of a collection tank or holding tank for liquid radioactive waste.

2. APPLICABLE REQUIREMENTS, OBJECTIVES AND CONCEPTS

SAFETY OBJECTIVE

2.1. The fundamental safety objective is to protect people and the environment from the harmful effects of ionizing radiation [3]. To meet this objective, a comprehensive safety analysis should be carried out to identify all sources of radiation and to evaluate the radiation doses that could be received by workers and the public, as well as potential effects on the environment. This safety analysis should examine:

- (1) All planned normal operational modes of the facility;
- (2) Performance of the facility following anticipated operational occurrences;
- (3) Design basis accidents;
- (4) Event sequences that may lead to a beyond design basis accident.

On the basis of this analysis, the robustness of the engineering design in withstanding postulated initiating events and accidents should be established, the effectiveness of the safety systems and of safety related systems should be demonstrated, and requirements for emergency response should be established.

2.2. Measures should be taken to minimize the likelihood of an accident that could lead to loss of control over the source of radiation. Even so, there remains a very low probability that an accident may happen, therefore, measures should be in place to mitigate the radiological consequences of an accident. Such measures could include engineered safety features, on-site accident management procedures established by the operating organization and, possibly, off-site protective measures established by appropriate authorities.

DOSE LIMITS AND CONSTRAINTS

2.3. The design of a research reactor should be such as to ensure that authorized annual dose limits¹ for site personnel and the public will not be exceeded in operational states (normal operation and anticipated operational

occurrences) or in decommissioning. The authorized dose limits should not exceed the values of the dose limits established in Ref. [2].

2.4. As part of the implementation of the principle of optimization (as discussed in the following section), a dose constraint may also be applied to individual doses associated with occupational exposure and public exposure. The purpose of defining a dose constraint for each source of radiation is to ensure that the sum of doses to the critical group remains within the authorized annual dose limits. For workers who do not enter the designated supervised areas and controlled areas, the dose constraints should be set at the same level as the individual dose limit for members of the public [8]. The dose constraints for members of the public apply to the average dose to the critical groups² of the population, that is, groups of persons that are reasonably homogeneous with respect to their exposure for a given radiation source, and are representative of individuals who receive the highest dose as a result of the operations that are being undertaken [2, 4]. A critical group may be specific with respect to age or gender [9]. Pre-operational studies should be carried out to identify the critical groups and critical pathways for the exposure of such groups. The annual discharge limits for specific radionuclides in liquid and gaseous effluents permit increased release rates over short time periods, thus, operational flexibility should be defined, with consideration of the technical possibilities, and account taken of the dose constraints for members of the critical groups, using the approved critical exposure pathways for all relevant operations involving the use of radioactive material. In setting discharge limits, it should be ensured that the maximum dose to an individual in the critical group does not exceed the dose constraint.

APPLICATION OF THE PRINCIPLE OF OPTIMIZATION

2.5. In principle, specification of the authorized dose limits is left to the appropriate regulatory body. For keeping all doses within limits and as low as reasonably achievable, the following economic and social factors should be taken into account:

¹ An authorized dose limit is one that has been established or formally accepted by a regulatory body.

² The new ICRP publication on Assessing Dose of the Representative Individual for the Purpose of Radiation Protection of the Public represents the public by the 'representative individual' rather than the 'critical group'.

- (a) The radiation exposure resulting from a practice should be reduced by radiation protection measures to values such that further expenditure for radiation protection measures in design, construction and operation would not be warranted by the associated reduction in radiation exposure;
- (b) In the design, issues such as reducing major disparities in the doses due to occupational exposure received by workers of different types who work in the controlled area (see paras 5.46–5.50), and avoiding arduous working conditions in controlled areas (social factors), should be taken into account.

2.6. In general, application of the optimization principle in radiation protection implies that a choice is to be made from a set of possible protective measures. To this end, feasible options should be identified, the parameters to serve as criteria for comparison and their appropriate values should be determined and, finally, the options should be evaluated and compared. The optimization principle should also be applied to design features whose purpose is to prevent, or to mitigate the consequences of, accidents at the facility that could lead to radiation exposure of the site personnel or the public.

2.7. The fundamental role of optimization in the design of a research reactor and its components is to provide a basis for decisions on which engineered provisions for controlling radiation exposures are practicable. This is frequently a matter of judgement, based on past experience. In most cases, the principle of optimization should be applied to achieve a balance between the need for dose reduction, the need to ensure reliable reactor operation and the costs involved. A qualitative approach based on expert judgement and on the utilization of the best available and proven technology may be sufficient to make decisions on the optimum level of protection that can be achieved. At the design stage of a research reactor, or for a major modification or at the decommissioning stage, where significant expenditure is involved, the use of a more structured approach may be appropriate and techniques that aid decision making may be useful.

DESIGN TARGET DOSES

2.8. In order to ensure that the design is such that doses are kept to levels which are as low as reasonably achievable and represent best practice, ‘design target doses’ should be set for individual doses and the collective doses to

workers and to members of the public. The setting of design target doses³ for individual doses to site personnel and to members of the public should be consistent with the concept of dose constraints, which is discussed in paras 2.24 and 2.26 of Ref. [2]. The design target doses should be set in accordance with the dose constraints, and with consideration given to technical and economical alternatives.⁴ In this regard, if a reduction in dose below a target dose can reasonably be achieved, it should be done.

2.9. To focus the design effort on those aspects that contribute most to the collective dose and individual doses to the workers, it is useful to set design target doses in compliance with national regulations for the collective dose to the groups of workers who are likely to receive the highest doses, such as maintenance workers or health physics staff. It is also useful to set design target doses for the collective dose for each category of work, such as maintenance of the major components, in-service inspection, refuelling and waste management. These target doses, combined with assessments at key stages in the design process of predicted doses, can be used to monitor the major contributions to the dose.

DESIGN TARGET DOSES FOR ACCIDENTS

2.10. The adequacy of the design provisions for the protection of workers and the public against postulated accident conditions should be judged by a comparison of calculated predicted doses with specified criteria for exposure, which are the design target doses for accidents. In general, the higher the probability of the accident considered, the lower the specified design target dose should be. The operator and/or designer may take account of this principle by setting different design target doses for accidents with different probabilities of occurrence. In addition, the regulatory body may define design target doses by specifying frequency criteria for all accidents in specified dose bands. For design basis accidents, it would be expected that there will be either no off-site radiological consequences or only minor radiological consequences

³ The term ‘target dose’ is used throughout this Safety Guide in relation to both individual doses and collective doses.

⁴ It is important to recognize that design target doses are not limits. They are useful design tools in the optimization process. Provided that any excess can be justified, design target doses may be exceeded. However, the achievement of a design target dose does not, in itself, demonstrate that the design satisfies the optimization principle.

outside the site boundary, depending on the national regulatory requirements. The regulatory body should specify what constitutes minor radiological consequences. Typically, these would correspond to very restrictive dose levels in respect of which there would be no need for any off-site measures.

2.11. It is beneficial to address design basis accidents and beyond design basis accidents separately. In the case of beyond design basis accidents, it is appropriate to set design target doses. In addition to providing assurance to the regulatory body, design target doses may be set to meet the concerns of members of the public.

3. RESEARCH REACTORS AND ASSOCIATED RADIOLOGICAL HAZARDS

INTRODUCTION

3.1. Research reactors constitute a diverse group of facilities that can be classified in many ways (e.g. as research reactors, training reactors and prototype reactors, and critical assemblies, by type of moderator and coolant or by purpose of utilization). No matter how these facilities are categorized, it is clear that their radiological hazards and the methods of control of these hazards will vary greatly. This section and those that follow discuss issues relating to radiation protection and radioactive waste management at research reactors. It is the duty of the radiation protection officers to evaluate which of these issues are applicable to the type of facility for which they are responsible.

RADIOLOGICAL HAZARD ACCORDING TO REACTOR TYPE AND UTILIZATION

3.2. Not all of the types of radiation sources mentioned in the following sections are relevant for all types of research reactors, nor will the importance of each source be equal for all types of research reactors or their utilization. A careful evaluation of the hazards, their magnitude and their impacts for the specific type of research reactor should be carried out to ensure the proper implementation of adequate programmes for radiation protection and radioactive waste management.

3.3. The radiological hazard will depend predominantly on the following aspects, as explained in the following sections:

- (a) Power level of the research reactor and its radionuclide inventory;
- (b) Type of reactor;
- (c) Transient characteristics of the reactor;
- (d) Irradiation facilities and experimental facilities in and around the reactor core, in particular, beam tubes and any pneumatic ‘rabbit’ systems used to transfer irradiation samples to and from the core.

Power level and radionuclide inventory

3.4. In the case of research reactors with very low power levels, including critical assemblies, the low neutron fluxes generally result in an insignificant production of activation products. Systems for the retention or reduction of gaseous releases, as well as the continuous and sophisticated monitoring of releases, may therefore not be required. As the amounts of liquid and solid activation products are also low, there may be little or no need for water purification circuits or for the shielding of solid activated components, devices or pipes. The fission product inventory of the core of such reactors is generally low, and shielding is usually required only against direct radiation from the fuel elements.

3.5. For reactors with power levels above the 10 kW range, the requirement for engineered safety features for the retention of gaseous, liquid or solid activation products and for appropriate shielding against the radiation from them becomes gradually more stringent. Similarly, additional measures should be taken to cope with normal and possible abnormal releases. The need for programmes for radiation monitoring and waste management also increases.

3.6. For reactors with power levels above the 1 MW range, depending on the design of the core and the fuel elements, fuel melting becomes a possibility and special design features are required to preserve the integrity of the fuel (e.g. in the event of a loss of coolant accident). In this case, special consideration should be given to operational aspects, as well as to staff training, to ensure an appropriate response to such events. These aspects should also include the capability to monitor adequately any possible accidental releases.

Type of reactor

3.7. The type of reactor significantly influences needs for radiation protection. While most research reactors of low and medium power levels will have similar characteristics, some designs, in particular at higher power levels, should have particular radiation protection features and programmes.

3.8. This applies, for instance, to heavy water moderated reactors, for which special attention should be paid to the production of ^3H (tritium), including its monitoring. This also applies to liquid metal cooled reactors, for which special precautions should be prescribed for coping with incidental leaks of coolant. Another example is that of light water reactors, for which gamma radiation dose rates from ^{41}Ar and ^{16}N should be taken into consideration.

Power excursions (transients)

3.9. Power excursions (transients) may lead to comparatively high power levels and consequent high levels of direct radiation if the core is not well shielded. Power excursions may be of particular importance for research reactors or critical assemblies of low power level, which in normal operating conditions do not require significant shielding. In the design of the irradiation facilities (e.g. beam tubes), the direct radiation caused by transients should be considered.

3.10. If such power excursions are part of the design for normal operation, the equipment and installations for both monitoring and protection should be able to withstand high power levels. Power excursions give rise not only to intense direct radiation fields, but also to fuel degradation and the release of fission products from the fuel if it is not designed to cope with such excursions.

3.11. Inherent safety features with a strong negative temperature coefficient may be included in the design so that transients cannot lead to core degradation. Such features are often used in the design of pulsed reactors (with the intentional generation of transients).

Irradiation facilities and experimental facilities

3.12. Irradiation facilities and experimental facilities use direct radiation from the core, the irradiated fuel or activated sources, which may pose a radiation hazard to personnel. For such facilities, special design features should be put in place to provide for radiation monitoring and radiation protection. This applies

specifically to beam tubes and thermal columns, even for reactors of low power levels.

3.13. Irradiation loops or rigs can present a significant radiological hazard owing to the increased risk of a release of radioactive material caused by high pressures and temperatures. Issues relating to the possible melting of fissile materials, which are usually present in loops or rigs, should be considered in the planning of the radiation protection programme for the facility.

3.14. Special precautions should be taken in irradiating materials that may readily decompose or change state or whose chemical reactivity may be enhanced, causing an overpressure or the release of gases that may be flammable and/or explosive.

3.15. The effect on core reactivity of material placed in irradiation facilities should be determined prior to its irradiation, especially when the irradiated material contains fissile or fertile material.

SOURCES OF RADIATION

3.16. In the radiation protection programme for any facility, account should be taken of all sealed and unsealed radiation sources that may be present in the facility. A full listing of such sources and their forms, locations and related activities during normal operation, as well as during possible abnormal situations, provides the basis for shielding calculations, zoning, the design of ventilation systems, surveillance planning, dose assessment, radioactive waste management and the determination of effluent releases [10]. It should be noted that spent fuel presents a radiological hazard due to direct radiation and due to releases in the event of cladding failures. Consideration should be given, therefore, to the handling, storage, transport and subsequent disposal of spent fuel. Specific guidance is provided in Refs [11, 12].

3.17. The following are examples of possible radiation sources in a research reactor:

- (a) Fuel in the reactor core;
- (b) Spent fuel and core components stored in the reactor building;
- (c) Transuranic nuclides, fission products and activation and corrosion products in the spent fuel pool or the coolant system;
- (d) Equipment, systems and piping containing activation products;

- (e) Solid and liquid radioactive waste and material arising from the treatment of radioactive waste;
- (f) Gaseous radioactive material;
- (g) Experimental facilities with the potential to generate activated material or other radioactive material;
- (h) Tools and facilities for the storage and handling of radioactive material, including sample activation and/or irradiation facilities, in-core experiments, beam ports and hot cells;
- (i) Material that has been irradiated in the reactor;
- (j) Startup neutron sources;
- (k) Neutron detectors (particularly fission chambers and self-powered neutron detectors);
- (l) Components of purification systems, such as filters and ion exchange columns.

3.18. Examples of possible radiation sources in a research reactor to be taken into consideration in the programmes for radiation protection and radioactive waste management in design and operation are provided in Annex I.

4. ASPECTS OF RADIATION PROTECTION AND RADIOACTIVE WASTE MANAGEMENT IN DESIGN

APPROACH TO DESIGN FOR OPERATIONAL STATES AND DECOMMISSIONING

Human resources

4.1. The designer should be fully aware of the measures for operational radiological protection and for the management of radioactive waste that need to be incorporated into the design.

4.2. If necessary, the designer should invite experts from relevant operating organizations and maintenance organizations to participate in the design of a new research reactor and in making design modifications to an existing facility, to ensure that requirements for radiation protection and radioactive waste management are met. In addition, relevant operating experience should be

transferred to the designer. In this way, the interrelation between design aspects and operating procedures can be properly addressed.

4.3. To implement this structured approach, the designer should have an appropriate safety culture in which the importance of radiation safety and of the safety of radioactive waste at each stage of the design is recognized. As part of the application of the optimization principle at the design stage, project management should set up a system of shared knowledge and common objectives and attitudes to ensure that the management of occupational exposure and public exposure benefits from the cooperation of all personnel who are involved in the project.

4.4. A good operating culture associated with the application of the optimization principle should be established by ensuring that all participants in a project are aware of the general requirements for ensuring radiation protection and of the direct and indirect effects of their individual activities or functions on the provision of radiation protection for workers and the public.

4.5. More precisely, a good operating culture in the application of the optimization principle should be established on the basis of:

- (a) Knowledge of the practices that result in exposure of site personnel and of members of the public;
- (b) A comprehensive training programme;
- (c) Management of the relationship between operation, maintenance and design by means of appropriate methodology;
- (d) Familiarity with the main factors, including exposure pathways, that influence individual doses and collective doses;
- (e) Familiarity with the available software to assist in optimization of the design;
- (f) Recognition that specialists in radiation protection should be consulted whenever necessary to ensure that aspects of the design that affect radiation protection are properly evaluated and taken into account.

4.6. In order to ensure that optimal safety is provided for in the design, specialists in radiation protection and radioactive waste management should be closely involved in the design process. Use should be made in the design process of advice from specialists based on:

- (a) Their expertise in all areas relating to the production, handling and transport of radioactive material on the site and the transport of radioactive material to the environment;
- (b) Their ability to provide safety related inputs, such as evaluation of sources of radiation and the associated doses, using available software and data from relevant operating experience;
- (c) Their familiarity with the relevant regulations, guidance and best practices.

Organizational aspects

4.7. The need to achieve an adequate level of radiation protection affects a wide range of issues associated with the design. Hence, there is a need to ensure that all design decisions that affect exposure to radiation are consistent with the requirements for radiation protection. However, the design process should be planned in such a manner that implementation of these requirements is an integral part of the project and is not on the critical path (i.e. affecting its scheduling and completion). There should be a means of ensuring that the design engineers implement the measures required for radiation protection and waste safety at all necessary stages of the design process.

4.8. In the organization of the design project, it should be ensured that:

- (a) Radiation protection specialists and waste safety specialists are consulted at the early stages of the design when options for the major aspects of the design are being evaluated;
- (b) The design incorporates good engineering practices that operating experience has shown to be effective in reducing exposure, and deviations from such practices are only acceptable when a net benefit has been demonstrated;
- (c) All decisions that have a major impact on radiation safety and waste safety should be reviewed by radiation protection and waste safety specialists;
- (d) There is an appropriate review mechanism in place to resolve any design or operational issues that may be in conflict with requirements for radiation safety and waste safety.

4.9. The whole design process should be carried out under an appropriate management system [13, 14].

4.10. There should be a strong commitment on the part of management to ensure that the optimization principle is effectively applied.

Design strategy

General approach

4.11. As discussed earlier, the design target doses set at the start of the design process should include:

- (a) Constraints on the annual collective dose and annual individual dose to site personnel;
- (b) Constraints on the annual individual dose to members of the public.

4.12. In practice, these two design target doses can be addressed independently, although in principle they are interrelated. For example, any enhancement of the waste treatment systems to reduce the release of radioactive material to the environment may necessitate additional work being carried out by site personnel, with a consequent increase in their exposures. In providing the best practicable means for reducing radioactive releases, the implications should be assessed to ensure that there is no undue increase in the exposures of site personnel.

4.13. In setting the design target doses, account should be taken, where practicable, of experience at similar research reactor facilities where there has been a good operating record in terms of radiation protection. Account should be taken of any differences in the design and in operation between these reference facilities and the facility that is being designed. Such differences might include differences in the power level, the materials used, the type of fuel, the burnup and the experimental set-ups.

Design for radiation protection of site personnel

4.14. The design provisions to ensure the radiation protection of site personnel should be developed along the following lines:

- (a) A strategy for controlling exposures should be developed so that important aspects are considered early in the design. In most types of reactor design, design provisions in two areas may have major impacts in reducing exposures. The first area is scheduled and unscheduled maintenance. Appropriate design provisions should be made for

inspection and maintenance. Hence, a proven design with high reliability and a low level of requirements for maintenance, especially unscheduled maintenance, would be the preferred option. The second area that should be considered involves design features that minimize the production and buildup of radionuclides, since reducing amounts of radionuclides will reduce radiation levels and contamination levels throughout the facility, whereas a local solution, such as increasing the shielding or improving the ventilation, will have only a local benefit.

- (b) General requirements should be developed and documented. These will include the principles on which the layout of the facility will be based and restrictions on the use of particular materials in the design of the reactor.
- (c) A logical layout should be developed for the facility, and zones should be defined on the basis of predicted dose rates and contamination levels, access requirements and specific requirements, such as the need to separate components that perform safety functions. The dose rates may be calculated by using the source terms that provide the basis for the radiation protection aspects of the design, or they may be calculated on the basis of operating experience at similar research reactors, provided that there are no significant differences in the relevant parameters for design and operation. The zoning should be consistent with regulatory requirements.
- (d) The maintenance programme and operational tasks should be specified, preferably on the basis of well established concepts. The collective and individual doses should be evaluated. Full use should be made of relevant operating experience, where available, particularly for work that is difficult to predict, such as unplanned maintenance. In such cases, the use of mock-ups would assist in the reduction of uncertainties.
- (e) At each stage of the design, the doses that are evaluated should be compared with the design target doses and dose constraints. Where there are options for the design, optimization studies should be performed. These are particularly important in cases where it is predicted that the design target doses will be exceeded.

4.15. The design provisions to facilitate subsequent life extension should include the following features:

- (a) Design features to enable in-service inspection that may facilitate the replacement of ageing structures, systems and components. Structures and components that are relatively inaccessible should be identified, and in each case their design life should be specified and clearly documented;

- (b) Measures for the prevention of corrosion or other deterioration of the containment or means of confinement and of other items important to safety, including the use of protective coatings and/or cathodic protection;
- (c) Provisions for the installation and removal of irradiated sample coupons, where possible, to facilitate periodic inspection.

4.16. An auditable record should be kept of all the decisions that are made in the course of the design process and the reasons for those decisions, so that each aspect of the design that affects exposure to radiation is adequately justified. This record should be part of the management system for the design.

4.17. An outline of the decommissioning plan should be developed to facilitate verification that the design includes the necessary features required to reduce and control exposures during decommissioning. In many cases, these features are the same as those required in operational states, but some additional special features may be required to facilitate decommissioning. If these additional features are significant, the requirements for operational states and those for decommissioning should be optimized.

4.18. A thorough review of design features, for the purpose of facilitating decommissioning, should be performed at the design stage for the reactor facility. In general, design features that are conducive to maintenance and inspection during the operational lifetime of the reactor will also facilitate decommissioning. To facilitate decommissioning, attention should be given to a number of factors, including the following:

- (1) Careful selection of materials to minimize:
 - (i) Activation;
 - (ii) Generation of radioactive waste;
 - (iii) The spread of activated corrosion products;
 - (iv) The effort required for the decontamination of surfaces;
 - (v) The use of potentially hazardous substances (e.g. oils, flammable materials, chemically hazardous materials, fibrous insulations).
- (2) Optimization of the design, layout and access routes of the facility to facilitate:
 - (i) The removal of large components;
 - (ii) Easy detachment and removal (by remote means) of significantly activated components;
 - (iii) Future installation of equipment for decontamination and waste handling;

- (iv) Decontamination or removal of embedded components, such as pipes and drains;
- (v) Adequate space for the storage of waste;
- (vi) Control of radioactive material within the installation.

4.19. The design should facilitate compliance with the design target doses for occupational exposures using all or some of the following measures:

- (1) Reduction of dose rates in working areas by:
 - (i) Source reduction (e.g. by material selection, decontamination, control of corrosion, control of water chemistry, filtration and purification);
 - (ii) Improvement of shielding;
 - (iii) Increasing the distance between workers and sources (e.g. by means of provisions for remote handling);
 - (iv) Ensuring good ventilation.
- (2) Reduction of occupancy times in radiation fields by:
 - (i) Specifying high standards for equipment to ensure very low failure rates;
 - (ii) Ensuring ease of maintenance or ease of removal of equipment;
 - (iii) Simplifying operating procedures;
 - (iv) Ensuring ease of access and good lighting.

Design for radiation protection of members of the public

4.20. As discussed in the previous section, design target doses should be set at the start of the design process for the annual individual doses to members of the public. Developments in the area surrounding the site and likely future population distributions should be taken into account as necessary.

4.21. Compliance with the design target doses should be achieved by considering any site specific features that could affect doses to members of the public. Such features should be identified at an early stage of the design process and should be taken into account in the design. This should include the identification of critical groups and the exposure pathways for these critical groups.

Commissioning

4.22. The measures that are included in the design to provide an optimized level of radiation protection in operational states are usually adequate for

radiation protection in the commissioning stage. Special care should be taken, however, during power and overpower tests. During these tests, comprehensive measurements, tests and verifications for radiation protection purposes should be carried out for ensuring the adequacy of the design (see paras 5.34 and 5.35 of Ref. [15]).

DESIGN FEATURES FOR RADIOACTIVE WASTE MANAGEMENT

General

4.23. The design should incorporate features that facilitate the safe handling, storage, transport and disposal of radioactive waste and the control of effluent discharges.

4.24. The design should include provisions for the safe management of solid, liquid and gaseous radioactive waste within the facility and in associated experimental devices. Provisions for the storage of waste in transit and for the removal of waste should also be considered.

4.25. Where necessary, provision should be made for an interim containment in areas where radioactive effluent or radioactive waste is stored prior to its treatment and discharge.

4.26. The design should be such as to ensure adequate flexibility of the facilities for handling radioactive waste to cope with faulty containers and radioactive waste of non-standard physical or chemical composition.

4.27. The design should be such as to minimize the generation of radioactive waste in all operational stages in the lifetime of the facility, including decommissioning. Such considerations should be compatible with the safety analysis and with regulatory limitations on radiation doses. Measures deployed in research reactors of different types include the following:

- (a) Selection of materials that do not activate easily (e.g. use of plastic for the pneumatic 'rabbit' system irradiation target carriers) or materials that decay quickly when activated (e.g. use of aluminium components near the core);
- (b) Making allowance for the thermal expansion and contraction of pool water in a manner that avoids or minimizes overflow to liquid retention tanks;

- (c) Minimization of air spaces near neutron sources to reduce the production of ^{41}Ar .

4.28. The following features for limiting radiation exposure due to the radioactive waste generated during operation of the facility should be considered in the design:

- (a) Provisions that reduce the quantity and concentration of the radioactive waste generated and transported within the facility or released to the environment;
- (b) Provisions for the isolation of radioactive waste from site personnel and the public, with access control. For example, this might be accomplished by zoning the facility in accordance with the potential for radioactive contamination and radiation exposure;
- (c) Provisions for local detection, collection and treatment of liquid spills before they are discharged as effluents;
- (d) Provisions for the decontamination of personnel and equipment;
- (e) Provisions for handling the radioactive waste arising from decontamination activities.

4.29. The extent to which the containment or the means of confinement is vented in operational states to prevent the buildup of radioactive gases should be addressed in the design.

4.30. The varying nature of the waste both as waste accumulates and as the circumstances that influence the characteristics of the waste vary should be taken into account in the design of the shielding, the containment and the isolation features associated with facilities, equipment and components for waste management.

Management of gaseous effluents

4.31. Measures for the management of gaseous effluents should be considered in the design, including the following:

- (a) Provision for radioactive gases to be channelled through proper ducting as appropriate and brought to a common release point;
- (b) Provisions for the proper selection of process gases and decay devices (e.g. the use of delay tanks for ^{16}N or retention tanks) to minimize releases of radioactive material;