IAEA Safety Standards

for protecting people and the environment

Protection against Internal Hazards other than Fires and Explosions in the Design of Nuclear Power Plants

Safety Guide

No. NS-G-1.11

IAEA

International Atomic Energy Agency

IAEA SAFETY RELATED PUBLICATIONS

IAEA SAFETY STANDARDS

Under the terms of Article III of its Statute, the IAEA is authorized to establish or adopt standards of safety for protection of health and minimization of danger to life and property, and to provide for the application of these standards.

The publications by means of which the IAEA establishes standards are issued in the **IAEA Safety Standards Series**. This series covers nuclear safety, radiation safety, transport safety and waste safety, and also general safety (i.e. all these areas of safety). The publication categories in the series are **Safety Fundamentals, Safety Requirements** and **Safety Guides**.

Safety standards are coded according to their coverage: nuclear safety (NS), radiation safety (RS), transport safety (TS), waste safety (WS) and general safety (GS).

Information on the IAEA's safety standards programme is available at the IAEA Internet site

http://www-ns.iaea.org/standards/

The site provides the texts in English of published and draft safety standards. The texts of safety standards issued in Arabic, Chinese, French, Russian and Spanish, the IAEA Safety Glossary and a status report for safety standards under development are also available. For further information, please contact the IAEA at P.O. Box 100, A-1400 Vienna, Austria.

All users of IAEA safety standards are invited to inform the IAEA of experience in their use (e.g. as a basis for national regulations, for safety reviews and for training courses) for the purpose of ensuring that they continue to meet users' needs. Information may be provided via the IAEA Internet site or by post, as above, or by e-mail to Official.Mail@iaea.org.

OTHER SAFETY RELATED PUBLICATIONS

The IAEA provides for the application of the standards and, under the terms of Articles III and VIII.C of its Statute, makes available and fosters the exchange of information relating to peaceful nuclear activities and serves as an intermediary among its Member States for this purpose.

Reports on safety and protection in nuclear activities are issued in other publications series, in particular the **Safety Reports Series**. Safety Reports provide practical examples and detailed methods that can be used in support of the safety standards. Other IAEA series of safety related publications are the **Provision for the Application of Safety Standards Series**, the **Radiological Assessment Reports Series** and the International Nuclear Safety Group's **INSAG Series**. The IAEA also issues reports on radiological accidents and other special publications.

Safety related publications are also issued in the **Technical Reports Series**, the **IAEA-TECDOC Series**, the **Training Course Series**, and the **IAEA Services Series**, and as **Practical Radiation Safety Manuals** and **Practical Radiation Technical Manuals**. Security related publications are issued in the **IAEA Nuclear Security Series**.

PROTECTION AGAINST INTERNAL HAZARDS OTHER THAN FIRES AND EXPLOSIONS IN THE DESIGN OF NUCLEAR POWER PLANTS

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

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SAFETY GUIDE

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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 — 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.

IAEA SAFETY STANDARDS

SAFETY THROUGH INTERNATIONAL STANDARDS

While safety is a national responsibility, international standards and approaches to safety promote consistency, help to provide assurance that nuclear and radiation related technologies are used safely, and facilitate international technical cooperation and trade.

The standards also provide support for States in meeting their international obligations. One general international obligation is that a State must not pursue activities that cause damage in another State. More specific obligations on Contracting States are set out in international safety related conventions. The internationally agreed IAEA safety standards provide the basis for States to demonstrate that they are meeting these obligations.

THE IAEA STANDARDS

The IAEA safety standards have a status derived from the IAEA's Statute, which authorizes the Agency to establish standards of safety for nuclear and radiation related facilities and activities and to provide for their application.

The safety standards reflect an international consensus on what constitutes a high level of safety for protecting people and the environment.

They are issued in the IAEA Safety Standards Series, which has three categories:

Safety Fundamentals

— Presenting the objectives, concepts and principles of protection and safety and providing the basis for the safety requirements.

Safety Requirements

— Establishing the requirements that must be met to ensure the protection of people and the environment, both now and in the future. The requirements, which are expressed as 'shall' statements, are governed by the objectives, concepts and principles of the Safety Fundamentals. If they are not met, measures must be taken to reach or restore the required level of safety. The Safety Requirements use regulatory language to enable them to be incorporated into national laws and regulations.

Safety Guides

— Providing recommendations and guidance on how to comply with the Safety Requirements. Recommendations in the Safety Guides are expressed as 'should' statements. It is recommended to take the measures stated 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. Each Safety Requirements publication is supplemented by a number of Safety Guides, which can be used in developing national regulatory guides.

The IAEA safety standards need to be complemented by industry standards and must be implemented within appropriate national regulatory infrastructures to be fully effective. The IAEA produces a wide range of technical publications to help States in developing these national standards and infrastructures.

MAIN USERS OF THE STANDARDS

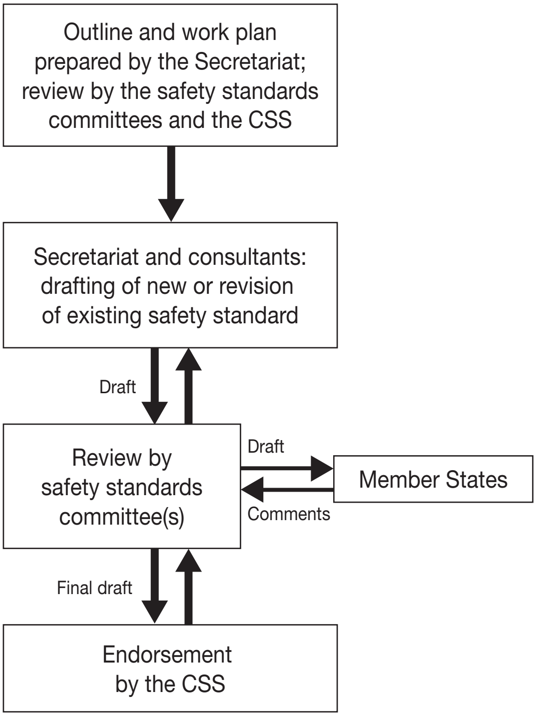
As well as regulatory bodies and governmental departments, authorities and agencies, the standards are used by authorities and operating organizations in the nuclear industry; by organizations that design, manufacture and apply nuclear and radiation related technologies, including operating organizations of facilities of various types; by users and others involved with radiation and radioactive material in medicine, industry, agriculture, research and education; and by engineers, scientists, technicians and other specialists. The standards are used by the IAEA itself in its safety reviews and for developing education and training courses.

DEVELOPMENT PROCESS FOR THE STANDARDS

The preparation and review of safety standards involves the IAEA Secretariat and four safety standards committees for safety in the areas of nuclear safety (NUSSC), radiation safety (RASSC), the safety of radioactive waste (WASSC) and the safe transport of radioactive material (TRANSSC), and a Commission on Safety Standards (CSS), which oversees the entire safety standards programme. All IAEA Member States may nominate experts for the safety standards committees and may provide comments on draft standards. The membership of the CSS is appointed by the Director General and includes senior government officials having responsibility for establishing national standards.

For Safety Fundamentals and Safety Requirements, the drafts endorsed by the Commission are submitted to the IAEA Board of Governors for approval for publication. Safety Guides are published on the approval of the Director General.

Through this process the standards come to represent a consensus view of the IAEA's Member States. 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 standards. Some 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 International



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

Labour Organization, the OECD Nuclear Energy Agency, the Pan American Health Organization and the World Health Organization.

The safety standards are kept up to date: five years after publication they are reviewed to determine whether revision is necessary.

APPLICATION AND SCOPE OF THE STANDARDS

The IAEA Statute makes the safety standards binding on the IAEA in relation to its own operations and on States in relation to operations assisted by the IAEA. Any State wishing to enter into an agreement with the IAEA concerning any form of Agency assistance is required to comply with the requirements of the safety standards that pertain to the activities covered by the agreement.

International conventions also contain similar requirements to those in the safety standards, and make them binding on contracting parties. The Safety Fundamentals were used as the basis for the development of the Convention on Nuclear Safety and the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. The Safety

Requirements on Preparedness and Response for a Nuclear or Radiological Emergency reflect the obligations on States under the Convention on Early Notification of a Nuclear Accident and the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency.

The safety standards, incorporated into national legislation and regulations and supplemented by international conventions and detailed national requirements, establish a basis for protecting people and the environment. However, there will also be special aspects of safety that need to be assessed case by case at the national level. For example, many of the safety standards, particularly those addressing planning or design aspects of safety, are intended to apply primarily to new facilities and activities. The requirements and recommendations specified in the IAEA safety standards might not be fully met at some facilities built to earlier standards. The way in which the safety standards are to be applied to such facilities is a decision for individual States.

INTERPRETATION OF THE TEXT

The safety standards use the form ‘shall’ in establishing international consensus requirements, responsibilities and obligations. Many requirements are not addressed to a specific party, the implication being that the appropriate party or parties should be responsible for fulfilling them. Recommendations are expressed as ‘should’ statements, indicating an international consensus that it is necessary to take the measures recommended (or equivalent alternative measures) for complying with the requirements.

Safety related terms are to be interpreted as stated in the IAEA Safety Glossary (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 within the 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 main text (e.g. material that is subsidiary to or separate from the body text, is included in support of statements in the main text, or describes methods of calculation, experimental 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 standard. Material in an appendix has the same status as the main 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. An annex is not an integral part of the main text. Annex material published by the IAEA is not necessarily issued under its authorship; material published in standards that is under other authorship may be presented in annexes. Extraneous material presented in annexes is excerpted and adapted as necessary to be generally useful.

CONTENTS

1. INTRODUCTION

BACKGROUND

1.1. This Safety Guide, which supplements the Safety Requirements publication on the Safety of Nuclear Power Plants: Design [1], was prepared under the IAEA's programme for establishing Safety Requirements and Safety Guides applicable to land based stationary thermal neutron nuclear power plants. Examples provided in this Safety Guide pertain to light water reactor plants; however, the recommendations provided in this Safety Guide are generally applicable to other types of plant with thermal neutron reactors.

1.2. This Safety Guide supersedes the Safety Guide on Protection against Internally Generated Missiles and their Secondary Effects in Nuclear Power Plants, published in 1980 as Safety Series No. 50-SG-D4. This revision principally consists of updating the technical content and the discussion. In the revision process, it was decided to extend the scope to cover internal hazards[1] in general (other than fires and explosions, which are covered in a separate Safety Guide [2]).

OBJECTIVE

1.3. The purpose of this Safety Guide is to provide guidance relating to an assessment of the possible consequences of internal hazards in nuclear power plants. This Safety Guide provides interpretation of the possible Safety Requirements on Safety of Nuclear Power Plants: Design [1] and recommendations on how to fulfil them. It is intended for use by safety assessors and regulators involved in the licensing process as well as designers of nuclear power plants, and it provides guidance on the methods and procedure for analyses to support an assessment of the possible consequences of internal hazards.

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[1] An internal hazard is a hazard that is initiated in the operations area of the plant, within the operations boundary of the site.

SCOPE

1.4. This Safety Guide discusses postulated initiating events[2] (PIEs) that may occur in the different operational states of the plant as stipulated in Ref. [1], and supplements the relevant paragraphs of Ref. [1]. It introduces the probabilistic and deterministic approaches for reviewing the following:

(a) PIEs, postulated in a deterministic approach, and their probability of occurrence[3], which is estimated in the probabilistic approach;
(b) The potential for or probability of structures, systems and components[4] (SSCs) being affected;
(c) The potential for or probability of damaging consequences;
(d) The overall assessment of consequences, to make judgements on their acceptability.

1.5. Guidance is provided on how to analyse the consequences of PIEs, including the analysis of secondary and cascading effects as well as the corresponding functional analysis. Means of protection against internal hazards are discussed, as well as methods and means of reducing the aforementioned probabilities.

1.6. The following internal hazards are reviewed in this Safety Guide: missiles; collapsing and falling objects; and pipe failures and their consequences (pipe whip, jet effects and flooding). For each of these hazards a description of the PIE and a discussion of specific considerations relating to prevention and protection against this PIE are provided. Other internal hazards (e.g. vehicular impacts on SSCs or the release of toxic or asphyxiant gases) are not explicitly

[2] A postulated initiating event is an event identified during design as capable of leading to anticipated operational occurrences or accident conditions. The primary causes of PIEs may be credible equipment failures or operator errors (both within and external to the facility), and human induced or natural events.

[3] Strictly speaking, this is a frequency of occurrence rather than a probability. To conform with the relevant technical literature, however, the terminology of probability is used in this Safety Guide.

[4] ‘Structures, systems and components’ is a general term encompassing all of the elements (items) of a facility or activity which contribute to protection and safety, except human factors. Structures are the passive elements: buildings, vessels, shielding, etc. A system comprises several components, assembled in such a way as to perform a specific (active) function.

covered in this Safety Guide but should be taken into account where applicable.

1.7. It is recognized that for existing plants some design orientated recommendations may not be practicably achievable; however, to the extent feasible, recommendations concerning maintenance, surveillance and in-service inspections should always be met. Consideration should also be given to analysing the consequences of failure for cases in which corrective actions are not feasible.

1.8. This Safety Guide deals principally with light water reactors. However, some considerations may be of interest for other types of reactor.

STRUCTURE

1.9. Section 2 is dedicated to general considerations in dealing with internal hazards; it covers the selection of PIEs, considerations on acceptability, analysis of consequences (including cascading and secondary effects) and considerations for protection and safety. In Section 3 the aforementioned internal hazards are reviewed. A section is dedicated to pipe failure, which is an initiating event common to pipe whip, jet effects and flooding.

2. GENERAL CONSIDERATIONS

POSTULATED INITIATING EVENTS

2.1. Requirements and concepts for the safe design of nuclear power plants are developed in Ref. [1], in which PIEs are defined. PIEs can challenge any level of defence in depth and have to be considered in the design process. The PIEs to be considered will include internal hazards. PIEs are defined in appendix I of Ref. [1].

2.2. According to Ref. [1], the plant design is required to minimize sensitivity to PIEs, which are selected on the basis of probabilistic or deterministic techniques. Appropriate measures for prevention and mitigation should be provided to cope with their consequences (see paras 4.3, 4.7, 4.8, 5.8 and 5.14 of Ref. [1]). These points are elaborated upon in this Safety Guide.

ACCEPTABILITY CONSIDERATIONS

2.3. According to the general principle of defence in depth, the following should be considered in the design of a plant:

(a) The prevention or limitation of the occurrence of PIEs;
(b) The protection of the SSCs whose availability is necessary to bring the plant into and maintain it in a safe shutdown state, or whose failure could result in unacceptable radioactive releases, against all possible effects caused by the PIEs considered;
(c) The robustness of the SSCs (such as their qualification);
(d) Other features, such as possible inherently safe behaviour, redundant parts of systems important to safety, diverse systems and physical separation.

2.4. PIEs and their effects should be included in the safety assessment of any equipment failure unless it can be shown that either:

(a) The probability of occurrence of this PIE (this probability is denoted P_1) is acceptably low (see para. 2.11–2.13) so as to preclude the need for considering its consequences; or
(b) The probability of a system or component being affected (this conditional probability is denoted P_2) is sufficiently low (see para. 2.11–2.13); or
(c) If a system is affected, the probability of this leading to unacceptable consequences[5] (this conditional probability is denoted P_3) is sufficiently low (see para. 2.11–2.13); or
(d) The overall probability of unacceptable consequences (this probability is denoted P) is sufficiently low (see para. 2.11–2.13). P is conceptually equal to the product $P_1 \times P_2 \times P_3$. P should be estimated with account taken of redundancy and other favourable design features as well as the possibility of common cause failures, the assumed unavailability of certain components and other unfavourable occurrences.

[5] 'Unacceptable consequences' means the loss of one or more of the three safety functions defined in the requirements of Ref. [1]: (a) the control of reactivity; (b) the removal of heat from the core; and (c) the confinement of radioactive material and the control of operational discharges, as well as the limitation of accidental releases.

2.5. These probabilities can be illustrated as follows:

(a) Conservative design is a way of reducing P_1.
(b) Provisions in the layout, such as physical separation between source and targets[6], are a way of reducing P_2.
(c) Comprehensive design and qualification of possible targets is a way of reducing P_3.
(d) Use of adequate operating procedures is a way to minimize P; for example, by minimizing the probability of inadvertent flooding (an effect on P_1) or by avoiding the spreading of a flood by taking proper actions (an effect on P_2).

2.6. In a deterministic approach such measures are deemed to preclude the occurrence of a PIE and/or an inadmissible impact on safety. This means that at least one of the probabilities P_1, P_2 or P_3 is deemed to be reduced to zero. In a probabilistic approach, comprehensive plant specific reliability data would preferably be used; otherwise the probabilistic approach could be used as a complement to the deterministic approach.

2.7. In order of preference, the best design approach is to practically eliminate the PIE (i.e. to make P_1 acceptably small); the next best approach is to separate SSCs from sources (i.e. to make P_2 acceptably small); there is also the option of making the consequences acceptable (i.e. to make P_3 acceptably small). However, to the extent possible, defence in depth should be maintained by ensuring that the second level of defence and, if necessary, the third level of defence are effective. It may also be necessary in some cases to use a combination of all three levels.

2.8. There may be groups of similar components designed according to the same principles that have comparable quality standards and conditions of operation. It may be possible to analyse the hazards associated with such components by means of a single analysis of the probability P_1.

2.9. In designing a nuclear power plant, protection against internal hazards should be considered at the time of the decision making process for the layout of the plant in order to minimize P_1 (e.g. some falling objects may be eliminated as PIEs if they can be installed on the ground floor) and/or P_2 (as in selecting an adequate location of the turbine generators in relation to the reactor building).

[6] The target is the safety related system concerned.

The extent of this minimization is highly dependent on the details of the plant layout and equipment.

2.10. In the course of the design or modification of a plant, the procedure for analysis as described here can be used as an optimization tool, and this may lead to design changes aimed at reducing one or more of the P_i factors. In a probabilistic approach, this procedure should be used for providing evidence of acceptable protection.

2.11. There is a wide variation in the level of confidence with which the frequencies and the consequences of rare events can be determined. Most reliance should be placed on those items that can be effectively controlled. This may mean in one case concentrating on the reduction of P_1 and in another case focusing mainly on P_2 or P_3. In order to cope with the uncertainty in quantifying P_1, P_2 or P_3, studies involving an appropriate combination of analytical and experimental work should be performed, to determine the worst case and to enable a conservative estimate to be made.

2.12. Where the related risks are uncertain, because of the uncertainty in quantifying the extraordinary severe consequences or the lack of confidence in the estimated probabilities, special care should be taken by providing for measures such as surveillance, monitoring, inspection, shielding and especially physical separation.

2.13. Inherent in the above discussion is the concept of an acceptably small probability. Specific values of P_1, P_2 and P_3 or their products are not provided in this Safety Guide; they will depend on practices in different States.

2.14. Decisions are made, either implicitly or explicitly, to give certain potential hazards very detailed and thorough consideration, while others receive only cursory review. Such decisions are based on risk. There is sometimes a limiting probability for events of certain maximum consequence, below which probability the risk is considered to be acceptable[7]. More often, the guidelines are heuristic and the probability limits are implicit. In this latter situation decisions are made on each case separately on the basis of deterministic calculations (such as calculations for stress analysis, the analysis of fracture

[7] In some States an acceptably small probability P is defined as being less than 10^{-7} to 10^{-6} per year, depending on the method and on the installation concerned.

mechanics or impact damage) combined with qualified expert judgement. The approval of specific bases for acceptability is a matter for the regulatory bodies.

ANALYSIS FOR SECONDARY AND CASCADING EFFECTS

2.15. PIEs may cause damage directly; this is termed a primary effect. In addition, they may cause damage indirectly by means of failure mechanisms that can propagate the damage. Damage caused indirectly by a PIE is termed a secondary effect. These secondary effects may cause damage that could exceed that caused by the primary effects. Where postulated equipment failure necessitates a safety assessment to demonstrate that the fundamental safety functions will be fulfilled, all cascading secondary effects of the failure should be included. In certain circumstances, the PIEs addressed in this Safety Guide may be regarded as secondary effects of another PIE; for example, a pipe whip may result in a secondary missile.

2.16. Secondary effects are such in nature that the potential damage can vary widely. Many factors come into play that are beyond the control of a designer. Owing to these difficulties, the preferred practice should be to emphasize the means of stopping the cascading effect or, in other words, of reducing P_1 and/or P_2 rather than P_3. The prevention of a pipe break should receive special attention since it may prevent several potential PIEs (e.g. flooding, pipe whip and jet effects).

2.17. Secondary and cascading effects induced by PIEs should be considered in the design of the plant. The design provisions should be supplemented by verification after construction by means of a systematic and thorough approach to ensure that all the possibilities have been considered. One such approach is to use a checklist in which all possible secondary effects have been listed and space is provided to note the basis for concluding that no unacceptable indirect damage could result. This approach should be supplemented by walk-down inspections.

2.18. In this systematic analysis, among the important secondary effects the following should be evaluated:

(a) *Secondary missiles.* A missile or a pipe whip may produce secondary missiles, such as pieces of concrete or parts of components, which may do unacceptable damage. In general it is very difficult to characterize such secondary missiles, and the most prudent course of action is to prevent their generation or to contain them at their source. For example, spontaneous multiple pipe breaks resulting in separated pipe parts as (secondary) missiles are improbable if the ductility and the fracture toughness of piping material are sufficiently high.

(b) *Falling objects*. There may be circumstances in which a pipe whip or a missile can damage the supporting structure of a heavy object located above a safety system such that an object falls, possibly causing further damage. It may in certain cases be possible to show that the falling object cannot cause unacceptable damage. If not, either the supporting structure should be modified to withstand the missile impact or means should be provided to prevent such an impact.

(c) *Failure of high energy pipes*[8] *and components*. If a PIE can result in the rupture of a pipe or component containing fluid with significant stored energy, this fluid energy may be released in such a way as to cause further damage by any of the following means or mechanisms: jets; high pressures; pressure waves; increasing temperatures and humidity levels; pipe whip; flooding; secondary missiles; chemical reactions; and high radiation levels. The rupture of high energy pipes or components may also give rise to a loss of coolant accident or other accidents that should be considered in the qualification of the safety systems. Unless it can be shown simply on the basis of the available energy and the location of the potential rupture, or by other suitably substantiated analytical means, that none of the above mechanisms would lead to significant damage to safety systems, means should be provided to prevent the PIE from rupturing the pipe or component, or possibly to minimize the likelihood of this event.

(d) *Flooding*. Where there is the possibility of an energetic missile striking pipes, tanks or pools normally filled with liquid, the potential for damage due to flooding should be evaluated. The draining of coolant from equipment or tanks by a siphoning action should also be considered in assessing the consequences of a pipe rupture. Depending on the amount and nature of the liquid concerned, indirect damage to items important to safety can result by means of such effects as an electrical short circuit, fire, hydrostatic pressure effects, wave action, thermal shock, instrument errors, buoyancy forces and criticality risk (in relation to boron dilution). If there is a potential for the significant flooding of items important to safety, in most cases the prudent course of action is to reduce P_2 to

[8] A high energy pipe is defined as a pipe with an internal operating pressure equal to or exceeding 2.0 MPa or an operating temperature equal to or exceeding 100°C in the case of water. Other limits may apply for other fluids. In some States pressurized gas piping systems are regarded as high energy systems regardless of the pressure.

acceptable levels, since it is very difficult to predict and mitigate all the possible effects of flooding.

(e) *Radioactive release.* Release of radioactive material may result from an impact on items containing such material or on items that are necessary for its control. The release may also result from flooding. Such a release may affect the functioning of some components. (Avoiding any release of radiation that could be of radiological significance is the general nuclear safety objective as established in Ref. [1], and this would be addressed by any safety analysis; in this sense, it is not a secondary effect.)

(f) *Chemical reactions.* Missile impacts or pipe whip impacts can release dangerous chemicals, while flooding, gaseous dispersion or jet effects may result in chemical reactions. The chemical reactions of concern may include: (i) the release of flammable or explosive fluids, which can result in fires or explosions; (ii) exothermic reactions between chemicals usually kept separate; (iii) attack by acids on structures or components; (iv) reactions such as rapid corrosive attacks that can weaken important materials or can generate large quantities of gas with consequent pressure effects; (v) reactions that can release toxic materials (either as the release of a source or as a result of chemical reactions); and (vi) the release or production of asphyxiant gases. As with flooding, the possible effects of chemical reactions are many and varied and are difficult to predict. The prudent course of action is to make P_2 acceptably small. In this regard the use of any chemical substances that might support such reactions should be limited to minimal amounts and only when indispensable.

(g) *Electrical damage.* Missiles, pipe whip and flooding may damage electrical equipment or cause its malfunction (such as spurious actuation). The number and extent of items of electrical equipment and wiring in a nuclear power plant make it virtually certain that a missile traversing the plant would disable some electrical circuits. The mechanism for damage in such cases can include the severance of cables, the destruction of equipment or electrically initiated fires. In designing protection against indirect damage from impacts on electrical equipment, such techniques as the physical separation of redundant circuits, the use of fail safe circuits, the proper application of fuses and circuit breakers, adequate fire protection and the appropriate use of barriers should all be evaluated. The most appropriate course of action will be determined by the specifics of the PIE under consideration. For example, if a postulated missile is metallic and can introduce unintended connections between cables, this may influence the degree of reliance on fuses and may make other means of electrical protection more attractive. It should be noted that the complex potential failure modes of electronic circuits mean that it is unlikely that a full assessment of the hazard consequences can be made; a pessimistic failure mode should be assumed unless the items are protected from the effects of the hazard.

(h) *Damage to instrumentation and control lines.* Some air or fluid commanded equipment as well as some instrumentation lines needed for the monitoring or control of technical parameters may be damaged owing to the phenomena of missiles, pipe whip or jet effects. This could lead to the spurious actuation of systems or to inadequate information being provided to the operator. A similar pessimistic assumption applies as for electrical damage.

(i) *Fire.* PIEs may result in fires; for example, if an impact produces a source of ignition energy such as an electrical arc in the proximity of flammable material. Chemical reactions or electrical short circuits may also result in fires. The potential for damage due to fires and possible further actions should be evaluated in accordance with Ref. [2].

(j) *Personal injury.* PIEs may directly or indirectly cause injury to plant personnel. In areas usually occupied by plant personnel performing a safety function, the probability of an impact due to a PIE should be made acceptably small. The PIE may also render areas inaccessible to personnel. If intervention by personnel is required in such areas, a means of rendering them safe should be established or else the need for such actions should be removed.

2.19. In the event that a PIE can be regarded as leading directly to an anticipated operational occurrence, it should be demonstrated that the design is capable of preventing escalation to a design basis accident. Similarly, in the event that a PIE can be regarded as leading directly to a design basis accident, it should be demonstrated that the design is capable of preventing escalation to a beyond design basis accident. For the analysis of these PIEs, the single failure criterion[9] will apply to the corresponding safety group, whereas, for the analysis of other initiating events, the components that are not affected by the event may be regarded as available [3].

2.20. In addition, the set of PIEs considered in the plant's safety analysis report represents only the few most challenging PIEs. The set of PIEs that should be considered in relation to internal hazards should be larger. It should cover a

[9] A single failure is a failure that results in the loss of capability of a component to perform its intended safety function(s), and any consequential failure(s) which result from it. The single failure criterion is a criterion (or requirement) applied to a system such that it must be capable of performing its task in the presence of any single failure.

complete set of probable breaks for the systems important to safety as well as for auxiliary systems whose failure could affect safety systems.

2.21. The procedure for analysis will best be performed in a stepwise manner. In the screening process, candidate components for PIE sources should be identified. This screening process should be followed with due caution, and in case of doubt the component in question should not be excluded but rather put on the list of potential hazards that have to be analysed in more detail. Probabilistic safety assessment may be useful for this purpose.

2.22. The screening process should describe the situations that give rise to the need for safety systems to operate. These situations are the PIE itself (if, for example, the PIE consists of a loss of coolant accident), the damage due to primary effects and the subsequent damage, if any, caused by secondary effects.

2.23. Further on, this process should be used to determine the systems that are operable. A system may be unavailable either because of the PIE itself or because a component of a safety system may be unavailable for reasons that lie beyond the scope of this Safety Guide. For example, a component of a safety system is assumed to have sustained a single failure or to be in the test or maintenance mode, or an operator error is assumed. Possible common cause failures should be taken into account.

2.24. It should be determined whether the remaining (intact) capacity of the safety systems is still sufficient for dealing with the situation that has occurred (i.e. the PIE together with the induced effects and cascade failures). If the adequate performance of the safety systems cannot be demonstrated, then either additional protection should be provided or the redundancy of the safety systems should be increased, or a combination of the two could be used, provided that adequate performance of the safety systems can be demonstrated.

2.25. In practice, protection against internal hazards will involve a great deal of engineering judgement and use of pragmatic rules. Therefore, as far as practicable, an experimental background should be provided in support of the theoretical analysis.

2.26. In placing reliance on special devices or features designed to cope with the consequences of a PIE, precautions should be taken to ensure that the special device is qualified for the PIE under consideration and that it will not itself become the source of a new PIE.

Methods and means to prevent PIEs

Design

2.27. A conservative design, with rigorous design limits, establishes the first level of defence against the failure of components and should be executed in order to reduce P_1. Careful analysis of static, dynamic and thermal loads, and combinations thereof, applied to the equipment, the application of adequate safety factors and thorough pre-service control of material properties, and the application of adequate quality assurance measures in fabrication, are commonly practised. The use of safety devices or systems to limit the maximum pressure or the rotational speed, for example, should also be considered as a way of reducing P_1. To the extent possible, the effects of ageing should be taken into account in the design of the components.

2.28. In cases in which the consequences of an equipment failure would jeopardize safety, the aforementioned design approach should be combined with inspection or surveillance at least, or with other methods of reducing P_1.

Inspections (see also Ref. [4])

2.29. Periodic non-destructive examination of the piping and components in reactor pressure circuits, as well as of their supports, should be required to detect flaws in the material that may have become enlarged during operation. The sensitivity of the inspection techniques that are used should be set to detect and characterize flaws substantially smaller than those that could cause severe failure. Care should be exercised to ensure that ongoing inspections do not increase P_1 by the thinning of pipework (or by other means).

2.30. If in-service inspection is to be effective, flaws caused in manufacturing should be identified and analyses should be made to predict their growth. Inspections should be made frequently enough to provide an adequate margin of time between the detection of growth and possible rupture. Periodic non-destructive examinations may be supplemented by surveys. An example is a survey for evidence of movement such as might be indicative of water hammer or other unintended loadings. Factors such as fatigue, corrosion or creep that can accelerate the growth of flaws should be thoroughly investigated.

2.31. In the event that an unexpected defect or plant malfunction is identified that challenges a given SSC, the possible implications for similar items in the plant, and possibly in similar plants elsewhere, should be considered.

2.32. Such in-service inspection in combination with other measures for reducing the probability of failure and with studies in depth, as, for example, in the leak before break acceptance procedure, can provide an acceptable basis for not postulating the gross failure of certain pressure vessels and piping as well as certain rotating equipment, so that no additional design measures are necessary to provide protection against certain types of internal hazard (missiles and pipe whip). However, the consequences of leaks such as jet impingement, flooding, humidity, increased temperatures, asphyxiant effects and radioactive releases should be considered.

Monitoring systems

2.33. In cases in which it is desired to reduce P_1, one technique of surveillance is to monitor the conditions that may give an indication of incipient failure. This technique is based on the experience that most failures, especially failures in ductile metal components, develop gradually, permitting corrective action to be taken in due time before a dangerous situation arises. Of all the methods used for reducing P_1, effective monitoring results in the least perturbation to the design or operation of the plant. It should be recognized that monitoring provides only a warning and does not prevent failures. Furthermore, the surveillance systems may provide information useful for maintenance planning. See also Ref. [4].

2.34. Applications of monitoring in nuclear power plants should include leakage detection systems for pipes and pressure vessels, monitoring for vibration on large rotating equipment and monitoring for loose parts; other examples of monitoring are directed at, for example, low and high cyclic fatigue, displacements, water chemistry, vibrations and thermal stratification effects, ageing effects, wear detection and the chemistry of lubricating materials.

2.35. In the design of a monitoring system, feedback of operational experience, including ageing effects, should be taken into account. Systems for vibration monitoring in rotating machines, for leak detection in high pressure water systems and for the detection of loose parts have been in use for these applications on a wide scale and for a long time. There have been many recorded instances in both nuclear and conventional power plants of vibration monitors alerting the plant operators to the deterioration of equipment in time to prevent major damage. In most nuclear power plants multiple systems based on humidity and temperature, radiation levels, pressures or sump water levels, among other things, have been installed to detect leaks of various sizes and in various locations. Here, too, there have been many cases in which small leaks were detected by installed monitors or routine plant inspections and major failures were thereby avoided.

2.36. The degree of reliance placed on monitoring systems in reducing equipment failures varies in practice. According to the principle of defence in depth, the use of monitoring systems should be considered a supplement to other means of reducing equipment failures rather than a sufficient measure on its own. For example, in the case of the prevention of primary circuit ruptures, leak detection systems and acoustic monitoring systems are considered adjuncts to conservative design and manufacturing, non-destructive examination and several other factors. However, even all of these measures together may be insufficient to obviate the need to postulate a pipe rupture for design purposes for higher order safety features or structures and components. An appropriate maintenance programme should be conducted for the monitoring system.

2.37. To preclude or to reduce the probability of large pipe breaks, and with them the consequences of missiles, pipe whip and jet impingement, for example, a comprehensive procedure should be performed to qualify certain piping systems[10].

2.38. Adequate operational procedures may also contribute to reducing the probability of generating a PIE. Examples include: the prevention of excessive thermal stresses in metal pressure vessels and the monitoring of vessel material for radiation embrittlement; the limitation of plant transients by the use of pressure relief valves and safety features activated by the protection system; prohibitions or restrictions during the conduct of dangerous operations; the use of seismic instruments to provide data for the assessment of the condition of the plant for continued operation following an earthquake; and the control of

[10] Examples of comprehensive procedures to qualify piping systems are the European safety practices on the application of the leak before break concept (EUR 18549), the United States Nuclear Regulatory Commission’s leak before break application (SRP 3.6.3.), the break preclusion procedure used in Germany (RSK guidelines) or the leak before break guideline used in Japan (JEAG 4613).

the water chemistry in the primary circuit and the secondary circuit to inhibit corrosion and corrosion assisted initiation of cracks.

Methods and means of protection of SSCs against possible effects

Provisions in the layout

2.39. Provisions in the layout should be made early in the process of plant design as a valuable way of reducing P_2. In this regard, feedback of experience from similar installations should be taken into account. Decisions on layout are of particular importance in relation to missiles and flooding hazards, and these considerations are addressed in the corresponding sections of this Safety Guide.

Barriers and physical separation

2.40. If the general layout of the plant is not sufficient for reducing P_2 to an acceptable level, it is possible to provide barriers between the source of the PIE and the candidate affected component. The barriers should preferably be placed close to the source of dynamic effects (missiles, pipe whip and other impacting masses). This covers the protection of all potential targets in the case of a missile and eliminates possible concerns about scattering. Additionally, where the postulated impacting mass can continue to gain energy during its travel, as in jet driven missiles or whipping pipes, the design requirements for the barrier are least severe nearest the source. However, it may be that the existing structure provides adequate protection for all but one or two small targets in some particular case, and then a special barrier might best be placed at the targets. In the case of postulated flooding, barriers should be provided in the form of appropriate doors, thresholds, platforms and retention walls. However, due consideration should be given to aspects of testing and maintenance; for example, weld seams should be kept easily accessible from the outside of vessels and pipes.

2.41. Physical separation should be provided between redundant items of safety equipment (including power supplies, instrumentation cables and any related systems) on the basis that the multiple components should be independent and their separation will help to eliminate some situations in which common external factors could result in multiple failures. On the basis of a case by case evaluation, it should be determined for any PIE whether or not multiple safety systems can be damaged. Special care should be taken when there are possible secondary effects, since a PIE could damage one component and the secondary effects could damage its redundant matching components.

Methods and means of avoiding unacceptable consequences

2.42. Wherever possible the design of SSCs should be a failure tolerant design. That is, should these items fail, their failure would tend to move the plant towards a safe plant condition. This technique has broader application to areas other than protection against internal hazards, but where valid it may help in mitigating the effects of postulated internal hazards.

2.43. As already discussed, PIEs may result in a subsequent release of fluid, which may change the environment in the plant by locally increasing the humidity, temperature, pressure and radiation level. Equipment should be used that can perform its safety functions in this environment and that is accordingly qualified. If a component is not qualified for such an environment, it should be deemed not available or it should be protected by means of encapsulating, shielding or another appropriate measure. However, an enclosure complicates maintenance activities and necessitates that the seal be restored upon the completion of each maintenance action.

2.44. The provision of an unpressurized guard pipe around certain sections of piping carrying high pressure fluids has been used in various cases as a well established technique for mitigating the possible effects of a rupture of the pressurized pipe. The disadvantage of such a solution would be the possible difficulty in conducting inspections of the internal pipe.

3. REVIEW OF INTERNAL HAZARDS

MISSILES

3.1. In the design and evaluation of nuclear power plants, internally generated missiles arising from PIEs (such as the failure of pressure vessels and pipes, the failure of valves, the ejection of a control rod and the failure of high speed rotating equipment) should be considered. The potential for secondary missiles should also be evaluated. Measures to prevent the initiation of internally generated missiles should be undertaken if such measures are practicable.

Otherwise, protection of SSCs against internally generated missiles should be provided by using the methods described in the following. Analyses of missile hazards and of the design of the plant to protect against them are usually performed by a combination of deterministic and probabilistic methods. Some missiles are postulated on a deterministic basis and their effects on the SSCs in terms of strikes and damage are also evaluated either deterministically or probabilistically. In a few cases, all aspects of the missile hazard — initiation, strike and damage — are treated probabilistically.

Prevention of the generation of missiles

Failure of pressure vessels

3.2. In nuclear power plants, pressure vessels that are important to safety are designed and constructed by means of extremely comprehensive and thorough practices to ensure their safe operation. Analysis is performed to demonstrate that levels of stress are acceptable under all design conditions. All phases of design, construction, installation and testing should be monitored in accordance with approved procedures to verify that all work is carried out in accordance with the design specifications and that the final quality of the vessel is acceptable. A surveillance programme during commissioning and operation, as well as a reliable system for overpressure protection, should be used to determine whether the vessels remain within their design limits. The gross failure of such vessels (such as the reactor pressure vessel) is generally believed to be sufficiently improbable that consideration of the rupture of these vessels as a PIE should not be necessary.

3.3. Other vessels in nuclear power plants may not undergo such stringent design, quality assurance and surveillance. Failures of such vessels containing fluids of high internal energy should be evaluated, as they may become sources of missiles if they rupture. The failure of a pressure vessel can result in a wide variety of failure modes depending on such factors as material characteristics, the shape of the vessel, the positions of welds, the design of nozzles, construction practices and operating conditions. Metal vessels composed of materials that behave in a brittle manner are more likely to produce missiles.

3.4. Further measures to reduce P_1 include the use of ductile material and additional anchoring or supporting of the vessel. Where it is determined that P_1 is not low enough, or if the vessel can possibly fail in a brittle manner, a range of missile sizes and shapes to cover the range of possibilities should be postulated and analysed to identify the design basis missiles. Alternatively, a simplified conservative approach is acceptable in order to determine the missiles to be considered.

3.5. A vessel, because of its unpredictable behaviour and the potential for severe damage, should be designed so that it cannot as a whole become a missile. If it is judged that the vessel as a whole could become a missile, an analysis should be made of the various locations of ruptures and break sizes to determine whether the resultant vessel blowdown forces would be sufficient to separate the vessel from its retaining supports (restraints). If a vessel could be separated from its restraints, the design of the vessel should be modified to prevent this type of failure.

3.6. For reactors equipped with vessel closure plugs to retain the fuel in position, special design features should be provided to ensure that the probability of ejection of the closure plug is low. In the absence of such special features, the consequences of the failure or the ejection of a single closure plug should be evaluated as for a missile.

Failures of valves

3.7. Valves in fluid systems that operate at high internal energy should be evaluated as potential sources of missiles. Valves are typically designed with various parts that are removable for maintenance purposes. These removable parts present the most significant potential for failures that lead to the production of a missile. The failures of valve stems or the valve bonnet or of retaining bolts are examples of failures that should be taken into consideration as good engineering practice even if such failures have not been observed. Valve bodies are usually constructed in such a manner that they are substantially stronger than the connected piping. For this reason it is generally accepted that the generation of missiles resulting from the failure of the valve body itself is sufficiently unlikely in most cases and that it need not therefore be considered in the design and/or evaluation of the plant.

3.8. The simplest and the preferred approach to the design of valves is to make P_1 acceptably small; there are several features that can conveniently be incorporated into the design of valves to achieve this. Valve stems should be equipped with appropriate devices having a demonstrable capability to prevent valve stems from becoming missiles in the event of their failure. Valve bonnets frequently have bolted closures. As a design rule, no failure of a single bolt should lead to the generation of a missile other than the bolt itself. This recommendation applies to valves, pressure vessels and other bolted components with a high energy content. However, consideration should be given to the potential for multiple bolt failures due to corrosion or stress corrosion in the event of the leakage of fluid contents past gasketted joints.

Ejection of a control rod

3.9. In most reactor designs features are incorporated by means of which solid neutron absorbing control elements (control rods) are inserted into and withdrawn from the core in a manner such that the travel housings for these elements form appendages on the reactor pressure vessel. For reactor designs in which significant fluid pressure is contained by the reactor pressure vessel, it has been customary to postulate, for design purposes, that a failure of one of these appendages can occur in a manner permitting the ejection of the control rod due to the driving forces of the fluid contained. This postulated ejection gives rise to a reactivity transient and to a loss of coolant accident, neither of which is dealt with in this Safety Guide, as well as to the generation of a missile which may, depending on the particular reactor design, have the potential for causing significant primary or secondary damage. For example, typical matters of concern include the possible damage to adjacent control rods, to safety systems and to the containment structures.

3.10. The probability of a control rod being ejected may be reduced in some reactor types by providing special design features. These features should be confirmed by test or by analysis to demonstrate that they have the capability to retain the control rod and drive assembly in the event of a failure of the travel housing for a control rod.

Failure of high speed rotating equipment

3.11. Nuclear power plants contain large items of equipment that have parts that rotate at high speed during operation, such as the main turbine generator set, the steam turbines, large pumps (such as the main coolant pump) and their motors, and flywheels. These rotating parts can attain a considerable energy of rotation, which in the event of their failure can be converted into translational kinetic energy of rotor fragments. Such failures can arise either from defects in the rotating parts or from excessive stresses due to overspeed.

3.12. Since rotating machinery usually has a heavy stationary structure surrounding the rotating parts, some consideration should be given to the energy loss after failure due to the energy absorbing characteristics of the stationary parts. Energy loss in the penetration of such structures is invariably a complex process, owing to the configuration of the structure. To the extent practicable the calculation of the energy losses should be based on empirical relationships developed in tests of similar, carefully defined structures. For the sake of simplicity, a conservative approach is often used in which it is assumed that no energy is lost in the interaction of the missile and the stationary casing of rotors.

3.13. There are historical examples that show that fragments of many sizes and shapes can be ejected in the event of the failure of rotating equipment. Test data indicate that for a simple geometry such as a disc, the failure process tends to result in a number of roughly equal segments. However, stress concentrations, structural discontinuities, defects in materials and other factors can all affect the failure process in such a way as to influence the type of fragments formed. Missiles from the failure of rotating machinery should be characterized on the basis of their potential for doing damage and should be included in the evaluation of possible primary and secondary effects.

3.14. Typical missiles postulated to be caused by the failure of high speed rotating equipment include:

(a) Fan blades;
(b) Turbine disc fragments or blades;
(c) Pump impellers;
(d) Flanges;
(e) Coupling bolts.

3.15. To determine P_1 for such rotating equipment the following steps should be taken:

(a) The design of the rotating machine itself should be evaluated for the selection of materials, speed control features and stress margins for all plant states considered in the design basis, including anticipated operational occurrences and design basis accidents.
(b) The manufacturing process for the rotating machine should be evaluated for conformance with the design intent, for the adequacy of the non-destructive examination and other testing to detect possible defects, and for the adequacy of the quality control measures taken to ensure that the equipment as installed meets all specifications.
(c) Means of preventing destructive overspeed should be evaluated for reliability. This will include equipment for the detection and prevention of incipient overspeed, associated power supply equipment and

instrumentation and control equipment, as well as the procedures involved in the periodic calibration and readiness testing of all these.

3.16. The speed of rotating equipment is determined by a balance between the input energy and the output load. A sudden reduction in the output load or a sudden increase in the input energy can result in overspeed. Where there is a significant possibility of unacceptable damage due to missiles, additional redundant means of limiting the rotational speed may be provided by such features as governors, clutches and brakes and by a combination of systems for instrumentation, control and valving to reduce the probability of overspeed occurring to an acceptable level.

3.17. It should be noted that while engineering solutions are available to limit speed and to prevent missiles due to excessive overspeed, these provisions by themselves may not make the probability of missiles being generated from rotating equipment acceptably small. Besides the failure caused by overspeed there is the possibility of a flaw in the rotor resulting in missiles being generated at or below normal running speed. These missiles should be dealt with by other means, such as conservative design, high quality manufacturing, careful operation, appropriate monitoring of parameters (such as vibration) and comprehensive in-service inspection. When all these means are properly used, the probability of missiles being generated through the failure of rotating machines can be significantly reduced.

Analysis for and protection against missiles

3.18. The next step in the analysis involving the postulation of missiles being generated as a result of equipment failure is to determine the directions and the possible targets of these ejected missiles.

3.19. It may be possible, by studying the fracture mechanics involved, to narrow the area of investigation. For example, the maximum range of the missiles may be limited by the available energy and mass. In certain cases, however, such as for large turbine missiles, the maximum possible range encompasses the entire plant site. Awareness of the directions in which missiles from a particular source may be ejected may often help in locating potential targets so as to avoid missile strikes. This is the case especially where the driving energy for translation is unidirectional, as for valve stem missiles. In other cases there may be a most probable plane or angular sector, as is the case for missiles from rotating machines. There is evidence from failures of rotating machines that energetic missiles are usually ejected within a very narrow angle of the plane of rotation unless they are deflected by a barrier of some kind (e.g. casing) at the source. In this latter case, tests or analyses should be performed in order to estimate the limits of the directions of travel.

3.20. The possible need for features that can retain energetic missiles resulting from the failure of equipment, or which will deflect such missiles into a harmless direction, should be considered in the design and/or evaluation. It is also possible in some cases to add such features, as for rotating equipment. It can often be shown that the heavy steel casings of pumps and the heavy stators of motors and generators may retain or deflect the fragments that may result from a disruptive failure of the rotor.

3.21. P_2 can often be reduced by means of a judicious orientation of the valve in the system. Unless this is precluded by other considerations, valve stems should be installed in such a manner that the ejection of the stem or of related parts would not result in an impact of a missile on critical targets.

3.22. A particularly instructive example of layout provisions is the main turbine generator. Barring other constraints of overriding importance, the layout of the main turbine generator should be such that potential critical targets (such as the control room) lie within the area least susceptible to direct strikes from the turbine; that is, within a cone with its axis along the axis of the turbine shaft. This arrangement takes account of the fact that large sections of rotors, if ejected, will tend to be expelled within 25° of the plane of rotation. The arrangement does not eliminate the possibility of their hitting a critical target, but it significantly reduces the probability of a direct strike.

3.23. It is often possible to lay out valves, pumps, motor generators and high pressure gas containers in locations where the only likely impact zone for a potential missile is an adequately strong concrete structure. While such an approach is straightforward, simple and easily understood as a means of eliminating hazards, provision should be made for the required maintenance and inspection of the equipment.

3.24. The provision of an unpressurized guard pipe around certain sections of piping carrying high pressure fluids may in some cases be useful for protection against missiles. Two protection features are obtained: protection of the surrounding structures and equipment from whipping pipes and possible secondary missiles, and protection of the inner pipe from missiles generated in the surrounding area.

3.25. Perhaps the most direct and obvious design approach to reducing P_2 is to provide barriers between the source of the missiles and the target. Barriers are also used to reduce certain secondary effects such as scabbing or even the ejection of concrete blocks from concrete targets. Both aspects of barriers are discussed in the following paragraphs.

3.26. Missile barriers have frequently been provided in nuclear power plants to absorb the energy of postulated missiles and to prevent their travel beyond the barrier. Usually missile barriers consist of reinforced concrete slabs or of steel plates. However, other means such as woven steel mats or missile deflectors could also be used. Generally the barrier should be placed at the source of the missiles, as stated in para. 2.40.

3.27. Evaluation of the adequacy of barriers, whether they are structures provided for other purposes or special missile barriers, necessitates the consideration of both local and general effects of missiles on the barrier. Depending upon the postulated missile's mass, velocity and impact area, the local or the general effect of the missile may dominate, but both should be evaluated. Local effects of missiles are penetration, perforation, scabbing or the ejection of concrete blocks and spalling, which are limited mainly to the area of impact on the target. General effects of missiles include buckling or structural failures in bending, tension or shear. Small missiles such as valve stems will have mainly local effects, while large, slow moving missiles such as those arising from structural collapse or falling loads will have mainly general effects. Faster large missiles such as those arising from rotating machinery may exhibit both local and general effects.

3.28. In analysing the local effects of missiles on missile barriers, the practice is to determine the depth of penetration of the missile into the target by using acceptable empirical equations. The equations have been derived from various experiments and are limited in the range of parameters for which test data were taken. It should be recognized that penetration depth formulas may not in all cases be adequate for determining the design of a missile barrier (e.g. the necessary thickness, strength and reinforcement of steel and/or concrete). The mass, velocity, impact area, shape and hardness of the missile, as well as the characteristics of the construction and strength of the targets, are all important parameters that should be considered. The selection of the appropriate formula needs expert engineering judgement, since there may not be a formula that is directly applicable and some extrapolation of the range of parameters may be necessary. An added factor with regard to local missile effects in considering reinforced concrete targets is the generation of secondary missiles by spalling or scabbing or the ejection of blocks. Such phenomena should be prevented wherever possible because of the scatter of the secondary missiles, which makes certain characteristics difficult to predict. The generation of secondary missiles can be prevented by making the barrier adequately thick or by providing a steel backing plate on the concrete surface.

3.29. The consideration of general missile effects on the barrier should include the possible deformation of the structure by local missile effects. If there is no major local deformation of the structure by penetration, then methods of energy balance and momentum balance can be used to predict the deflections or stresses in principal members for the purpose of determining whether the barrier can contain the missile and continue to perform its design function. If, however, local missile effects are severe, as they often are, an applied force–response time history should be developed and the structural response should be analysed as for an impulse load. The dynamic loads induced by missile impacts should be considered with due attention to the frequency response of the target structure. This is particularly important when the response of the barrier may interfere with the operability of equipment either mounted directly on the barrier or installed in the vicinity of the barrier.

3.30. In the event that the product of P_1 and P_2 cannot be proven in a particular case to be acceptably small, the next approach is to make P_3 acceptably small. This can be done by making a detailed analysis of the potential impact on the target and demonstrating that the impact and its potential secondary effects do not prevent the safety requirements from being met.

3.31. Where redundant safety systems are involved, use should be made of physical separation to ensure that the general safety requirements are met even if missiles damage one or more of the redundant safety systems. This is an extension of the discussion of layout, but there are some aspects of this approach that warrant special consideration.

3.32. The value of the physical separation of redundant critical targets is strongly affected by the number and range of possible missiles. Physical separation and adequate redundancy may be sufficient for cases in which only one or two energetic missiles can result from an equipment failure. However, if the generation of multiple missiles in several directions simultaneously is possible, then the benefit of separation by distance and redundancy could be considerably reduced. The arrangements and locations of potential targets and missiles should be considered with the aim of minimizing the effects of events of this kind.

COLLAPSE OF STRUCTURES AND FALLING OBJECTS

3.33. Any structure or non-structural element or object of substantial potential energy could be considered a possible source of a PIE. All such structures (cooling towers, stacks and turbine buildings) should be examined to determine whether their collapse could affect SSCs. Structures classified as liable to affect SSCs in the event of their collapse should be designed and built so that the probability of their collapsing can be shown to be negligible; otherwise the consequences of their collapse should be evaluated. Similarly, the hazard posed to SSCs by falling objects (cranes and lifted loads) should be evaluated.

Structures and non-structural elements

3.34. Safety related structures in nuclear power plants are designed to withstand extreme loads such as those arising as a result of earthquakes, high winds, impacts of aircraft of certain types, external explosions, external flooding, snow and loss of coolant accidents. Collapse of these structures due to internal causes is therefore considered to be unlikely. Reference [5] covers the evaluation of structures for protection against external hazards arising from natural and human-made phenomena. Also, the practice for design in most States with nuclear power programmes is to ensure that no failure in a structure classified in a lower class will be able to propagate to an SSC classified in a higher class. If this is not the case, failure in the structure classified in the lower class should be evaluated as a PIE. In addition to minimizing P_1, physical separation of SSCs should be used to reduce P_2 by ensuring that no single structural collapse could affect all redundancies.

3.35. The failure of non-structural elements such as block walls, stairs and scaffolding could have consequences for SSCs. External hazards (such as earthquakes, high winds, explosions or impacts of aircraft) could be the cause of such a failure and they are usually evaluated on the basis of Ref. [5]. However, there may be situations in which the failure of non-structural elements may be caused by internal initiating events such as operator error or accidents during maintenance. The consequences for SSCs should be evaluated in these cases. Care should be taken either to avoid such failures or to minimize the potential damage to SSCs by means of proper location and adequate barrier design.

Dropping of heavy equipment

3.36. If heavy items of plant equipment are located at significant heights, an evaluation should be made of the possible hazards associated with dropping such equipment, if the probability of this event is not negligible. Generally, the cause of the dropping of heavy equipment would be an external phenomenon such as an earthquake or an aircraft impact, but it may also be human error. References [5, 6] provide methods for preventing such events and for analysing their safety significance. Following the recommendations of Refs [5, 6] will reduce the likelihood of dropping heavy equipment as a result of internally initiated events.

3.37. The nature of the object and the cause of its dropping should be analysed in order to characterize the possible direction, size, shape and energy of the missile or missiles generated and their possible consequences for safety.

3.38. Functional design requirements often govern the physical location of equipment in this category. Where it is functionally necessary to tolerate proximity between heavy equipment and critical targets, it is possible to provide sufficient design measures such as redundant cables on cranes or interlocks to reduce the probability of failure. Also, additional care should be taken in the handling of heavy loads in the vicinity of SSCs. Special attention should be paid to the periodic inspection and maintenance of cranes (e.g. their interlocks, cables and brakes), nooses, straps and shackles, and related items.

3.39. In the particular case of cranes and heavy crane loads such as fuel shipping casks, it is often functionally impractical to interpose shields or barriers between the potential missile and the target. For reactors that use a system for fuel storage in water, attention should be paid to the fuel casks because of the possible consequences if they are dropped into the fuel storage pool. This possibility is normally analysed by means of calculations to determine whether there would be a gross rupture of the pool if a fuel cask were to be dropped from the maximum operational height and by demonstrating whether the water make-up systems would have an adequate capacity to maintain the level of the pool water in the event of leakage caused by a dropped cask. Another practice that should be considered is to restrict the handling of fuel casks to an area remote from the pool itself and remote from other critical target areas.

PIPE FAILURES AND THEIR CONSEQUENCES

Assumptions for PIEs

Types of failure considered and their locations

3.40. Depending on the characteristics of the pipes under consideration (internal parameters, diameter, stress values, fatigue factors), the following types of failure should be considered as PIEs:

(a) For high energy pipes, except for those qualified for leak before break, for break preclusion or for low probability of failure: circumferential rupture or longitudinal through-wall crack.
(b) For low energy pipes[11]: leak with limited area.

3.41. It is accepted to postulate only a limited leak (and not a break) if it can be demonstrated that the piping system considered is operated under 'high energy' parameters for a short period of time (e.g. less than 2% of the total operating time) or if its nominal stress is reasonably low (e.g. a pressure of less than 50 MPa).

3.42. The locations where a failure has to be postulated should be determined as follows:

(a) At the terminal ends (fixed points, connections to a large pipe or to a component) and at intermediate points of high stress for a piping system designed and operated according to the rules applied for systems important to safety;
(b) In all locations for other pipes.

For piping systems of nominal diameter less than 50 mm, breaks should be postulated at all locations.

3.43. A circumferential pipe rupture may result from: a failure of the piping by a stochastic, spontaneous double ended guillotine break; damage by a degradation failure mechanism such as corrosion or fatigue (i.e. a crack

[11] A low energy pipe is defined as a pipe with an internal operating pressure of less than 2.0 MPa or an operating temperature of less than 100°C in the case of water. Other limits may apply for other fluids.

growing over its critical size); an impact due to the rupture of other piping; or an impact of a different kind on the piping under consideration. The most probable location of such a pipe separation is any circumferential weld between the straight pipe parts and the pipe components such as pipe bends, T intersections, reducers, valves or pumps; in general, where there are changes in stiffness and vibration or fluid stratification caused by temperature differences. The frequency of a double ended guillotine break of high energy piping may be derived from operating experience and calculations of fracture mechanics. This frequency may also be available from evaluations made for the purposes of probabilistic safety assessment.

3.44. A large longitudinal through-wall crack in high energy piping resulting in a large leakage area should be considered a PIE, although it is less probable than a circumferential crack.

3.45. Complete instantaneous breaks of high energy pipes should be postulated in analysing the capacity of the emergency core cooling system and the pressure bearing capacity of the containment. The consequences of breaks in these pipes include flooding and increases in pressure, humidity and temperature. The effects of these on the qualification of components and the infiltration of impurities into the emergency core coolant water should be taken into account in the design.

Induced phenomena

3.46. PIEs may have an impact on safety systems by means of local effects, such as direct mechanical contact or jet impingement, as well as global effects, such as flooding, increases in humidity, increases in temperature, asphyxiant effects and higher radiation levels. These possible effects should be analysed.

3.47. In particular, as well as a break, a leak with a limited area should be considered to be a PIE that could lead to an internal flooding hazard[12]. For flange connections and for different types of sealing, the possible leak areas should be analysed case by case.

[12] In some States the size of such a leak is determined to be 0.1 times the area of the pipe cross-section. In other States the following formula is used: the area is given by $S \times D/4$, where S is the thickness of the pipe and D is its internal diameter.

3.48. Three main phenomena that could be induced by pipe failures — pipe whip, jet effects and flooding — are discussed in the following sections.

Preclusion and prevention of pipe breaks

3.49. In some States it has been judged that the application of very high quality standards for high energy piping, analogous to those for vessels, could reduce the risk of pipe ruptures to such a low level that it is effectively precluded.

3.50. A pipe break need not be assumed if a successful qualification for leak before break, for break preclusion or for low probability of failure has been performed for the piping under consideration, resulting in a sufficiently low frequency of the occurrence of a spontaneous break[13, 14]. In general, a fracture mechanics analysis should be performed to calculate the leak size. In lieu of such an analysis, a subcritical crack corresponding to a leak size of 10% of the flow cross-section should be postulated[15]. The leak detection system should be shown to have a sensitivity that is adequate to detect the minimum leakage from a crack that is just subcritical.

3.51. For primary or secondary piping without qualification for leak before break or for break preclusion, the probability of a pipe break can be reduced significantly if additional safety orientated measures are applied, such as surveillance measures (increased in-service inspections or monitoring for leakage, vibration and fatigue, water chemistry, loose parts, displacements, and erosion and corrosion).

PIPE WHIP

Phenomenon of pipe whip

3.52. The phenomenon of pipe whip in its classical form can occur only as a consequence of a double ended guillotine type pipe break in high energy

[13] In some States a limiting probability of 10^{-7} per year is recommended for high quality piping qualified for leak before break or break preclusion.

[14] It should be noted that piping qualified for break preclusion should itself be protected from the consequences of internal hazards such as pipe breaks, missiles or the dropping of heavy loads.

[15] In some States it is accepted for sections of high quality pipes of limited length (‘super pipe’) not to postulate any failure (either break or leak).

piping. As the free cross-sections of the broken pipe are propelled by the forces of the discharging high energy fluid contained in the system, the adjacent free pipe branches are accelerated, which tends to move them from their installed configuration. In the case of unlimited or sufficiently large movement of the pipe branch, the increasing bending moment develops a plastic hinge at the location of the nearest pipe whip restraint or at a rigid or sufficiently stiff support. This defines the length of the pipe branch that rotates coherently about this point during the phase of free pipe whip movement.

3.53. On the impact of the whipping pipe with other equipment, structures or components, its motion is slowed down or stopped and the kinetic energy of the moving pipe branch is transferred partially or totally to the target as an impulsive loading. Such mechanical impacts on safety related targets should be prevented or, if unavoidable, should be investigated for inadmissible consequences.

3.54. In the case of a large longitudinal through-wall crack in high energy piping, no classical pipe whip occurs in the vicinity of this break since there is no separation of the pipe. However, large displacements should be considered on the basis of the assumptions that the piping forms a V shape with three plastic hinges and has the potential to affect other safety related equipment.

Analysis of pipe whip

3.55. The whipping pipe branches should be analysed geometrically to determine possible directions of motion that might endanger target SSCs, as well as to evaluate their kinetic energy. Any possible mechanical impact on the target should be investigated by means of an appropriate dynamic analysis made on the basis of a detailed assessment of the system transient, to quantify the discharge forces and the energy of the whipping pipe as well as the fraction of the energy that would be transferred to the target (the extent of the analysis can be limited on the basis of conservative assumptions). In addition, the analysis should include an assessment of the effectiveness of the pipe whip restraints, demonstrating that pipe deflections may be kept small by the physical restraints. In the case of terminal end breaks, consideration should be given to the secondary effects on the remaining terminal ends.

3.56. The characteristics of the broken pipe should be taken directly from the design of the system and the location and type of the postulated rupture. In the case of pipe whip it is usually conservative to assume a full circumferential rupture and to assume that the pipe will form a hinge at the nearest rigid restraint. Simplified but proven engineering formulas are available for the analysis of a free whipping pipe with the formation of a full plastic hinge, and their use should be considered.

3.57. For the analysis of the consequences of an impact, it should be assumed that any impact of a whipping pipe onto a pipe of similar design but smaller diameter than the impacting pipe in general results in damage (a break) to the target pipe. Impacted target pipes of a diameter equal to or larger than the impacting pipe need not be assumed to lose their integrity[16]. However, if an additional mass (such as a valve or an orifice plate) is present on the whipping branch, the kinetic energy of the motion is increased. In this case the target pipe may be broken even if it is larger than the whipping pipe.

3.58. In the investigation of the whipping pipe, consideration should be given to the potential for a subsequent break after an impact on a target, with the ejection of secondary missiles. Sources of missiles may be single concentrated masses within or attached to a pipe branch, such as valves and pumps or heavy form parts. If these components have separate supports by design to prevent such breaks and the formation of secondary missiles, the analysis should be extended to these anchor points. Attention should also be paid to instrumentation wells and similar attachments to the pipe as further possible sources of missiles.

Protection against the consequences of pipe whip

3.59. Although the probability of a severe pipe rupture in the piping systems of a nuclear power plant is generally accepted to be low, it is usual practice to restrict the motion of possible broken pipes at selected locations by the use of physical restraints. If piping is equipped with a sufficient number of effective pipe whip restraints at appropriate locations, the phenomenon of pipe whip may be considered to be excluded.

3.60. In addition to the prevention of pipe whip by means of a sufficiently low frequency of the double ended guillotine type pipe break, and its exclusion by means of pipe whip restraints, it may be necessary to take protective measures to reduce the probability of safety related piping or equipment being hit or

[16] In some States the possibility of a limited leakage from the impacted pipe is considered if the thickness of the impacted pipe is smaller than that of the impacting pipe.

inadmissibly damaged. In particular, special measures should be taken to protect isolation valves in the vicinity of a possible pipe break or a leak and to ensure the operability of these valves.

3.61. No special measures for protection against the consequences of an impact due to pipe whip need to be provided if any one of the following conditions is met:

(a) The breaking of the pipe is precluded as described in paras 3.40–3.51. This design inherently provides the necessary accessibility for improved in-service inspection.
(b) The whipping pipe is physically separated from safety important piping (such as that for the physical separation of trains) and from safety related SSCs by protective barriers or shielding or by an appropriate distance.
(c) It can be demonstrated for a whipping pipe after a double ended guillotine break that the unrestrained free movement of either end of the ruptured pipe in any possible direction around a plastic hinge formed at the nearest pipe whip restraint or rigid support cannot cause an impact on any SSC important to safety.
(d) It can be demonstrated that the internal energy of the whipping pipe is insufficient to impair to an unacceptable extent the safety function of any affected safety related SSC.

JET EFFECTS

Phenomenon of jet effects

3.62. A jet is a stream of fluid ejected from a leak or break in a pressure retaining system, in a particular direction and with a significantly high velocity.

3.63. Jets usually originate from a broken component such as a pipe or vessel containing high energy pressurized fluid. The PIE is then a leak or break of that pipe or vessel. Jets can be excluded for low energy systems.

3.64. Other possible sources of jets should be taken into account where appropriate. An example of such a source is a jet of gas (the possible effects of its burning are considered in Ref. [2]).

3.65. Once a high energy pipe or vessel has broken, the generation of a jet cannot be avoided. The only way to prevent the generation of a jet is to prevent the PIE itself. However, there are means of limiting the jet in time and/or space.

For example, valves installed upstream and check valves installed downstream of the point of failure can stop the jet soon after it is initiated. Barriers around the failed pipe can limit the range of the jet (see also paras 2.40 and 2.41).

Analysis of jets

3.66. For each postulated location and size of a break, the jet geometry (shape and direction) and its physical parameters (pressure and temperature) should be evaluated as a function of time and space.

3.67. The jet's origin is usually assumed to be a circumferential break or a longitudinal leak of a vessel or pipe. The resulting jet is then limited to a particular direction. In the case of circumferential breaks, the jet may be orientated either axially or radially with respect to the pipe. Radial jets arise in the early stages of the separation of the two limbs of the pipe as a result of the counter-impingement of the two axial jets, one from each limb. The radial jet may persist for a sustained period if the motion of the limbs is arrested before they become misaligned.

3.68. If the PIE generates more than one jet, the possible interference of the jets should be taken into account. An example of this situation is the double ended break of a pipe without restraints, in which two jets may be generated, one from each of the broken ends of the pipe.

3.69. The influence of the motion of the jet's source (such as a whipping pipe) on the jet's geometry should be taken into account as well as other possible influences (such as objects in the vicinity of the jet's trajectory).

3.70. Either an up to date computer code or a simplified approximation on the basis of experimental data, or appropriate conservative assumptions, can be used for the analysis of the jet's shape and properties.

Protection against the consequences of jets

3.71. As the next step, an analysis of the consequences of jets should be performed. The following effects of jets on targets should be taken into account: mechanical load (pressure, impact), thermal load (temperature, including thermal stresses and shocks where appropriate) and properties of fluids (such as possible short circuits in electric equipment due to the conductivity of liquid water). Possible chemical effects should also be taken into account, especially if the fluid ejected is other than water. It may be necessary to analyse the effects of jets on targets that are not SSCs also, if their damage may lead to significant secondary consequences. A typical example is damage to pipe insulation. Although the insulation is not itself important to safety, debris from insulation material could block the sump strainer of the recirculation pump for the emergency core cooling system.

3.72. In addition to the direct impingement of a jet onto targets (local effects), flowing fluid may also have a significant effect on the general environmental conditions in a room. The effects will depend, among other things, on the time duration and the parameters of the jet and on the dimensions of the room. If this is a concern, then the general environmental parameters and their influence on the functioning of SSCs should also be analysed. Such an analysis is usually performed as part of the process for the environmental qualification of equipment. However, the set of PIEs that are considered in the process of equipment qualification are usually limited to a relatively narrow range of design basis accidents that are analysed in the safety analysis report for the plant. A larger set of PIEs should be considered in the context of internal hazards (see para. 2.20), including the influence of pressure, temperature, humidity, water level and activity on the functioning of SSCs. For example, a break in an auxiliary system is not usually analysed among the design basis accidents, but it should be considered in the evaluation of internal hazards. It should be shown by analysis that the general environmental conditions generated by a jet are not more severe than those considered in the process for equipment qualification. If this cannot be ensured, the components concerned should be requalified or else they should be protected.

3.73. Changes in the general environmental conditions in a room may result from factors not related to internal hazards. Such changes are outside the scope of this Safety Guide and the corresponding protection measures should be considered in the qualification process for equipment.

3.74. Protection against direct jet impingement is similar to protection against missiles (see paras 3.1–3.32). Protective measures can be designed in such a way as to cope with both missiles and jets, or generally with as many internal hazards as possible.

3.75. The differences between missiles and jets that should be taken into account in designing the protection include, for example:

(a) Their time duration (missiles are generally assumed to cause instant impacts, whereas jets, in addition to their instant impact, endure for some period of time; the possible penetration of a jet through the barrier due to erosion should be investigated).

(b) The behaviour of jets and missiles after impinging on a barrier is quite different; barriers should be designed in such a way that they do not deflect either jets or missiles in unfavourable directions.

(c) Since a jet is not a compact solid, barriers such as nets, which are effective against some missiles, would not protect SSCs against jets.

FLOODING

Phenomenon of flooding

3.76. Flooding can be caused by any PIE that results in the release of a liquid (usually water). Such PIEs include, for example, leaks from or breaks of pipes, vessels or tanks as well as any event that can lead to the actuation of a spray system (containment spray or fire extinguisher sprays), no matter whether the actuation is spurious or desired.

3.77. In a general sense, flooding means not only the formation of pools of water on the floor of a room but also the collection of liquid in higher locations, if sufficient drainage is not assured. For example, water (arising from sprays or condensed steam) can collect in cable trays even if they are located well above the floor level. Equipment located in such a place should then be considered to be subject to flooding. In addition, water from these trays may be drained to other undesired locations.

3.78. Examples of PIEs for flooding include:

(a) A leak or break of the primary or secondary system;
(b) Spurious actuation of the containment spray system;
(c) A leak or break of the secondary feedwater system;
(d) A leak or break of the emergency core cooling system;
(e) A leak or break of the service water system;
(f) A leak or break of the fire water system;
(g) Human error during maintenance (e.g. in leaving a valve, an access hole or a flange open by mistake).

3.79. Prevention principles are in general similar to those for other internal hazards. Since flooding can be caused by the leaking or breaking of a vessel, tank or pipe, any measure that reduces the probability of a leak or a break (P_1) also reduces the probability of flooding.

3.80. The reduction of human error is another important way to reduce the probability of flooding.

Analysis of flooding

3.81. All possible PIEs should be carefully identified. The best approach is to base the list of PIEs on a list of SSCs and then to identify all the possible sources of liquid (water in the case of pressurized water reactors and boiling water reactors), including sources in other rooms. This identification should be supported by room by room walk-downs.

3.82. For each PIE, P_1 should be determined, with account taken of possible human errors.

3.83. For all PIEs, unless P_1 is acceptably small, a liquid level as a function of time should be determined not only for the room with the source of the liquid but also for all rooms to which the liquid could spread (through doors, pipe conduits or cracks in walls or floors). In the case of breaks in pipes connected to tanks or pools, account should be taken of possible siphoning effects, which can increase the amount of liquid drained. Possible blocking of drain holes by debris should be taken into account if this would lead to more severe conditions. In determining the liquid level using a volume–height relation, the as-built status of the room should be used. The possible collection of liquid in upper parts of the room (e.g. in cable trays) should also be analysed. In some cases it may be necessary to analyse the flooding also with regard to the transport of objects and/or small particles to undesired locations. A typical example is the blockage of the strainers of the emergency core cooling system. Isolation debris, corrosion particles and even human hair can be transported by water and can block the strainers.

3.84. If the liquid is water, flooding is usually considered to be of concern mainly for electrical devices. If the liquid is in contact with a hot object, a pressure excursion is possible; this phenomenon should be considered in the design of civil engineering structures. Other possible consequences, such as those stated in para. 2.18, should also be considered.

Protection against the consequences of flooding

3.85. Sometimes intentional flooding is a design feature, and flooding phenomena should then be given full consideration in the design (e.g. some components of instrumentation and control systems should be qualified accordingly for containment sprays, and some doors and walls should be qualified as waterproof for fire protection sprays). Being a design feature, such intentional flooding may not generally be considered an internal hazard; however, owing to its similar nature, intentional flooding should be included in the set of flooding events.

3.86. Reduction in the probability P_2 of SSCs being affected by flooding can be achieved, for example, in the layout of the plant. Effective physical separation of redundant systems may in this case mean vertical separation. The SSCs can be located on a pedestal that is higher than the maximum possible flooding level. If this is not possible, a barrier (either a wall around the component or a complete enclosure) can be used. It should also be ensured by all available means that flooding (unless it is intentional flooding as a design feature) is mitigated as soon as possible and its spreading to unfavourable regions is prevented (e.g. by means of suitable thresholds). Means that can be used to mitigate flooding include:

(a) Appropriate design (isolation valves on potentially hazardous pipes, drains and pumps);
(b) Detection systems (flood warnings);
(c) Procedures (operational and/or emergency procedures).

For all actions taken in mitigation, the likelihood of success should be carefully evaluated. In case of any doubt, their failure should be assumed in the analysis. In the deterministic approach, the most severe single failure should always be assumed.

3.87. The probability P_3 of systems or components being seriously damaged can be reduced by using equipment qualified for operation in the wet or even submerged.

3.88. If neither measure can be practically achieved, then the overall probability of unacceptable consequences can be reduced by using redundant systems or components that are physically separated. It should be taken into account that there is great potential for common cause failures since liquid can flood an entire room and even spread to other rooms.

3.89. The possible formation of waves should be taken into account and analysed, if flooding is fast enough (such as in the event of a total breach of a tank). A wave may increase the fluid level locally significantly above the value predicted on a steady state basis. Waves can also impose a large mechanical load on SSCs. If such a possibility is identified, an appropriate means of protection (such as by a barrier, an appropriate layout or the redundancy of SSCs with physical separation) should be provided.

3.90. In addition to the direct impacts of flooding as described in this section, flowing fluid may also have a significant effect on the general environmental conditions in a room. Such effects should be considered in the qualification process for equipment.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Nuclear Power Plants: Design, Safety Standards Series No. NS-R-1, IAEA, Vienna (2000).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Protection against Internal Fires and Explosions in the Design of Nuclear Power Plants, Safety Standards Series No. NS-G-1.7, IAEA, Vienna (2004).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Assessment and Verification for Nuclear Power Plants, Safety Standards Series No. NS-G-1.2, IAEA, Vienna (2002).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Maintenance, Surveillance and In-service Inspection in Nuclear Power Plants, Safety Standards Series No. NS-G-2.6, IAEA, Vienna (2002).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, External Events Excluding Earthquakes in the Design of Nuclear Power Plants, Safety Standards Series No. NS-G-1.5, IAEA, Vienna (2003).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Seismic Design and Qualification for Nuclear Power Plants, Safety Standards Series No. NS-G-1.6, IAEA, Vienna (2003).

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