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DESIGN OF REACTOR CONTAINMENT  
STRUCTURE AND SYSTEMS FOR NUCLEAR  
POWER PLANTS

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INTERNATIONAL ATOMIC ENERGY AGENCY VIENNA,



## FOREWORD

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## CONTENTS

1.	INTRODUCTION.....	4	Field Code Changed
2.	CONTAINMENT SAFETY FUNCTIONS AND DESIGN APPROACH.....	5	Field Code Changed
3.	DESIGN BASIS OF STRUCTURES SYSTEMS AND COMPONENTS.....	7	Field Code Changed
3.1.	GENERAL.....	7	Field Code Changed
3.2.	POSTULATED INITIATING EVENTS (PIES) .....	8	Field Code Changed
3.3.	INTERNAL HAZARDS .....	98	Field Code Changed
3.4.	EXTERNAL HAZARDS .....	109	Field Code Changed
3.5.	ACCIDENT CONDITIONS.....	12	Field Code Changed
3.5.1.	Design basis accidents.....	12	Field Code Changed
3.5.2.	Design extension conditions.....	13	Field Code Changed
3.6.	DESIGN LIMITS .....	15	Field Code Changed
3.7.	RELIABILITY .....	16+5	Field Code Changed
3.7.1.	Systems designed to mitigate design basis accidents .....	16	Field Code Changed
3.7.2.	Safety features for design extension conditions without significant fuel degradation.....	17+6	Field Code Changed
3.7.3.	Safety features implemented to mitigate the consequences of an accident with core melting.....	17	Field Code Changed
3.8.	DEFENCE IN DEPTH .....	18+7	Field Code Changed
3.9.	PRACTICAL ELIMINATION OF PLANT STATES THAT COULD LEAD TO AN EARLY RADIOACTIVE RELEASE OR A LARGE RADIOACTIVE RELEASE. ....	18	Field Code Changed
3.10.	SAFETY CLASSIFICATION.....	19+8	Field Code Changed
3.11.	ENVIRONMENTAL QUALIFICATION .....	20+9	Field Code Changed
3.12.	CODES AND STANDARDS .....	21+0	Field Code Changed
3.13.	USE OF PROBABILISTIC ANALYSES IN DESIGN .....	21	Field Code Changed
4.	DESIGN OF CONTAINMENT STRUCTURE AND ASSOCIATED SYSTEMS ..	22+1	Field Code Changed
4.1.	GENERAL.....	22+1	Field Code Changed
4.1.1.	Layout and configuration of containment systems .....	22+1	Field Code Changed
4.1.2.	Maintenance and Accessibility .....	23+2	Field Code Changed
4.1.3.	Operator actions.....	24+3	Field Code Changed
4.1.4.	Sharing of parts of the containment system between units.....	24+3	Field Code Changed
4.1.5.	Ageing effects .....	24+3	Field Code Changed
4.1.6.	Decommissioning .....	25+4	Field Code Changed
4.2.	STRUCTURAL DESIGN OF CONTAINMENT .....	25+4	Field Code Changed
4.2.1.	General design process .....	25+4	Field Code Changed
4.2.2.	Loads and load combinations .....	26+5	Field Code Changed
4.2.3.	Engineering criteria.....	28+7	Field Code Changed
4.2.4.	Local stresses and fatigue.....	32+1	Field Code Changed
4.2.5.	Ultimate capability and failure mode.....	32+1	Field Code Changed
4.3.	STRUCTURAL DESIGN OF STRUCTURES WITHIN THE CONTAINMENT .....	32+1	Field Code Changed
4.3.1.	In-vessel retention strategy .....	33+2	Field Code Changed
4.3.2.	Ex-vessel retention strategy .....	33+2	Field Code Changed
4.4.	STRUCTURAL DESIGN OF SYSTEMS .....	34+3	Field Code Changed
4.5.	ENERGY MANAGEMENT .....	34+3	Field Code Changed

4.5.1.	Control of pressure and temperature during plant operation.....	<del>3433</del>	Field Code Changed
4.5.2.	Control of pressure and temperature in accidents.....	<del>3433</del>	Field Code Changed
4.6.	CONTROL OF RADIONUCLIDES.....	<del>3837</del>	Field Code Changed
4.6.1.	Containment source term.....	<del>3837</del>	Field Code Changed
4.6.2.	Leaktightness of the containment.....	<del>3938</del>	Field Code Changed
4.6.3.	Secondary containment.....	<del>4039</del>	Field Code Changed
4.6.4.	Containment bypass.....	<del>4139</del>	Field Code Changed
4.6.5.	Reduction in airborne radionuclides.....	<del>4140</del>	Field Code Changed
4.7.	MANAGEMENT OF COMBUSTIBLE GASES.....	<del>4442</del>	Field Code Changed
4.7.1.	Generation of combustible gases.....	<del>4442</del>	Field Code Changed
4.7.2.	Threats due to combustible gases.....	44	Field Code Changed
4.7.3.	Measures for the prevention of hydrogen combustions challenging the containment integrity.....	45	Field Code Changed
4.8.	MECHANICAL FEATURES OF THE CONTAINMENT.....	46	Field Code Changed
4.8.1.	Provisions for containment isolation of piping and ducting systems.....	46	Field Code Changed
4.8.2.	Isolation valves.....	48	Field Code Changed
4.8.3.	Penetrations.....	48	Field Code Changed
4.8.4.	Air locks, doors and hatches.....	49	Field Code Changed
4.9.	MATERIALS.....	50	Field Code Changed
4.9.1.	Concrete.....	50	Field Code Changed
4.9.2.	Metallic materials.....	51	Field Code Changed
4.9.3.	Soft sealing materials.....	51	Field Code Changed
4.9.4.	Covering, thermal insulation and coating materials.....	<del>5251</del>	Field Code Changed
4.10.	INSTRUMENTATION.....	<del>5352</del>	Field Code Changed
4.10.1.	Monitoring the stability of the containment structure.....	<del>5453</del>	Field Code Changed
4.10.2.	Detection of deviations from normal operation.....	54	Field Code Changed
4.10.3.	Periodic testing.....	56	Field Code Changed
4.10.4.	Monitoring of the availability of systems.....	56	Field Code Changed
4.10.5.	Initiation of automatic operation of systems.....	<del>5756</del>	Field Code Changed
4.10.6.	Post-accident monitoring.....	<del>5857</del>	Field Code Changed
4.10.7.	Sampling.....	<del>5958</del>	Field Code Changed
5.	TESTS AND INSPECTIONS.....	<del>6059</del>	Field Code Changed
5.1.	COMMISSIONING TESTS.....	<del>6059</del>	Field Code Changed
5.1.1.	Structural integrity test.....	<del>6059</del>	Field Code Changed
5.1.2.	Integrated leak tests (of the containment envelope).....	<del>6059</del>	Field Code Changed
5.1.3.	Local leak tests of isolation devices, air locks and penetrations.....	61	Field Code Changed
5.1.4.	Functional tests of equipment and wiring in the containment.....	<del>6261</del>	Field Code Changed
5.2.	IN-SERVICE TESTS AND INSPECTIONS.....	<del>6261</del>	Field Code Changed
5.2.1.	Structural integrity tests.....	62	Field Code Changed
5.2.2.	Integrated leak tests (of the containment envelope).....	<del>6362</del>	Field Code Changed
5.2.3.	Visual inspection.....	63	Field Code Changed
5.2.4.	Periodic tests.....	<del>6463</del>	Field Code Changed

## 1. INTRODUCTION

### BACKGROUND

1.1. This Safety Guide was prepared under the IAEA programme for safety standards for nuclear power plants. It is a revision of the Safety Guide on Design of Reactor Containment Systems for Nuclear Power Plants (Safety Series No. NS-G-1.10, 2004), which is now superseded by this safety guide.

1.2. The confinement of radioactive material in a nuclear power plant, including the control of discharges and the minimization of radioactive releases into the environment, is a fundamental safety function to be ensured in any operational condition and accident condition. In accordance with the concept of defence in depth, this fundamental safety function is achieved by means of several barriers and levels of defence. For nuclear power plants, confinement of radioactive material in accident conditions primarily relies on the integrity and leaktightness of a strong structure surrounding the reactor termed “containment” in this publication. Moreover, taking into account energy and combustible gases released in case of accident, systems designed to preserve the integrity of the containment or to avoid a bypass of the containment confinement are necessary. Systems necessary for the normal operation, or to minimize radioactive releases, to remove energy or to preserve the structural integrity of the containment in accident conditions are termed “associated systems” or “systems” in this publication.

1.3. Issues related to the confinement of spent fuel are addressed in [13].

### OBJECTIVE

1.4. The objective of this Safety Guide is to make recommendations on the implementation and fulfillment of SS-R 2/1 Revision 1 requirements relevant for the containment structures and systems. It is expected that this publication will be used primarily for land based, stationary nuclear power plants with water cooled reactors designed for electricity generation or for other heat generating applications (such as for district heating or desalination). It is recognized that for other reactor types, including future plant systems featuring innovative developments, some of the recommendations may not be appropriate or may need some judgment in their interpretation.

### SCOPE

1.5. Recommendations given in this Safety Guide are targeted primarily to new nuclear power plants. For plants designed with earlier standards, comprehensive safety assessments are to be carried out considering these recommendations in order to identify safety improvements that are oriented to prevent accidents with radiological consequences and mitigate such consequences should they occur. Reasonably practicable or achievable safety improvements are to be implemented in a timely manner [17].

1.6. This Safety Guide addresses the functional aspects of the major associated systems associated to the containment for the management of energy, radionuclides and combustible gases.

Consideration is given to the definition of the design basis for the containment and [associated](#) systems, in particular to aspects affecting the structural design, the reliability and the independence of systems that do not belong to the same level of defence.

1.7. Recommendations are provided on the tests and inspections that are necessary to ensure that the containment and its associated systems are capable to accomplish their intended functions throughout the operating lifetime of the nuclear power plant.

1.8. Design limits and engineering criteria, together with the system parameters that should be used to verify them, are specific to the design and to the individual Member State, and are therefore outside the scope of this Safety Guide. However, general recommendations are provided.

## STRUCTURE

1.9. In Section 2 the safety functions related to the containment and its associated systems are indicated, and the application of the main requirements of SSR 2/1 rev 1 to be considered are addressed. Section 3 provides recommendations to the design basis of the containment and systems. Section 4 provides specific recommendations for the design of the containment structures and systems. Section 5 covers tests and inspections, and provides recommendations for commissioning tests and for in-service tests and inspections.

## 2. CONTAINMENT SAFETY FUNCTIONS AND DESIGN APPROACH

This section addresses the application of the principal technical requirements given in [2] for the design of the containment structures and systems.

### SAFETY FUNCTIONS

2.1. The containment and its associated systems are designed to perform together with other design provisions the following safety functions (see Requirements 4 and 54) :

- i. Confinement of radioactive material in operational states and in accident conditions,
- ii. Protection of the reactor against external natural and human induced events,
- iii. Radiation shielding in operational states and in accident conditions.

2.2. Conditions under which those functions need to be accomplished are identified and characterized to define the different elements of the design bases of the relevant structures, systems and components (see Requirement 14).

### CONFINEMENT OF RADIOACTIVE MATERIAL

[2.3.](#) The containment structure and its associated systems is primarily designed to [to ensure that any radioactive release from the nuclear power plant to the environment is as low as reasonably achievable, to](#) comply with the authorized limits on discharges in operational

states and the dose limits accepted by the regulatory requirements in accident conditions to ensure a good level of protection of the people and the environment (see Requirement 55):

- For operational states, the cumulative annual effective dose received by people living in the vicinity of a nuclear site is expected to be comparable to below the effective dose due to natural exposition originally existing at the site (an increase of up to -dose limit of-1 mSv over the dose received in a year /year per site from exposure due to naturally occurring radiation sources is recommended by ICRP usually considered for new builds),
- Radiological releases in accident conditions are are to be dealt with as follows: minimized, and long-term off-site contamination avoided:
  - ✓ For design basis accidents and design extension conditions without significant fuel degradation, the releases are minimized such that off-site protective actions (e.g. evacuation, sheltering, iodine thyroid blocking, food restrictions) are not necessary (see Requirement 19 item 5.25),
  - ✓ For accident with core melting, the releases are minimized such that only off-site protective actions limited in terms of areas and times are necessary (see Requirement 20 item 5.31A),
  - ✓ Sequences which might lead to an early radioactive release or a large radioactive releases are “practically eliminated” by appropriate design provisions (see item 2.13/4).

Moreover the containment and its associated systems are designed so that releases are below the prescribed limits and as low as reasonably achievable (see Requirement 55).

2-3-2.4. Leaktightness of the containment is an essential element to confine radioactive material and to minimize radiological releases. Leaktightness is generally characterized by specified leak rates (overall leak rate, specific leak rates for containment penetrations, and hatches and containment isolation valves) which are not expected to be exceeded under accident conditions. Equipment ensuring the role of confinement barrier is designed and qualified to keep integrity and leaktightness, prior and during conditions for which they are necessary (see Requirement 55).

2-4-2.5. A containment isolation system is necessary to confine radiological releases into the containment atmosphere caused by accident conditions (see Requirement 56).

2-5-2.6. To preserve the containment structural integrity in accident conditions, systems designed to ensure that the design limits of the containment structure (e.g. pressure, temperature, combustible gases) not be exceeded are implemented as necessary. Multiple means are implemented for the energy management in accident conditions, and those specifically dedicated for conditions with core melting are functionally separated and independent as far as practicable from other systems. (see Requirements 58 and 7).

2-6-2.7. Stresses in the civil structures due to loads or combinations of loads caused by operating conditions and accident conditions are such that the structural integrity of the containment and of the systems required for the mitigation of the accident conditions is maintained with appropriate margins. (see Requirement 42).

2.8. Regardless of the multiplicity of design provisions taken to prevent accident from escalating to significant core damage, a set of the most likely representative core melting conditions is postulated. For such conditions, ~~additional complementary~~ safety features are implemented to minimize the radiological releases (see Requirement 20).

~~2-7-2.9.~~ As a ~~Additionally to supplementary~~ measures ~~to those~~ implemented to mitigate the consequences of the postulated conditions, the use of non-permanent equipment is considered, and adequate connection points and interfaces with the plant are installed with the objective to avoid ~~unacceptable~~ large release and unacceptable off-site contamination in case of accidents exceeding those considered in the design ( see Requirement 58).

2-8-2.10. In accident conditions, high energetic phenomena that could jeopardize the structural integrity and the leaktightness of the containment are dealt with adequately by incorporating features for their practical elimination (see Requirements 20 and 58).

#### PROTECTION AGAINST EXTERNAL HAZARDS

2.11. The containment is designed to protect SSCs housed inside the containment against the effects of natural and human induced external hazards identified by the site hazard evaluation, and against the effects of hazards originated by equipment installed at the site. For both of them, causation and likelihood of hazard combination is considered (see Requirement 17).

~~2-9-2.12.~~ The containment is also designed to provide protection against the effects of possible malicious acts directed against the facility, but these aspects are outside the scope of this Safety Guide.

#### RADIATION SHIELDING

~~2-10-2.13.~~ In operational states and in accident conditions, the containment contributes to the protection of plant personnel and the public from undue exposure due to direct radiation from radioactive material contained within the containment. The composition and thickness of the concrete, steel and other materials is such that the dose limits and dose constraints for operators and the public remain below acceptable limits and as low as reasonably achievable in, and following accident conditions (see Requirement 5).

### **3. DESIGN BASIS OF STRUCTURES SYSTEMS AND COMPONENTS**

#### 3.1.GENERAL

3.1. The design of the containment structure and systems important to safety should be conducted taking into account the recommendations of GS-G-3.1 [15] and GS-G-3.5 [16] to meet the requirements 1 to 3 of SS-R 2/1 Rev.1 and GSR Part 2 requirements [14].

3.2. The design of the containment structure and systems important to safety should be conducted taking into account design recommendations for safety and security in an

integrated manner in such way that safety and security measures do not compromise each other. Recommendations for security are detailed in [18].

3.3. The design basis for the containment and its associated systems should include any condition created by normal operation, anticipated operational occurrences, accident conditions (design basis accidents and design extension conditions). Load combinations created by internal and external hazards should also be included in the design basis of the structures, systems and components.

3.4. Design conditions and design loads should be derived from combinations of bounding conditions determined for the relevant plant states or hazards.

3.5. Strength of structures and performances of systems necessary for operational states should be derived from the following needs:

- To confine the radioactive material,
- To minimize radiological releases,
- To contribute to biological shielding,
- To maintain pressure and temperature within the range specified for operational states,
- To establish and maintain adequate environmental conditions in the working areas,
- To provide for the necessary access and egress of personnel and materials,
- To perform containment structural and leaktightness tests,
- To accommodate the loads occurring during operational transients (e.g. loads due to differential thermal expansion).
- Other factors, including security considerations, also need to be taken into account.

### 3.2.POSTULATED INITIATING EVENTS (PIES)

The following recommendations provide guidance to fulfil Requirement 16 [2].

3.6. The PIEs relevant for the containment structures and systems should include equipment failures and errors potentially leading to accident conditions with a significant release of radioactive material or with a significant release of energy inside the containment. PIEs occurring in shutdown modes, with an open containment or when systems may be disabled for maintenance, should also be considered.

Typical postulated initiating events that should be relevant for the design of the containment and its associated systems are:

- Large, medium and small breaks in the Reactor Coolant System;
- Large, medium and small breaks in the main steam/feedwater system;
- Equipment failure in systems carrying radioactive liquid or gas within the containment;
- Fuel handling accidents in the containment.

### 3.3.INTERNAL HAZARDS

The following recommendations provide guidance to fulfil Requirement 17 [2] with its associated requirements relevant for “Internal Hazards”.

3.7. Internal hazards that should be considered for design are those hazards of internal origin that may jeopardize the performance of the containment and its associated systems. A list of typical internal hazards usually considered is given for guidance; nevertheless, this list should be supplemented as needed to include specific hazards of the design:

- Breaks in high energy systems located inside or outside the containment;
- Breaks in systems or components containing radioactive material located in the containment;
- [Failure of Fuel handling equipment accidents](#);
- Heavy load drop;
- Internal missiles;
- Fires and explosions;
- Flooding.

3.8. Layout and design provisions should be taken to protect the containment structure and its associated systems against the effects of the internal hazards:

- The containment structure and the systems should be protected against impacts of high energy (internal missiles, pipe whipping, heavy loads), or designed to withstand their loads and the loads caused by explosions as well;
- The redundancies of the systems should be segregated to the extent possible or adequately separated, and protected as necessary to prevent the loss of the safety function performed by the system (prevention of Common Cause Failure initiated by the effects of the internal hazards)
- The implemented segregation, separation and protection should also be adequate to ensure that the modelling of the system response described in the analysis of the PIEs be not compromised by the effects of the hazard;
- A single hazard should not have the potential for a common cause failure between safety systems designed to control design basis accidents and ~~the dedicated systems or safety~~ features required ~~for in the event of accident~~ [design extension conditions](#) with core melting.

3.9. Methods, design and construction codes used should provide adequate margins to justify that cliff edge effects would not occur in the event of a slight increase of the severity of the internal hazards (see Requirements 9 and 11).

More detailed recommendation is provided in [3].

### 3.4.EXTERNAL HAZARDS

The following recommendations provide guidance to fulfil Requirement 17 [2] with its associated requirements relevant for “External Hazards”.

3.10. ~~Hereafter~~ A list of typical external hazards, and their contribution as appropriate, usually considered is given for guidance in [19] but should be supplemented as needed to include the site specific hazards:

<del>Human origin hazards</del>	<del>Natural hazards</del>
<del>Aircraft crash</del>	<del>Earthquake</del>
<del>Explosion and/or fire of a combustible fluid container</del>	<del>Hurricane and/or tropical cyclone</del>
<del>(e.g. in a shipping accident, an industrial accident, a pipeline accident or a traffic accident)</del>	<del>Flood</del>
	<del>Tornado</del> <del>Wind</del>
	<del>Snow icing</del>
	<del>Impact of an external missile</del>
	<del>Blizzard</del>
	<del>Tsunami (tidal wave)</del>
	<del>Seiche (fluctuation in water level of a lake or body of water)</del>
	<del>Volcanic eruption, sand storm</del>
	<del>Fire</del>
	<del>Extreme temperature (high and low)</del>

3.11. Containment structures and buildings housing systems required to mitigate accident conditions should be designed to withstand the loads imposed by ~~caused by the~~ external hazards and protected against the effects caused by the neighboring buildings not designed to withstand SL-2 seismic loads.

3.12. Systems required for the energy management, the control of radionuclides and of combustible gases in accident conditions should be protected against the effects of external hazards or designed to withstand the loads caused by the external hazards. For each hazard, components whose operability or integrity is required during or after should be identified and specified in the design basis of the component.

3.13. ~~Design methodologies should contain measures to confirm that adequate margins exist to avoid cliff edge effects. Methods, design and construction codes used should provide adequate margins to justify that cliff edge effects would not occur~~ in the event of a slight increase of the severity of the external hazards (see Requirements 9 and 11).

3.14. Short term actions necessary to meet the dose limits and engineering criteria established for the containment in the event of design basis accidents or design extension conditions should be accomplished by permanent systems (see Requirement. 5.17.[2]).

3.15. The autonomy of systems designed for the energy management, the control of radionuclides and the management of combustible gases inside the Primary containment during accident conditions should be longer than the time necessary prior to crediting off-site support services. The autonomy can be achieved crediting the provisions taken at the unit and at the site provided that the potential for some specific hazards to give rise to impacts on several or even all units on the site simultaneously has been considered (see Requirement. 5.15B [2]).

The following recommendations provide guidance to to prevent an early radioactive release or a large radioactive release fulfil the (Requirement 5.21A [2]).

3.16. Structures, systems and components (SSCs)~~SCs~~ ultimately necessary to prevent an early radioactive release or a large radioactive release refer in particular to some of the SSCs necessary to mitigate the consequences of accidents with core melting. A detailed list of these SSCs is design dependent, however, in general and for the scope of this Safety Guide it should include at least:

- Containment structure;
- Equipment or structure ~~Systems~~ necessary to contain the molten core;
- Systems necessary to remove heat from the molten core;
- Systems necessary to remove heat from the containment and transfer heat to the ultimate heat sink in design extension conditions;
- Systems to prevent hydrogen fast deflagration or detonation~~detonations~~;
- Containment venting system (if it exists);
- Containment isolation.

For external flooding this would mean that either all the structures hosting the above mentioned systems are located at an elevation higher than the one derived from the site hazard evaluation the beyond design basis flood, or adequate engineered safety features (such as water tight doors etc.) should be in place to protect these structures and ensure that mitigating actions can be maintained:

3.17. Margins provided by the design of the containment structure should be adequate large enough so that its can be demonstrated that its integrity is preserved in case of natural hazards exceeding those resulting from the site hazard evaluation.

3.18. Margins provided by the design of the associated systems ultimately necessary to avoid an early radioactive release or a large radioactive release early or large radiological release should be adequate large enough so that it can be demonstrated that the integrity and operability of those

systems would be preserved in case of natural hazards causing loads exceeding those resulting from the site hazard evaluation.

More detailed recommendations are provided in [9].

### 3.5. ACCIDENT CONDITIONS

3.19. Accident conditions relevant for the design of the containment and of the associated systems should be those having the potential to cause excessive mechanical loads or to jeopardize the capability to limit ~~the releases dispersion~~ of radioactive substances to the environment.

3.20. Accident conditions should be used for determining capabilities, loads and environmental conditions in the design of the containment structures and systems.

3.21. The determination of capabilities, loads and environmental conditions should be based on , but not necessarily limited to the following:

- The mass and energy of releases inside the containment as a whole and as a function of time;
- The heat transfer to the containment structures and those to and from components;
- The mechanical loading, both static and dynamic, on the containment structure and its sub compartments;
- The releases of radionuclides inside the containment;
- The amount of radionuclides released to the environment;
- Cooling and stabilization of the molten core;
- Localization of the corium (for ex-vessel corium retention strategy);
- The rate of generation and amount of combustible gases released inside the containment.

The following recommendations provide guidance to fulfil Requirement 18 [2].

3.22. To the extent practicable, codes and engineering rules that are used for design should be documented, validated and, in the case of new codes, developed according to up to date knowledge and recognized standards for quality assurance. Users of the codes should be qualified and trained with respect to the operation and limits of the code and with respect to the assumptions made in the design.

3.23. Calculation of boundary conditions for design basis accidents and design extension conditions should be ~~adequately~~ documented, indicating the relevant assumptions for the evaluation of parameters, the engineering criteria and the computer codes that are used.

3.24. Computer codes should not be used beyond their identified and documented domain of validation.

#### 3.5.1. Design basis accidents

The following recommendations provide guidance to fulfil Requirement 19 [2].

3.25. For the performances of the containment structures and systems, design basis accident conditions should be calculated taking into account the less favorable initial conditions and equipment performances, and the single failure<sup>1</sup> which has the largest impact on the performance of the safety systems. Care should be taken when introducing adequate conservatism, since:

- For the same event, an approach considered conservative for designing one specific system could be non-conservative for another;
- Making assumptions too conservative could lead to the imposition of unrealistic stresses on components and structures.

3.26. Containment structure and systems should be designed such that venting is not necessary during DBAs.

### 3.5.2. Design extension conditions

The following recommendations provide guidance to fulfil Requirement 20 [2].

3.27. Design extension conditions should be identified and used to establish the design bases of containment structure and of systems necessary to meet the radiation protection objectives established for that category of accidents. For design extension conditions without significant fuel degradation the radiological consequences should be comparable to those established for design basis accidents, and for accident with core melting, the radiological release should be such that the necessary off-site protective actions remain limited in terms of times and areas.

3.28. Calculation performed to assess conditions imposed by DECs ~~specify the design bases of the containment structure and systems~~ may be less conservative than those imposed used by ~~for~~ design basis accidents provided that margins be still sufficient to cover uncertainties. Performing sensitivity analyses could also be useful to identify the key parameters.

3.29. DEC's relevant for the design of the containment structure and the systems should be identified on the basis of postulated sequences engineering judgement as well as deterministic supplemented by and probabilistic analyses assessment and engineering judgement.

3.30. For design extension conditions without significant fuel degradation, in general, the following three types of DEC's should be considered:

- Very unlikely events that could lead to conditions inside the containment ~~situations~~ beyond the capability of the containment safety systems designed installed to mitigate conditions inside the containment imposed by caused by design basis accidents (e.g. by a LOCA, main steam line break, etc.);
- Multiple failures (e.g. common cause failures in redundant trains) in the containment systems that prevent the safety systems from performing their intended function

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<sup>1</sup> IAEA glossary, 2007 edition: A single failure is a failure which results in the loss of capability of a component to perform its intended safety function(s), and any consequential failure(s) which result(s) from it.

- Multiple failures that cause the loss of a safety system while this system is used to fulfil the fundamental safety functions in normal operation (e.g. residual heat transport systems)’

3.31. As multiple failures are likely caused by the occurrence of dependent failures that may lead to the failure of the safety systems, an analysis of dependences between redundant trains of systems installed to control the pressure build up or to remove energy from the containment in the event of a DBA should be conducted to identify relevant possibilities for DECs.

3.32. Following conditions should be considered as generic candidates for design extension conditions relevant for the design of the containment structures and systems:

- Station Black out
- Loss of the ~~means designed to containment spray system~~ controlling the pressure build up in the event of a design basis accident;
- ~~Loss of the heat transfer chain to the ultimate heat sink removing heat from the containment in the event of a design basis accident.~~
- Loss of wetwell heat sink (BWR)
- Loss of the ultimate heat sink

The following recommendations provide guidance to fulfil Requirements 20 and 68 of [2] for design extension condition with core melting:

3.33. A set of the most likely representative conditions in case of an accident with core melting should be considered to provide inputs to the design of the containment and of the safety features necessary to mitigate the consequences of an accident with core melting. Conditions with core melting, retained as boundary conditions for the design of the containment structures and for the associated systems, should be justified on the basis of PSA level 2 analyses supplemented by engineering experience with the aim at selecting the more likely and representatives ones.

3.34. For the establishing the design extension conditions with significant core melting that need to be considered as bounding condition in the design of safety features for DEC, the following aspects affecting accident progression that will influence containment response and fission product source term should be taken into account:

- Containment status (containment open or by passed);
- Radioactive material initially released to the containment;
- Pressure at onset of core damage;
- Timing of core damage: early ECCS failure (injection phase) vs. long term cooling failure;
- Status of containment safety features (spray, fan coolers, suppression pool);
- Status of AC power sources;
- Status of SFP systems if in the containment.

3.35. Dedicated design provisions should be implemented to prevent ~~an early or a late~~ containment failure in case of DEC. These provisions should aim to prevent a significant over pressurization of the containment structure, to stabilize the molten core and to remove the heat from the containment and to avoid fast deflagration and detonation of combustible gases.

3.36. ~~Different means to control the pressure build up in accident conditions inside the containment should be implemented, and venting (if any) should be used as the last resort mean. Venting of the containment should not be the primary mean to control the pressure build up inside the containment.~~

3.37. ~~Venting the containment should not be needed in case of controlled DBAs.~~

3.38. For ~~a~~ containment with a small free volume for which venting the containment would be necessary to preserve the integrity of the containment, its use should not lead to an early or a large radioactive release (see Requirement 6.28A). In that case:

- Venting line should be equipped with filters of adequate high-capacity and high efficacy (e.g. HEPA filters);
- Containment venting system should be designed to withstand loads from external hazards and the static and dynamic pressure loads existing when the containment venting system is operated;
- It should be possible to reliably open and close the vent lines valves;
- Provisions should be taken to prevent from exceeding the design limit with regard to sub atmospheric pressure.

### 3.6.DESIGN LIMITS

The following recommendations provide guidance to fulfil Requirements 15 and 28 of [2].

3.39. The performance of the containment and of the systems should be assessed against a well-defined and accepted<sup>2</sup> set of design limits and criteria.

3.40. A set of primary design limits for the containment and for the systems should be established ensuring the achievement of the overall safety functions of the containment. These primary design limits are usually expressed in terms of:

- Overall containment leak rate at design pressure;
- Unfiltered Direct leakages;
- Limits on radioactive releases, dose limits or dose constraints for public, specified for operational states and accident conditions;
- Dose limits or dose rate limits, and dose constraints for personnel specified for the biological shielding function.

3.41. Furthermore, design limits should be specified for each containment system as well as for each structure and component within each system. Limits should be applied to operating parameters (e.g. maximum coolant temperature and minimum flow rate for air coolers), performance indicators (e.g.

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<sup>2</sup> 'Well defined and accepted' generally means either widely accepted by Member State regulatory bodies or proposed by international organizations.

~~maximum closing time for isolation valves and penetration air leakage), for each relevant plant state category, limits and engineering criteria should also be specified for each system as well as for each structure and component.~~

### 3.7.RELIABILITY

The following recommendations provide guidance to fulfil Requirements 21, 22, 23, 24, 25, 26, 29 and 30 of [2].

3.42. The following factors should be considered to achieve the adequate reliability of the systems necessary to control energy, radioactive materials and combustible gases released inside the containment:

- Safety classification and the associated engineered requirements for design and manufacturing;
- Design criteria relevant for the systems (number of redundant trains, seismic qualification, qualification to harsh environmental conditions, power supplies,);
- Consideration of vulnerabilities for common cause failures (diversity, separation, independence);
- Layout provisions to protect the system against the effects of internal and external hazards;
- Periodic testing and inspection;
- Maintenance;
- Use of equipment designed to be fail-safe.

#### 3.7.1. Systems designed to mitigate design basis accidents

3.43. Energy management and control of radionuclides in the event of design basis accidents should be possible despite the consequential failures caused by the postulated initiating event and a single failure postulated in any system needed to accomplish the function. Unavailability for maintenance or repair should be considered in addition.

3.44. The on-site AC power source (Emergency power source) should have adequate capability to supply power to electrical equipment necessary for the energy management and control of radionuclides in the event of design basis accidents.

3.45. Vulnerabilities for common cause failures between the redundancies of the safety systems should be identified, and design or layout provisions be implemented to remove the more likely in order to achieve a high reliability required for safety systems. make the redundancies independent to the extent practical.

3.46. Recommendations related to the reliability of the system with regard to the effects of internal or external hazards and environmental conditions are addressed in paragraphs 3.3, 3.4 and 3.10 respectively.

### **3.7.2. Safety features for design extension conditions without significant fuel degradation**

3.47. A reliability analysis of the safety systems designed for the energy management should be conducted to identify needs for additional safety features to preserve the containment integrity.

3.48. The more likely combinations of PIEs and common cause failure (CCF) between the redundancies of the safety systems should be analyzed. If consequences exceed the limits given for DBAs, the vulnerabilities for CCF should be removed or additional design features should be implemented to cope with such situations. The additional features for the energy management should be designed and installed such that they should be unlikely to fail for the same common cause.

3.49. Needs for additional ~~systems or~~ safety features are reactor technology and design dependent.

3.50. Additional Complementary safety features should have an adequate reliability to contribute to the practical elimination of situations that could lead to an early radioactive release or to a large radioactive release~~early and large releases.~~

3.51. Similar recommendations as indicated for systems designed to mitigate design basis accidents should be applied, taking into account that meeting the single failure criterion is not required and that the relevant additional features are expected to be unlikely to fail for the same CCF leading to the failure of the systems designed for design basis accidents.

3.52. Additional safety features for such DEC's should be supplied from a different and diverse power source (e.g. by the alternate power source installed at the unit).~~The additional safety features should be preferably emergency power supplied by the alternate AC power source.~~

### **3.7.3. Safety features implemented to mitigate the consequences of an accident with core melting**

The following recommendations provide guidance to fulfil Requirement 20 of [2].

3.53. Components necessary to mitigate the consequences of an accident with core melting should be capable of being supplied by any of the available power sources.

3.54. Safety systems and specific safety features necessary to mitigate the consequences of an accident with core melting should be independent. ~~Independence between safety systems and specific safety features necessary to mitigate the consequences of an n accident with core melting should be implemented.~~

3.55. Recommendations related to the reliability of the system with regard to the effects of internal or external hazards and environmental conditions are addressed in paragraphs 3.3, 3.4 and 3.110 respectively.

### 3.8.DEFENCE IN DEPTH

The following recommendations provide guidance to fulfil Requirement 7 of [2].

3.56. Different systems should be implemented for the energy management (for pressure [and temperature control](#), and for containment heat removal ~~from the containment~~) in the different plant states.

3.57. Following recommendations contribute to implement independence :

- Successive items, belonging to different levels of defence, necessary to control the pressure inside the containment or to remove energy from the containment should be identified;
- Vulnerabilities for CCF between those items should be identified and the consequences assessed. The vulnerabilities for CCF should be removed to the extent possible where the consequences for the integrity of the containment structure and for radioactive releases are judged not acceptable. In particular, safety features designed to mitigate the consequences of accidents with core melting should be independent from equipment designed to mitigate the conditions inside the containment caused by design basis accidents;
- Independence implemented between systems should not be compromised by vulnerabilities for CCF in I&C systems necessary for the [safety](#) actuation of the systems or the monitoring of the containment conditions (see paragraph 4.10 for more recommendations for I&C systems and Instrumentation).

### 3.9.PRACTICAL ELIMINATION OF [SITUATIONS THAT COULD LEAD TO AN EARLY RADIOACTIVE RELEASE OR TO A LARGE RADIOACTIVE RELEASE,EARLY OR LARGE RELEASES](#)

Conditions arising that could lead to an early radioactive release or a large radioactive release are required to be practically eliminated by design (see Requirement 5.31)

3.58. Regarding the scope of this Safety Guide, such possibilities should include:

- Conditions involving high energetic phenomena the consequences of which could not be mitigated with implementation of reasonable technical means,
- Core melt accident combined with a containment bypass.

Typical examples of conditions to be practically eliminated:

- Severe accident conditions that could damage the containment in an early phase as a result of a direct containment heating, steam explosion or hydrogen detonation;

- Severe accident conditions that could damage the containment in a late phase as a result of a basemat melt-through<sup>3</sup>;
- Severe accident conditions with an open containment, notably in shutdown modes;
- Severe accident conditions with unintentional containment bypass.

3.59. A low probability number for an accident with core melting should not be a reason for not protecting the containment against the conditions generated by such an accident.

### 3.10. SAFETY CLASSIFICATION

The following recommendations provide guidance to fulfil Requirement 22 of [2].

3.60. According to Member States practices, generally the effect of the failure of a SSC should be considered both on the accomplishment of the function, and on the level of the radioactive release. For items to which both effects are relevant, the safety class and the associated quality requirements needed to achieve the expected reliability are defined with due account taken of those two effects. For items which do not contain radioactive material the safety class and the quality requirements are directly derived from the consequences assuming the function is not accomplished.

3.61. Engineering requirements applicable to a whole system (e.g. single failure criterion, independence, emergency power supplied, etc.) should be derived from the consequences assuming the function is not accomplished.

3.62. The classification should be established in a consistent manner such that all systems necessary for the accomplishment of a single function are assigned in the same class,

3.63. More detailed guidance is given in the Safety Guide SSG-30 [4].

3.64. Pressure retaining equipment should be designed and manufactured according to requirements established by proven codes and standards widely used by the nuclear industry. For each individual component, the requirements to be applied should be selected with due account taken of the two effects resulting from its failure (function not accomplished and radioactive release).<sup>4</sup> ~~However, according to international practices, the pressure retaining boundary of components which are part of the reactor coolant pressure boundary should be designed and manufactured in compliance with the highest standards defined by the industry for nuclear application<sup>5</sup> (e.g. ASME Section III, Division 1, subsection NB [5], RCC M1 code [6] or similar standards).~~

3.65. Following the above recommendations:

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<sup>3</sup> ~~These conditions should be analyzed during the identification of situations to practically eliminate. Nevertheless, their consequences could generally be mitigated with implementation of reasonable technical means.~~

<sup>4</sup> ~~However, according to international practices, the pressure retaining boundary of components which are part of the reactor coolant pressure boundary should be designed and manufactured in compliance with the highest standards defined by the industry for nuclear application<sup>4</sup> (e.g. ASME Section III, Division 1, subsection NB [5], RCC-M1 code [6] JSME SNC1, or similar standards), except parts of the RCPB whose failure would result in leakage that is compensable by the normal water make-up system.~~

<sup>5</sup> ~~Except parts of the RCPB whose failure would result in leakage that is compensable by the normal water make-up system.~~

- In the event of a design basis accident, systems necessary for the containment isolation, for the control of the pressure build up inside the containment (e.g. containment spray system), or to remove heat from the containment and transport heat from the containment to the ultimate heat sink should be assigned in SSG-30 safety class 1.
- Systems implemented as a back-up of the safety systems for design extension conditions should be assigned at least in SSG-30 safety class 2;
- Systems necessary to preserve the containment integrity in the event of an accident with core melting should be assigned at least in SSG-30 safety class 3 (e.g. ex-vessel core cooling/corium cooling system, RCS depressurization system, containment spray system, venting and filtering system, systems to prevent hydrogen detonation, heat transport chain).

### 3.11. ENVIRONMENTAL QUALIFICATION

The following recommendations provide guidance to fulfil Requirement 30 of [2].

3.66. The structures, systems and components of the containment should be qualified to perform their functions in the entire range of environmental conditions that might prevail prior to or during their operation until their mission time be completed, or should otherwise be adequately protected from those environmental conditions.

3.67. The relevant environmental and seismic conditions that may prevail prior to, during and following an accident, the ageing of structures, systems and components throughout the lifetime of the plant, synergistic effects, and margins should all be taken into consideration in the environmental qualification [12] [7].

3.68. Environmental qualification should be carried out by means of testing, analysis and the use of expertise, or by a combination of these.

3.69. Environmental qualification should include the consideration of such factors as temperature, pressure, humidity, radiation levels, and local accumulation of radioactive aerosols, vibration, water spray, steam impingement, flooding and contact with chemicals. Margins and synergistic effects (in which the damage due to the superposition or combination of effects may exceed the total damage due to the effects separately) should also be considered. In cases where synergistic effects are possible, materials should be qualified for the most severe effect, or the most severe combination or sequence of effects.

3.70. Techniques to accelerate the testing for ageing and qualification may be used, provided that there is an adequate justification.

3.71. For components subject to the effects of ageing by various mechanisms, a design life and, if necessary, the replacement frequency should be established. In the qualification process for such components, samples should be aged to simulate the end of their design lives before being tested under design basis accident conditions.

3.72. Components that have been used for qualification testing should generally not be used ~~for construction purposes~~ unless it can be shown that the conditions and methods of testing do not themselves lead to an unacceptable degradation of safety performance.

3.73. Qualification data and results should be documented as part of the design documentation.

### 3.12. CODES AND STANDARDS

The following recommendations provide guidance to fulfil the requirement 4.15 of Requirement 9 of [2].

3.74. For the design of the structures and systems of the containment, widely accepted codes and standards should be used. The selected codes and standards:

- Should be applicable to the particular concept of the design;
- Should form an integrated and comprehensive set of standards and criteria;
- For design and construction the newest edition of the codes/standards should be preferably considered. However another edition might be used with justification.

3.75. Codes and standards have been developed by various national and inter- national organizations, covering areas such as:

- Quality assurance;
- Materials;
- Structural Design of pressurized components;
- Civil structures;
- Pressure vessels and pipes;
- Instrumentation and control;
- Environmental and seismic qualification;
- Pre-service and in-service inspection and testing;
- ~~Quality assurance;~~
- Fire protection.

### 3.13. USE OF PROBABILISTIC ANALYSES IN DESIGN

Probabilistic analyses should complement the deterministic approach by identifying additional features (to achieve a balanced design). The use of probabilistic analyses should not be considered as a substitute to a design approach based on deterministic requirements, but as a part of the process to identify potential safety enhancements and to judge their effectiveness.

3.76.

~~3.76.~~

3.77. Probabilistic safety analysis should be used taking into accounts its limitations in support of demonstrating the practical elimination of conditions that could lead to an early radioactive release or

~~a large radioactive release~~ ~~early or large releases~~. In particular PSA may be used for analyzing the containment isolation provisions, for preventing containment by-pass and the total failure of the energy management systems.

3.78. As a complement to a number of investigations related to fabrication, testing, inspection, evaluation of the operating experience, PSA should be used together with deterministic calculations in demonstrating a very low probability of ~~an early radioactive release or a large radioactive release~~ ~~early or large releases~~ for postulated design extension conditions with core melting. This should include inter alia the analysis of the reliability of containment systems, e.g. containment cooling system, containment filtered venting, etc. and other aspects that have traditionally been considered in level 2 PSA.

~~3.79.2.1. The use of probabilistic analyses should not be considered as a substitute to a design approach based on deterministic requirements, but as a part of the process to identify potential safety enhancements and to judge their effectiveness.~~

## 4. DESIGN OF CONTAINMENT STRUCTURE AND ASSOCIATED SYSTEMS

### 4.1. GENERAL

4.1. A number of systems are design dependent and may be different in their design principles (e.g. use of active or passive systems for the energy management, in-vessel or ex-vessel core cooling in the event of an accident with core melting, etc.). Nevertheless, structures or systems having to accomplish the same safety function in different technologies should be designed in compliance with the same design requirements.

4.2. Regardless of permanent design provisions for DBAs and for DEC, features enabling the safe use of non-permanent equipment for restoring the capability to remove heat from the containment should be installed (see Requirement 6.28B).

#### 4.1.1. Layout and configuration of containment systems

4.3. The layout of the containment should be defined with account taken of several factors that are dealt with in this Safety Guide and that are summarized below:

- Provision of adequate separation between divisions of safety systems and between redundant safety features for DEC where relevant;
- Location and provisions to protect items important to safety against the effects of internal hazards;
- Sufficient air flow routes between separate compartments inside the containment;
- The cross-sections of openings between compartments should be of such dimensions as to ensure that the pressure differentials occurring during pressure equalization in accident conditions do not result in unacceptable damage to the pressure bearing structure or to systems that are important in mitigating the effects of accident conditions;

- Provision for sufficient space and shielding to ensure that maintenance and operations can be carried out without causing undue radiation exposure of personnel;
- Provision of the necessary space for personnel access and the monitoring, testing, control, maintenance and movement of equipment;
- Placement of the equipment and structures so as to optimize biological shielding;
- Optimization of the number of and location of penetrations in areas of the containment wall so as to prevent unfiltered leaks and to ensure accessibility for inspection and testing;
- Optimization of location of the equipment to minimize risks associated to fuel handling, and keeping a confinement in this plant state
- Ensuring an adequate single free volume in the upper part of the containment to improve the efficiency of the containment spray (if any);
- Minimization of water retention to facilitate water and condensates flowing back to the containment sumps.
- Ensuring an adequate free volume and adequate cooling flow paths;
- The lower part of the containment should be designed to facilitate the collection and identification of liquids leaked, ~~and also the channeling of water to the sump or to the internal water storage tank in the event of an accident.~~
- Allow the replacement of equipment that maybe foreseen during the plant life time (e.g. SGs)

#### 4.1.2. Maintenance and Accessibility

The following recommendations provide guidance to fulfil the relevant requirements of Requirements 6, 32, 81 and the requirement 5.15 of [2]. Recommendations [18] to prevent non authorized persons from accessing the containment and the buildings that housed the systems important to safety should also be implemented in an integrated manner with the recommendation for safety.

4.4. The design should take into account the potential exposure to radiation associated with operations such as maintenance or repair that would be needed to be conducted after an accident, or with operations that it may be necessary to conduct following the emergency procedures as well as with the recovery actions following an accident. Evaluations should include the consideration of access paths. If the doses due to such exposures exceed the applicable dose limits ~~and dose constraints,~~ additional shielding or even the repositioning of components should be considered. The use of other connecting points should also be considered.[NS-G-1.13]

4.5. Maintenance related factors considered in the containment design should include the provision of adequate working space, shielding, lighting, air for breathing, and working and access platforms; the provision and control of environmental conditions; the identification of equipment; the provision of hazard signs; the provision of visual and acoustic alarms; and the provision of communication systems.

4.6. The accessibility of both the containment and the systems should be considered for all operational states. The ability to ensure that radiation doses to operators remain within the

acceptable dose ~~constraints limits~~ will determine whether access can be allowed to the primary and/or the secondary containment (if applicable) during power operation, or whether plant shutdown is required for permitting such access.

4.7. If entry into the primary or secondary containment during power operation for the purposes of unplanned maintenance or even for routine (planned) maintenance is envisaged, provision should be made to ensure the necessary radiological protection and adequate working conditions of plant staff. This provision should include the application of the principle of keeping exposure as low as reasonably achievable, the provision of the necessary communication systems and alarms, and monitoring of the containment atmosphere, especially in the case of inert containments or containments at sub atmospheric pressure.

4.8. At least ~~one two~~ emergency escape routes from the containment should be provided. In addition, security provisions for controlling access to the containment should be considered.

#### **4.1.3. Operator actions**

4.9. In the event of an accident, ~~there should be no need for any action to be taken by the operator within a certain grace period. For necessary manual intervention,~~ the operator should have adequate information available as well as sufficient time to diagnose and assess the conditions in the plant before taking any manual action.

#### **4.1.4. Sharing of parts of the containment system between units**

The following recommendation provides guidance to fulfill Requirement 33 of [2].

4.10. Each unit of a multiple unit nuclear power plant should have its own safety systems and its own safety features for design extension conditions.

4.11. Means allowing interconnections between units should be installed to facilitate the management of accidents not considered in the design of the NPP.

#### **4.1.5. Ageing effects**

The following recommendation provides guidance to fulfil Requirement 31 of [2].

4.12. The containment may be subject to several ageing phenomena such as the corrosion of metallic components, the creep of tendons and the reduction of pre-stressing (in pre-stressed containment), the reduction of resilience in elastomeric seals, and the shrinkage and cracking of concrete. ~~All~~ Ageing mechanisms should be identified and taken into account in the design. Provision should be made for controlling monitoring the ageing of the containment, for testing and inspection of components where possible, and for periodically replacing items whose safety characteristics are susceptible to age-related degradation. More detailed guidance is provided in [7].

#### **4.1.6. Decommissioning**

4.13. Provisions should be taken to facilitate the decommissioning and dismantling of equipment, and to minimize the production of contaminated wastes (see Requirement 12). Guidance on these aspects is given in [8].

## **4.2. STRUCTURAL DESIGN OF CONTAINMENT**

### **4.2.1. General design process**

4.14. Pressures and temperatures which can be reached at all the different plant states are fundamental parameters used for the design of the containment and the associated systems. Those parameters result from assessing the containment conditions for each of them taking into account the relevant methodologies and rules.

4.15. The design pressure should not be lower than the value of the peak pressure that would be generated by the design basis accident with the most severe release of mass of material and energy and increased by 10%.

4.16. The design temperature should be defined as the value of the peak temperature that would be generated by the design basis accident with the most severe release of energy.

4.17. Pressure and temperature used in the load combinations should be determined with adequate margins to avoid cliff edge effects and to take into account:

- Uncertainties in the amounts of fluids released and in the release rates in terms of both mass and energy, including chemical energy from metal– water reactions;
- Structural tolerances;
- Uncertainties in relation to the decay heat;
- The heat stored in components;
- The heat transferred in heat exchangers;
- Uncertainties in the correlations of heat transfer rates;
- Conservative initial conditions.

4.18. Design for a specific maximum leak rate is not a straightforward or purely quantitative process. A number of factors should be taken into account, including the limitation of stresses in accident conditions, the adequate choice of components (e.g. isolation valves), the adequate choice of sealing materials, limitation of the number of containment penetrations and control of the construction quality. Existing operational data, experience and practices should be used to the extent possible.

4.19. The mechanical behavior (stresses and deformations) of the containment structure, as tentatively determined on the basis of the design pressure and the design temperature, should be verified for all load combinations and should comply with the corresponding engineering criteria for the integrity and leaktightness of the containment.

4.20. The mechanical resistance of the containment and of the associated systems should be assessed in relation to the expected range of events and their anticipated probability over the plant lifetime, including the effects of periodic tests.

4.21. In steel containments the load bearing and leaktightness functions are fulfilled by the steel structure. The metallic structure should be protected against missiles generated inside and outside the containment as a result of internal and external hazards that affect the plant.

#### **4.2.2. Loads and load combinations**

4.22. ~~All~~ loads (static and dynamic) that are foreseen to occur should be quantified and grouped according to their probability of occurrence, on the basis of operating experience and engineering judgment.

4.23. Loads should be combined with account taken of:

- Load type (i.e. static or dynamic, global or local);
- Whether loads are consequential or simultaneous (e.g. LOCA pressure and temperature loads);
- Physical barriers that protect equipment from hazard effects;
- Time history of each load (to avoid the unrealistic superposition of load peaks if they cannot occur coincidentally).

4.24. At the end of the analysis the number of load combinations may be reduced by grouping them appropriately. The analysis will be performed only for the most demanding cases.

4.25. The steel liner of the containment (where applicable) should be able to withstand the effects of imposed loads and to accommodate relative movements of the liner and the concrete of the containment without jeopardizing its leaktightness. The liner should not be credited in the structural evaluation for the resistance of the containment.

4.26. The metallic liner, structures, penetrations and isolation valves of the containment should be protected against the effects of the internal hazards or if not should be designed to withstand the loads.

4.27. For containment design with double walls, the pressurization of the space between the two containment walls caused by a high energy piping break should be considered, unless such a break is precluded by the design.

TABLE 2. TYPICAL MINIMUM SET OF LOADS ON THE CONTAINMENT TO BE CONSIDERED AT THE DESIGN STAGE

Load category	Load	Remarks
Pre-service loads	Dead	Loads associated with the masses of structures or components
	Live	Loads associated for example with component restraints
	Pre-stressing	Only for pre-stressed concrete structures
	Loads in construction	Temporary loads due to construction equipment or the storage of major components
	Test pressure	See Section 5
	Test temperature	See Section 5
Normal or service loads	Actuation of safety relief valve	Boiling water reactors only
	Lifting of relief valve	Boiling water reactors only
	Air cleaning of safety relief valve	Boiling water reactors only
	Operating pressure	In normal operation, including transient conditions and shutdown
	Operating temperature	In normal operation, including transient conditions and shutdown
	Pipe reactions	In normal operation, including transient conditions and shutdown
	Wind	Maximum wind speed assumed to occur over plant operating lifetime (see [9])
	Environmental and related loads and site	For example, snow load, buoyant forces due to the water table and extremes in atmospheric temperature
	External pressure	Loads resulting from pressure variations both inside and outside the primary containment
	Extreme wind speeds	Loads generated by extreme wind speeds, i.e. maximum wind speed that may be associated with the site
Loads due to extreme external events	Design basis earthquake	See [12]
	Loads associated with extreme wind speeds	Associated missiles to be considered
	Aircraft crash	See also [9]
	External explosion	See also [9]

Load category	Load	Remarks
Loads due to accidents	DBA pressure	Calculated peak pressure in an accident
	DBA temperature	Calculated peak temperature in an accident
	Design pressure	DBA pressure + 10%
	Design temperature	DBA temperature
	DBA pipe reactions	See also [3]
	Jet impingement and/or pipe whip	See also [3]
	Local effects consequential to a DBA	See also [3]
	Dynamic loads associated with a DBA	Loads are design dependent (e.g. for a boiling water reactor design: discharge line clearing loads, pool swell, condensation oscillation and discharge line 'chugging')
	DEC pressure	Calculated peak pressure in the most penalizing condition ( <a href="#">peak and time dependent profile</a> )
	DEC temperature	Calculated peak temperature in the most penalizing condition ( <a href="#">peak and time dependent profile</a> )
Actuation of the depressurization system	Depressurization of the primary circuit (where applicable)	
Internal flooding	See also [3]	

### 4.2.3. Engineering criteria

4.28. Engineering criteria for leaktightness and integrity of the containment and appurtenances (penetrations, isolation systems, doors and hatches), as proposed in 4.31 and 4.32 should be established on the basis of stress and deformation limits for different load combinations. Meeting the criteria given by codes and standards internationally recognized provides reasonable assurance that structures and components are capable of performing their intended functions.

4.29. It should be demonstrated in the analysis that the engineering criteria for structural integrity and leaktightness are met with an adequate margin so as to avoid 'cliff edge' effects.

4.30. In any case, design limits should be defined according to the expected performance (see paragraph 3.6). Design margins should be provided by either [or both](#) :

- Limiting stresses and deformations to some fraction of the ultimate limit for that material; or
- Use of the load factor approach (i.e. increasing the applied loads by a certain factor).

4.31. For the design of the structural integrity of the containment, the following levels should be considered:

- Level I: elastic range. No permanent deformation of, or damage to, the containment structure occurs. Structural integrity is ensured with large margins.
- Level II: small permanent deformations. Local permanent deformations are possible. Structural integrity is ensured, although with margins smaller than those for Level I.

4.32. For the design of the leaktightness, the following levels should be considered :

- Level I: leak tight structure. Leakages from the containment are below the design value<sup>6</sup> and can be correlated with the internal pressure on the basis of analysis, experience and test results.
- Level II: possible limited increase of leak rate. The leak rate may exceed the design value, but the leaktightness can be adequately estimated on the basis of analysis, experience and test results.

4.33. The detailed load combinations are design dependent. Table 3 presents a minimum set of recommended load combinations and engineering criteria for a typical containment of pressurized water reactor.

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<sup>6</sup> In this context 'design value' has the meaning of the value of the leakage rate established as a target of the design and used in the safety analysis to determine the radiological releases under design pressure and design temperature.

TABLE 3. LOAD COMBINATIONS AND ENGINEERING CRITERIA

Load description	Design	Test	Normal operation	Normal operating plus extreme wind speed	SL-2 Earthquake	External pressure	DBA	SL-2 plus DBA	Aircraft crash	Fire	External explosion	DEC wo core melting	DEC w core melting
Dead	x	x	x	x	x	x	x	x	x	x	x	x	x
Live	x	x	x	x	x	x	x	x	x	x	x	x	x
Pre-stressing applicable) (if applicable)	x	x	x	x	x	x	x	x	x	x	x	x	*
Test pressure		x											
Test temperature		x											
Sustained loads		x	x	x	x	x	x	x	x	x	x	x	x
Operating loads			x	x	x	x	x	x	x	x	x	x	x
Operating temperature			x	x	x	x			x		x		
Pipe reactions			x	x	x	x			x	x	x		
Extreme wind				x									
External pressure						x							
SL-2 <sup>7</sup> earthquake					x			x					
Design pressure	x												
Design temperature	x												
DBA <sup>8</sup> pressure							x	x					
DBA temperature							x	x					
DBA pipe reactions							x	x					

<sup>7</sup> SL-2 : seismic level 2

<sup>8</sup> DBA : design basis accident

Load description	Design	Test	Normal operation	Normal operating plus extreme wind speed	SL-2 Earthquake	External pressure	DBA	SL-2 plus DBA	Aircraft crash	Fire	External explosion	DEC wo core melting	DEC w core melting
Aircraft crash									x				
Fire										x			
External explosion											x		
DEC w core melting pressure													x
DEC w core melting temperature													x
DEC wo core melting pressure												x	
DEC wo core melting temperature												x	
Engineering criteria for steel containment:													
- structural integrity	I	I	I	I	II	II	I	II	N/A	II	N/A	II	II
- leaktightness	I	I	I	I	N/A	II	I	II	N/A	II	N/A	I	II
Engineering criteria for the pre-stressed concrete wall for :													
- structural integrity	I	I	I	I	II	N/A	II	II	II	II	II	II	II
- leaktightness	I	I	I	I	N/A	N/A	I	II	N/A	N/A	N/A	I	II
Engineering criteria for a liner on pre-stressed concrete wall	I	I	I	I	II	N/A	II	<del>II</del> N/A	N/A	II	N/A	II	II

4.34. To provide margins, loads resulting from earthquake level SL2 and design basis accidents should be combined using SSR method (Square Root of the Sum of the Squares) in a quadratic manner, although one cannot realistically be a consequence of the other since the pressure boundary is designed to withstand seismic loads caused by earthquake level SL2 [12].

#### **4.2.4. Local stresses and fatigue**

4.35. Localized stress, including those at welding regions and regions with changing geometry, and their effects on the mechanical performance of structures, including leak rates, should be evaluated.

4.36. For pre-stressed concrete containments, particular attention should be paid to identifying areas of low pre-stressing (such as areas surrounding large penetrations and transition zones between cylinder and basemat), to concentrated stresses near penetrations and near anchorages of the tendons and to tensioning sequence during the construction.

4.37. For containments provided with a metallic liner, the zones of anchorage of the liner to the concrete and the connections of the liner to other metallic structures such as penetrations are also critical areas. Local effects of stress in these zones should be analyzed and taken into account.

#### **4.2.5. Ultimate capability and failure mode**

4.38. To determine the ultimate load bearing capacity and confinement capacity, it should be considered to make a global evaluation of the structural behavior of the containment under static (pressure, temperature and actions of pipes) and dynamic (seismic) loads and to identify the most limiting parts so as to evaluate margins, and to study the failure mode of the structure. Local effects, thermal gradients and details of design should also be considered so as to identify possible mechanisms for large leaks. In this regard, special attention should be paid to the behavior of piping penetrations, soft sealing materials, electrical penetrations and structural singularities.

4.39. Failure modes such as liner tearing, penetration failures and tendon failures should be analyzed. To the extent possible, a failure should not be catastrophic and should not cause additional damage to systems and components for retaining radioactive material.

### **4.3. STRUCTURAL DESIGN OF STRUCTURES WITHIN THE CONTAINMENT**

4.40. Consideration should be given to the possibility of large releases of mass and energy inside the containment, and the need for the internal structures to withstand the pressure differentials that could arise between different compartments so as to prevent any collapse. For each compartment, the most unfavorable location for a break should

be considered. Openings between compartments should be considered by means of a conservative approach at the design stage and should be verified to be free of unintended obstructions after construction has been completed.

4.41. Consideration should be given to the need for the internal structures to withstand the loadings associated with accident conditions, and so to withstand the dynamic loads that are caused by high energy discharges or pipe breaks, water flowing from the discharge line of the safety valves and the relief valves into the suppression pool, the swelling of the pool water, the oscillation of condensate water, chugging and any other relevant hydraulic phenomena.

4.42. The loads on the structures inside the containment, in case of design extension conditions, depend on the strategy to cope with the molten core adopted in the specific design.

#### **4.3.1. In-vessel retention strategy**

4.43. In this strategy, the heat from the molten core is removed through the wall of the vessel. This requires the reactor cavity to be flooded at least to a level above the location of the molten core. Mechanical and thermal loads in the walls of the cavity should be considered. Features should be included to remove the heat from the cavity and to avoid its pressurization.

4.44. The structures of the cavity should be considered as items ultimately necessary to avoid large releases and consequently they should be such that design margins are adequate to deal with seismic loads exceeding SL-2.

#### **4.3.2. Ex-vessel retention strategy**

4.45. In this strategy, the containment should be equipped with an [ex-vessel retention structure \(core catcher or wet cavity for BWR\)](#) dedicated to contain and cool the molten core outside of the vessel.

4.46. The [ex-vessel retention structure core catcher](#) should be designed to minimize the production of combustible gases due to molten corium concrete interaction.

4.47. The structures and materials used for the design of the [ex-vessel retention structure core catcher](#) should be appropriate to withstand the different loads and effects caused by the ingress of the corium in the different elements of [ex-vessel retention structure, the core catcher](#).

4.48. The structures and the cooling system of the [ex-vessel retention structure core catcher](#) should be appropriate and designed for stabilizing and confining the corium inside [the core catcher](#).

4.49. The core catcher should be considered as items ultimately necessary to avoid large releases and consequently it should be such that design margins are adequate to deal with seismic loads exceeding SL-2.

#### 4.4. STRUCTURAL DESIGN OF SYSTEMS

4.50. For containment systems, a set of representative loads and load combinations, as well as a set of adequate engineering criteria, should be established by a similar procedure as for the containment structures, with account taken of all the relevant accident conditions.

#### 4.5. ENERGY MANAGEMENT

Energy management is a term used to describe the management of those design features of the containment that affect the energy balance within the containment and thereby play a part in maintaining pressure and temperature within acceptable limits.

##### 4.5.1. Control of pressure and temperature during plant operation

4.51. During normal plant operation, a ventilation system should be operated to maintain the pressure ~~and~~ temperature ~~and humidity~~ in the containment within the limits specified for normal operation. More detailed recommendations are given in [9].

##### 4.5.2. Control of pressure and temperature in accidents

4.52. The design performance of the systems for energy management should be established so as to be able in the event of an accident to control pressure and temperature within the specified limits and to reach a stable state, with the containment depressurized, within a reasonable period of time (typically a few days) after its onset.

###### 4.5.2.1. Inherent energy management features

4.53. The free volume of the space within the containment envelope is the primary physical parameter determining peak pressures after postulated pipe rupture events. It can thus be used as an inherently safe and reliable design feature. If the volume of the containment is subdivided into compartments that are provided with collapsing panels or louvres that open in the event of energy released, these collapsing panels or louvres should be designed to open quickly at the predetermined pressure so as to achieve fast equalization of the pressures in the various compartments and to utilize the full free volume of the containment.

4.54. The containment structure and its internal structures, as well as the water stored within the containment, act as a passive heat sink. In the postulated conditions of a pipe rupture accident, the heat transfer rate and heat capacity of structures and components of structures are important parameter in determining pressures and temperatures. The primary mechanism for heat transfer is the condensation of steam on

exposed surfaces, and the thermal conductivity of the structure plays an important part in determining the rate of heat transfer. All conditions that could affect the transfer of heat to the structures, such as the effects of coatings or gaps, should be considered in a conservative manner in the design, and adequate margins should be applied.

#### *4.5.2.2. Containment spray systems*

4.55. The energy management function of the spray system is to remove energy from the containment atmosphere in order to limit both the maximum values and the time durations of the high pressure inside the containment in accident conditions.

4.56. Containment spray systems should be designed so that a major fraction of the free volume of the containment envelope into which the steam may escape in an accident can be sprayed with water.

4.57. The spray headers and nozzles should be designed to provide an even distribution of water droplets, which should be small enough to reach thermal equilibrium with the containment atmosphere quickly during their fall.

4.58. The initial source of water for the containment spray system after a pipe rupture is usually a large storage tank or the the suppression pool (for BWR). Later the spray system may operate in a recirculation mode and take water from appropriate collection points in the containment sump or the suppression pool. Sufficient flow paths enabling water and condensates to return back to the sumps should exist.

4.59. When the spray system is designed to operate in a recirculation mode, the spray nozzles should be designed against clogging by the largest postulated pieces of debris that can reach them through the intake screens. In the same way, the spray pumps should be protected from cavitation or failure due to accumulation of debris ~~which can exist in the sumps and may cross the sump filters~~. The minimum net pump suction necessary for the operation of the pumps should be calculated taking into an accumulation of debris on the surface of the filters (if any).

4.60. The pressure limiting effect of spray systems may depend on the time necessary for spray to be delivered after the energy released. The delay time for spray delivery should therefore be determined for use in analyses of containment pressure and temperature transients. The actuation times of components and time necessary to fill the spray piping, headers and nozzles should be taken into account in the analyses.

#### *4.5.2.3. Pressure suppression pool systems*

4.61. Containments of a design with a suppression pool system are divided into two separate compartments called the dry well (which contains the reactor) and the wet well (which contains the suppression pool). The two compartments are normally isolated from one another. When the pressure in the dry well is sufficiently higher than the pressure in the wet well, steam and gases flow from the dry well to the wet well

and the steam condenses into the pool of water. In some designs, communication between the dry well and the wet well can also occur if the pressure in the wet well is higher than the pressure in the dry well. In the containments of some designs the suppression pools are also used to collect the steam discharged from the safety valves or the relief valves, or to provide water for recirculation in the emergency core cooling system, [decay heat removal system and containment spray system](#). Complex hydraulic and pressure transients occur when steam and gases are vented into the suppression pool water. The design of the dry and wet wells and connection features should be such that the hydraulic responses and the dynamic loads can be reliably determined by analysis and tests.

4.62. The hydraulic response [of](#) and [loads imposed to the pressure suppression pool in the different plant states should be determined and considered for design](#), ~~the loading function associated with various likely combinations of normal operating events and anticipated operational occurrences should be determined.~~

4.63. The structural design of the pressure suppression pool system should be such as to ensure that the pool, as well as the containment system as a whole and other safety systems, remains functional in all operational states and/or all postulated accident conditions.

4.64. The pressure suppression pool system should be designed in such a way that the pathway for steam and gases from the dry well to enter the wet well following a postulated accident condition is through submerged vents in the wet well water pool.

4.65. The leakage between the dry well and the wet well that bypasses the submerged venting lines should be minimized and should be taken into account in the design.

4.66. The use of the water inventory in the pressure suppression pool system for other functions should not impair the performance of its main function of providing a means of [controlling](#) the pressure in the dry well in case of accident condition

4.67. The dry well should be designed to withstand, or should be protected from (e.g. by automatic vacuum breaker valves), excessive under pressure caused by operation of the spray system either on purpose or inadvertently.

#### *4.5.2.4.External recirculation cooling*

4.68. For energy management systems designed with an outside recirculation, piping not housed inside the containment should be considered as an extension of the containment and should be subject to specifications for structural integrity and leaktightness comparable with those applied to containment structure itself.

4.69. A minimum and adequate net pump suction head should be available to the recirculation pumps under any accident conditions for which the operation of the pumps is necessary.

4.70. Devices at which suction takes place should be designed to minimize cavitation and to prevent the ingress of foreign material (such as thermal insulation), which could block or damage the recirculation system.

4.71. To avoid the clogging of ~~sump screens or strainer filters~~~~screens and filters~~, special care should be taken in the design of piping, component insulation and the intake ~~sump screens or strainer filters~~~~screens and filters~~ themselves, and consideration should be given to the chemical effects as determined by the sump ~~and suppression pool~~ water chemistry and temperature, and to corrosion/erosion of some metallic components and their interaction with the debris. In addition the material used inside the containment (thermal insulation material, paints, etc.) should be carefully considered. The design should also avoid certain combination of these materials which may worsen the ~~sump clogging~~ issue of clogging at sump screens or strainer filters. (see paragraph 4.9.4 “Covering, thermal insulation and coating materials”).

4.72. Special consideration should be also given to the effects of debris by-passing the sump ~~screens or strainer~~ filters on the potential for blockage of flow channels in fuel assemblies.

4.73. Piping crossing the containment walls should be equipped with containment isolation devices (see paragraph 4.8.1 “Provisions for containment isolation”), and devices necessary to isolate leaks in the external recirculation loops and to maintain a sufficient water inventory for cooling. Non-isolable leakage (e.g. between the containment penetration and the isolation valve) should be prevented by design (e.g. by means of the provision of a guard pipe).

4.74. An intermediate and closed cooling system should be provided for heat transport to the ultimate heat sink. This cooling system should be equipped with features to detect activity and isolate leaks within the recirculation loop.

#### 4.5.2.5. Passive containment cooling systems

4.75. For containment with a steel shell, heat released in the containment under accident conditions can be removed passively through the ~~steel shell~~~~containment walls~~. A secondary and outside envelope is needed and containment is designed to remove ~~the~~ heat by providing a natural circulation path for air (the chimney effect). Containment spray is implemented by ~~and means for~~ spraying of the outside of the steel shell.

4.76. Heat can also be removed from the containment by the installation of a number of heat exchangers on the inner walls of the containment and transferred outside the primary containment by natural convection to passive cooling condensers.

4.77. ~~Where~~ ~~if such~~ passive containment cooling is adopted, the following aspects should be considered:

- The area of the cooling surface should be sufficient to transfer the heat generated in the containment and to cool down the atmosphere and the structures inside the containment. The heat transfer coefficient should be conservatively determined.
- The necessary natural circulation within the containment and that to the outside heat sink should be ensured for all relevant plant states for which such passive transfer is necessary.
- The possibility for freezing outside conditions should be considered for normal as well as accident conditions.
- The entire system should be qualified and validated by means of tests and analyses.
- A thorough search should be conducted for possible harmful effects and failure modes, in order to achieve a high degree of confidence that the safety functions will be fulfilled.

#### 4.6. CONTROL OF RADIONUCLIDES

4.78. Containment structure and systems should be designed to meet the objectives for preventing and limiting the radiological release specified for the different plant states as indicated in 2.1.

4.79. Compliance of the radiological release with the relevant limit should be demonstrated by crediting the provisions designed for the relevant plant state only. The demonstration should be conducted according to models and analysis rules applicable to the plant state category.

4.80. Design provisions necessary to minimize the doses and the radiological releases should consider that the source terms are specific to each plant state (magnitudes and physicochemical forms).

4.81. An assessment of potential radioactive releases from the containment should be made for the design basis accidents and design extension conditions in order to identify any potential weaknesses with regard to the leaktightness of the containment and to determine ways to eliminate them.

##### 4.6.1. Containment source term

4.82. To design the overall containment performance and in particular the measures for radionuclide management, the amount and isotopic composition of the radionuclides postulated to be released from the containment (the source term) should be estimated for the various accidents to be considered.

4.83. For design basis accidents, this should be done by means of a conservative analysis of the expected behavior of the core and of the safety systems. Initial conditions for the relevant parameters (e.g. for the inventory of radionuclides in systems and for leak rates) should be the less favorable values authorized by the limits and conditions of the plant.

4.84. The anticipated evolution of the physicochemical forms of the radionuclides in the containment should be assessed, with account taken of the latest knowledge (e.g. it is known that certain paints enhance the production of organic iodine).

4.85. Once iodine is trapped in water pools inside the containment, it may volatilize again in the medium to long term if appropriate pH conditions are not maintained. Therefore all conditions should be assessed that could change the pH of the water pools during an accident and, if necessary, provide the necessary means to keep the water pools alkaline.

#### **4.6.2. Leaktightness of the containment**

4.86. An effective way to restrict radioactive releases to the environment is to maintain the leak rate below conservative specified limits throughout the plant's operating lifetime<sup>9</sup>. As a minimum, leak rates should be small enough to ensure that the relevant dose limits are not exceeded during normal operations or in accident conditions.

4.87. At the design stage, a target leak rate should be set that is well below the safety limit leak rate, i.e. well below the leak rate assumed in the assessment of possible radioactive releases arising from accidents. This margin should be established to reduce the likelihood that unforeseen modifications made at the stage of design or construction cause an actual leak rate to approach the safety limit leak rate.

4.88. To limit the number of leak paths, the number of penetrations should be optimized as indicated by the recommendation 4.34. The external extensions of the penetrations should be installed in a confined building, at least until the first isolation valve, in order to collect and filter any leaks before a radioactive release occurs.

4.89. Leak rates of isolation devices, air locks and penetrations should be specified with account taken of their importance to safety and the integral leaktightness of the containment.

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<sup>9</sup> Examples of such limits that are applied in Member States are: 0.25–0.5% overall leakage of the contained mass of free gas and steam per day at design pressure for steel containments or concrete containments with a steel liner; 1.0–1.5% per day overall leakage for pre-stressed concrete containments without a steel liner.

4.90. A reliable design of and actuation for containment isolation system should be incorporated, as described in paragraph 4.8.1 “Provisions for containment isolation”, to ensure the leaktightness of the containment in the event of an accident.

4.91. Containment structure and systems should be designed to limit leaks and to avoid, to the extent possible, the creation of unfiltered leak paths to the environment.

#### **4.6.3. Secondary containment**

4.92. Secondary confinement is an arrangement, in which the primary containment is completely or partially enclosed within a secondary envelope. The purpose of the secondary envelope is not to take over the functions of the primary containment should it fail but to allow for the collection of leaks from the primary containment and for a filtered release via the vent stack. When such a design option is implemented, the secondary containment structure is also often designed as the shielding structure of the containment.

4.93. When a secondary confinement is provided, direct leaks (i.e. leak paths from the containment directly to the outside) should be prevented to the extent possible.

4.94. When employing a partial secondary confinement (i.e. one which does not completely enclose the primary containment), the envelope should enclose the more leakage prone areas of the primary containment (such as the penetration areas).

4.95. Criteria should be set for the control of direct leaks and for the leaktightness of the secondary confinement envelope. It should be verified periodically by means of testing that these criteria are being met.

4.96. Systems associated with the secondary confinement should be designed to collect, filter and discharge gases and liquids containing radionuclides that have leaked from the containment in accident conditions, or to pump leaked liquids back into the containment.

4.97. To maximize the efficiency of the secondary confinement, a filtered ventilation system should be provided and designed to maintain a negative gauge pressure in DBAs. If a negative gauge pressure cannot be achieved and maintained in the confinement volume, account should be taken in the calculations of the radiological consequences of the unfiltered leakage to the environment that will result.

4.98. The confinement volume should be kept at negative gauge pressure in normal operation, to enable the leaktightness of the secondary containment to be monitored.

#### **4.6.4. Containment bypass**

Containment bypass events arise when primary coolant and any accompanying fission products escape to the outside atmosphere without being processed by containment systems for the control of radionuclides.

4.99. Appropriate design provisions should be taken to demonstrate that conditions leading to an early radioactive release or a large radioactive release ~~early or large release~~ have been practically eliminated.

4.100. Design and quality of piping circulating outside the containment high contaminated liquids or high airborne activity in the event of an accident with core melting should be adequate to be leak tight under the conditions they are operated. Loads and process conditions should be properly considered and combined.

4.101. Conditions for the opening of the containment (equipment hatch, fuel transfer tube, etc.) should be specified and adequate to prevent from arising of accidents with a release of activity to the atmosphere of the containment, or to close the containment shortly.

4.102. Possible paths for interfacing system LOCAs should be eliminated as far as possible, either by relocating the system in the containment or by increasing the design pressure of the low pressure system above the pressure of the reactor coolant system. For any remaining possible paths for interfacing system LOCAs, reliable provisions for preventing or stopping the leak outside the containment should be implemented.

4.103. In pressurized water reactors, a steam generator tube rupture is a containment bypass event that could lead to significant releases of radioactive material. Preventive design features should be installed in steam generators to reduce the frequency of such events to a very low value. The design of the plant should allow a fast isolation of the affected steam generator in order to minimize the radiological release and not to exceed the radiological limit defined for the relevant plant state category.

4.104. Many containment designs include systems to recirculate water from collection points inside the containment envelope, either through heat exchangers or directly, for reinjection into the reactor vessel or into the containment spray system in an accident. Parts of these recirculation systems may be located outside the containment envelope, giving rise to a potential for leakage of radionuclides from pumps, valves or heat exchangers outside the containment envelope. Where a design of this type is used, provisions should be made to minimize the uncontrolled release of radionuclides to the environment resulting from such leakage, to test the leak rate periodically, and to detect and isolate accidental leaks by qualified means.

#### **4.6.5. Reduction in airborne radionuclides**

##### *4.6.5.1. General*

4.105. As an application of the defence in depth concept, and in addition to the measures taken to ensure the leaktightness of the containment, measures should be taken to reduce the inventory of radionuclides in the containment atmosphere.

4.106. In general, a single system is not sufficient for reducing the concentrations of radionuclides, and multiple systems should be employed. Methods used for the reduction of airborne radionuclides in water cooled reactors of extant and new designs are:

- Deposition on surfaces,
- Spray systems,
- Pressure suppression pools,
- Ventilation systems.

4.107. As long as active systems for the reduction of the concentrations of airborne radionuclides are in the standby mode in normal operation, they should be testable.

#### *4.6.5.2. Deposition on surfaces*

4.108. The containment structure and its internals provide the first mechanisms for the removal of airborne radioactive material, since they present a large surface area for deposition. The plate-out and desorption factors ascribed to the containment structure should be conservatively based on the best available knowledge of deposition of radionuclides on surfaces. The surfaces of the containment and its internal structures should be decontaminable to the extent possible.

#### *4.6.5.3. Containment spray system*

4.109. The radionuclide management function of the containment spray system is intended to reduce amounts of airborne radioactive substances by removing them from the containment atmosphere and retaining them in the water of the containment sump or the suppression pool. This serves to limit any radiological consequences resulting from leakage of radioactive material from the containment to the atmosphere.

4.110. Important parameters and factors that should be considered in the design of the containment spray system include spray coverage, spray drop size, drop residence time and the chemical composition of the spray medium:

- Chemicals should typically be added to the spray water to enhance the removal of radionuclides from the atmosphere. Radioiodine is of particular importance, because of its potential consequences in terms of high specific doses. The chemical additive system should be designed to maximize the dissolution of radioiodine and to maintain the sump chemistry or the suppression pool chemistry such that radioiodine will not be released from solution in the long term following an accident.

- Any chemicals added should be non-corrosive for the materials present in the containment, both in the short term and in the long term after an accident. Corrosion might not only reduce the strength of vital structural components and impair the operation of safety systems but might also generate combustible gases and other undesirable compounds.

#### *Pressure suppression pool*

4.111. Water pools or tanks through which the containment atmosphere is bubbled for steam condensation should be considered a valuable means for the removal of radioactive products. However, care should be taken in evaluating the efficiency of such a process, since it is dependent on the thermodynamic conditions of water and steam. For example, the sub-cooling degree of the water and the consequent efficiency of steam condensation have significant effects on the scrubbing efficiency of a suppression pool.

#### *4.6.5.4. Ventilation and venting systems*

4.112. Where ventilation systems are used for cleaning exhaust air to mitigate the consequences of an accident, filters should be so designed and maintained as to preclude any loading of the filters with pollutants beyond authorized limits prior to their use in relation to an accident.

4.113. The ventilation system should, if necessary, be provided with equipment (such as moisture separators and preheaters before the filters) to prevent the temperature from dropping below the dew point at the air filter inlet.

4.114. The efficiency of the absorption material in iodine filters should be demonstrated in laboratory tests under simulated accident conditions as deemed appropriate. Provisions should be made to test periodically the filter system in situ.

4.115. Ventilation systems are often used to collect, filter and discharge air from a secondary confinement, which may become contaminated with airborne radionuclides in accident conditions as a result of leakage from the primary containment. For such cases the recommendations in paragraph 4.8.1 "Provisions for containment isolation" apply.

4.116. Where containment venting systems are installed, ~~the system the discharge~~ should be ~~designed filtered~~ to ~~minimize control~~ the release of radionuclides to the environment [15]. ~~The system design could include a Typical~~ filtering systems such as include sand, multi-venturi scrubber systems, HEPA or charcoal filters, or a combination of these. HEPA, sand or charcoal filters may not be necessary if the air is scrubbed in a water pool.

4.117. Noble gases cannot be filtered out, but consideration should be given to the use of systems to delay their release until further radioactive decay has occurred.

## 4.7.MANAGEMENT OF COMBUSTIBLE GASES

### 4.7.1. Generation of combustible gases

Hydrogen and oxygen are generated during normal operation of a plant as a result of the radiolysis of water in the core. In accident conditions (e.g. during after-a LOCA, or to a larger extent during an accident with core melting), combustible gases might be released into the containment atmosphere.

4.118. Sources of combustible gases include:

- Radiolysis of the water in the core,
- Radiolysis of the water in the sump or the suppression pool,
- Metal–water reactions in the core,
- Chemical reactions with materials in the containment,
- Degassing of hydrogen dissolved in the primary coolant,
- Releases from the hydrogen tanks used for control of the primary coolant chemistry,
- Molten core concrete interaction producing hydrogen and carbon monoxide.

All these contributions should be evaluated.

4.119. The amount of combustible gases generated should be calculated for normal operation, LOCA and design extension conditions. The uncertainties in the various possible mechanisms for generation should be taken into account by the use of adequate margins. If the amount of hydrogen expected to be generated by metal–water reactions is estimated on the basis of the assumption of total oxidation, uncertainty evaluation may be not necessary.

4.120. Uncertainties during accidents with core melting are essentially linked to such phenomena as flooding of a partially damaged core at high temperatures, the late phase of core degradation, the slumping of molten core material into residual water in the lower head of the reactor pressure vessel, and the long term interactions between molten core material and concrete. Appropriate margins should be considered in the design to cover these uncertainties.

4.121. Additional hydrogen production due to molten core concrete interaction should be estimated.

### 4.7.2. Threats due to combustible gases

Threats to the containment structures are reactor technology and design dependent but usually refer to a risk of over pressurization caused by a large production of non-condensable gases or by a fast the combustion/deflagration or

detonation of a combustible gas. Both should be considered and their effects assessed. However, for inert containment (e.g. for some BWR) the risk of hydrogen explosion is low due to the presence of inert gas and the absence of oxygen in normal power operation. For such type of containment, the primary threat is the fast over pressurization caused by a large production of hydrogen in a small free volume. For non-inert containment (PWR, CANDU, BWR) generally characterized by a large free inner volume, the primary threat in the short term is the risk of hydrogen explosion due to potential high local hydrogen concentration.

4.122. To identify a need for the installation of special features to control combustible gases, an assessment of the threats to the containment should be made. The assessment should cover generation, transport and mixing of combustible gases in the containment, combustion phenomena (diffusion flames, deflagrations and detonations) and the consequent thermal and mechanical loads.

4.123. The contribution of combustible gases should be taken into account for combustion ignition and containment over pressurization.

4.124. Leaks and releases of combustible gases from the containment should also be taken into account when evaluating the threats both to environment and connected buildings (e.g. penetration buildings or auxiliary buildings hosting safety equipment).

4.125. Ingress of oxygen into inert containment should be prevented for example by a maintaining an overpressure in the containment by limiting depressurization or by additional nitrogen supply.

4.125-4.126. Any manual actuation of the operation of the spray system should be evaluated taking into account the negative impact of spraying caused by condensation of steam.

#### **4.7.3. Measures for the prevention of hydrogen combustions challenging the containment integrity ~~detonation~~**

4.126-4.127. Systems for hydrogen removal, deliberate ignition, homogenization or inerting should be provided.

4.127-4.128. The efficiency of the systems should be such that global and local hydrogen concentrations are low enough to preclude combustions challenging the containment integrity ~~fast deflagration or detonation~~. Design provisions in the design for achieving this goal are, for example, an enhanced natural mixing capability of the containment atmosphere coupled with a sufficiently large free volume, passive autocatalytic recombiners and/or igniters suitably distributed in the containment, or an inert containment.

##### **4.7.3.1. Removal**

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~~4.128-4.129.~~ Passive means such as passive autocatalytic recombiners and/or active means such as igniters should be provided for burning/removing hydrogen.

#### 4.7.3.2. *Homogenization*

~~4.129-4.130.~~ The containment design either should incorporate active means (such as sprays and mixing fans qualified for operation in a combustible gas mixture) or should facilitate the action of mechanisms (such as large volume dispersion or natural circulation) to enhance the uniform mixing of the containment atmosphere within and between compartments. This is to ensure that local hydrogen concentrations do not reach detonation limits following an accident.

#### 4.7.3.3. *Inerting*

~~4.130-4.131.~~ One possible way to avoid combustion is to inert the containment atmosphere during reactor operation (usually with nitrogen). This is mainly applicable to a small containment.

### 4.8. MECHANICAL FEATURES OF THE CONTAINMENT

~~4.131-4.132.~~ The mechanical features of the containment comprise the mechanical components of the outermost barrier and the mechanical parts of the extensions of this barrier (i.e. piping, valves, ducts and penetrations). Together with the containment structure, these features comprise the containment envelope.

~~4.132-4.133.~~ The leaktightness criteria for mechanical features of the containment and its extensions should be consistent with the assumptions used in the radiological analyses for accidents.

#### 4.8.1. Provisions for containment isolation of piping and ducting systems

The following recommendations provide guidance to fulfil Requirement 56 of [2].

~~4.133-4.134.~~ Each line penetrating the containment that is not part of a closed loop<sup>10</sup> and that either (a) directly communicates with the reactor coolant during normal operation or in accident conditions or (b) directly communicates with the containment atmosphere during normal operation or in accident conditions should be provided with two isolation valves in series. Each valve either should be normally closed or should have provisions to close automatically. Where the line communicates directly with the reactor coolant or the containment atmosphere, one valve should be provided inside the containment and one valve outside. Each valve should be reliably and independently actuated. Isolation valves should be located as close as practicable to the containment.

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<sup>10</sup> A closed loop is a piping or ducting system that penetrates the containment envelope and that is designed to form a closed circuit either inside or outside, or inside and outside the containment in operational states and in accident conditions.

4.134-4.135. Loops that are closed either inside or outside the containment should have at least one isolation valve outside the containment at each penetration. This valve should be an automatic valve, a normally closed valve or a remotely operated valve<sup>11</sup>. Where the failure of a closed loop is assumed as a postulated initiating event or as a consequence of a postulated initiating event, the previous recommendation will apply to each line of the closed loop.

4.135-4.136. Loops that are closed both inside and outside the containment envelope should have at least one isolation valve, an automatic valve, a normally closed valve or a remotely operated valve located outside and as close as practicable to the containment at each penetration.

4.136-4.137. Small dead-ended instrumentation lines that penetrate the containment should have at least one isolation valve outside the containment.

4.137-4.138. Containment isolation valves for instrumentation lines that are closed (i.e. not in communication with the atmosphere) are not required provided that they are designed to withstand accident conditions for which the confinement is necessary. The rooms where these lines emerge should be equipped with a filtration-ventilation system to maintain sub atmospheric pressure. Such rooms and the equipment within them should be designed to withstand increased levels of temperature and humidity due to possible leakage from these lines.

4.138-4.139. The need for an automatic isolation of the containment in accident conditions should not prevent the systems necessary to mitigate those accidents from accomplishing their intended functions.

4.139-4.140. Overpressure protection should be provided for closed systems that penetrate the containment and for isolated parts of piping that might be overpressurized by a raise of the temperature inside the containment atmosphere in accident conditions.

4.140-4.141. The extensions of the containment envelope should be designed and constructed to levels of performance that are at least equivalent to those for the containment itself.

4.141-4.142. For specific operational conditions (e.g. conditions with an open containment, or inhibited containment automatic isolation), the risk to safety should

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<sup>11</sup> An automatic valve is a valve or damper that can be actuated either by the protection system signals or by other instrumentation and control circuits without action by the operator or by the process medium itself. For example, certain types of check valves are considered automatic valves. A normally closed valve is a valve that is closed under active administrative control (such as being locked closed or continuously monitored to show that the valve is in the closed position) except for intermittent opening for specific purposes such as monitoring, testing or sampling. A remotely operated valve is a valve or damper that can be actuated by an operator from the control room and in some cases also from the supplementary control points.

be assessed and temporary provisions should be implemented as needed to ensure the containment isolation function could be accomplished in a timely manner.

4.42.4.143. Particular consideration should be given to the containment isolation features of the following systems which potentially could create a by-pass of the confinement:

- Systems designed for removing heat from the core, the core debris or from the containment that can transport radionuclides outside the containment in accident conditions;
- Systems that can transport airborne radionuclides from the containment atmosphere to outside the containment in design basis accidents (i.e. systems used in some designs to mix the atmosphere inside the containment in order to prevent the ignition of hydrogen);
- Supporting systems or auxiliary systems (inside the containment) for which, in the event of leakage, fluids with a high activity might be released outside the containment (i.e. in some designs the component cooling water system, the containment sump purge system or the sampling systems).

4.43.4.144. Systems connected to the primary circuit in normal operations (i.e. primary circuit filtration systems or in some designs the chemical and volume control system) and systems connected to the containment atmosphere should be automatically isolated in accident conditions when they are not necessary for safety.

#### 4.8.2. Isolation valves

4.44.4.145. To achieve the objective of limiting any radioactive release outside the containment, the isolation devices should be designed with a specified leaktightness and closure time.

4.45.4.146. Design provisions for leakage tests (such as nozzles and instrumentation test lines) should be made such that each isolation valve may be tested.

#### 4.8.3. Penetrations

The following recommendations provide guidance to fulfil the requirement 6.21 of [2].

4.46.4.147. Containment penetrations should be designed to withstand at least the same loads and load combinations as the containment structure,

4.47.4.148. Containment penetrations should be accessible so that leaks from individual penetrations can be detected in the leaktightness tests.

##### 4.8.3.1. Piping penetrations

~~4.148~~~~4.149~~. In the mechanical design of piping penetrations, including isolation valves, the loads originating from the piping system as well as loads originating from the containment should be taken into account.

#### *4.8.3.2. Electrical penetrations*

~~4.149~~~~4.150~~. Penetrations through the containment for electrical power cables and instrument cables should be leak tight. Means for ensuring the leaktightness of these penetrations may be based on the following:

- Pressure glass penetrations. The pressure glass design consists of studs embedded in a pressurized disc of glass flanged to the containment. Cables are connected to the studs, which extend on both sides of the glass disc and provide continuity for the electric power. The glass ensures electrical isolation between the studs and acts as a sealant. The design should include double seals on the flange to ensure the leaktightness of the assembly. These penetrations should be removable and individually testable for leaktightness at the design pressure;
- Pressurized and continuously pressure monitored penetrations. For pressurized penetrations, the pressurization should normally be higher than the internal pressure in the containment that could occur in accident conditions. so that leaktightness can be tested continuously. In any case, the pressure should not be lower than the pressure used in the containment leak rate test. The effects of increase in temperature on the design pressure of the fluid inside the penetrations should be assessed and taken into account in the design of the penetrations;
- Injected sealant penetrations. Penetrations of this type should be leak testable in integrated leak tests.

~~4.150~~~~4.151~~. Preference should be given to designs of electrical penetrations that allow each penetration to be tested individually.

~~4.151~~~~4.152~~. Heat produced by the electrical cables should be taken into account in selecting the materials for electrical penetrations. The materials used should be heat resistant and non-flammable. Penetrations using sealant injection should be at least flame retardant.

#### **4.8.4. Air locks, doors and hatches**

The following recommendations provide guidance to fulfil Requirement 57 of [2].

~~4.152~~~~4.153~~. Penetrations for access by personnel or equipment to the containment (containment air locks) should have air locks equipped with doors that are interlocked to ensure that at least one of the doors is closed during reactor operations and accidents. In addition, they should be designed to prevent any undue exposure of operators to radiation in operational states of the plant.

~~4.153~~-4.154. The two air lock doors should be designed to withstand the same plant conditions as the containment. Local transient internal effects, such as exposure to open flames caused by hydrogen burning, need not be considered for the outer door.

~~4.154~~-4.155. The chamber between the two air lock doors should be so sized as to allow the passage of necessary maintenance equipment and a sufficient number of personnel, so as to avoid having to open the air lock too frequently during plant shutdown and maintenance.

~~4.155~~-4.156. The inner door of the air locks should be of a pressure sealing type. Double seals should be provided on each door and there should be provisions for testing the leaktightness of the doors and the inter-seal space. Low pressure alarms should be provided if inflatable seals are used.

~~4.156~~-4.157. Equipment hatches are large openings in the containment structure that are normally closed. They are usually designed with a bolted flange, whose leaktightness is ensured by means of soft elastomeric seals. Loads and deformations due to pressure and temperature effects should be taken into account in the design of equipment hatches.

~~4.157~~-4.158. Containment openings (i.e. penetrations, air locks and hatches) should normally be closed. Exceptions are allowed if they are necessary for operational reasons and provided that the openings can be closed quickly and reliably to comply with established engineering criteria that apply for the accident. Conditions allowing the opening of the equipment hatches should be specified and met prior to the opening.

## 4.9.MATERIALS

### 4.9.1. Concrete

~~4.158~~-4.159. Concrete should have characteristics of quality and performance (strength, density porosity) consistent with its use. The quality of the concrete used for containment structures should be correspondingly high, consistent with the safety function of the containment. Design considerations will depend on the containment concept. For example: a concrete containment with stressed cables usually ensures both strength and leaktightness, whereas a reinforced concrete containment structure usually ensures only strength while its steel liner ensures leaktightness.

~~4.159~~-4.160. Consideration should be given to the design capacity of the concrete to cope with the loads (pressure loads and thermal loads) and environmental conditions (of heat, moisture and radiation) generated by design basis accidents. This should lead to strict specifications for the concrete in terms of strength and leaktightness.

~~4.160~~~~4.161~~. Concrete with appropriate rigidity, thermal expansion and resistance to compression should be used for all electrical penetrations, large penetrations such as equipment hatches and the joint with the basemat.

~~4.161~~~~4.162~~. In a pre-stressed containment not sealed with a metallic liner, the concrete should remain in a pre-stressed condition even in accident conditions. Concrete materials that would limit creep or shrinkage over the years and with low porosity should be used. The possible loss of pre-stress of the containment tendons over the operating lifetime of the plant should be evaluated and considered in the design.

~~4.162~~~~4.163~~. Sleeve concrete interfaces should be designed to minimize leaks by avoiding direct paths through the interface.

~~4.163~~~~4.164~~. Design and construction processes should be such as to prevent the development of cracks or high leak zones.

~~4.164~~~~4.165~~. Ageing effects should be evaluated in the selection and design of types of concrete [7].

#### **4.9.2. Metallic materials**

~~4.165~~~~4.166~~. Metallic materials used for containment structures and systems, including welds, should be of high quality; qualified and certified materials that meet national safety standards should be used.

~~4.166~~~~4.167~~. In the selection of metallic materials, the following considerations should be taken into account:

- Thermal and mechanical loads;
- Chemical interactions, including those with chemicals used in containment spray systems;
- [Sensitivity to ageing effects](#);
- Resistance to brittle fracture;
- Resistance to corrosion.

~~4.167~~~~4.168~~. Metallic materials such as zinc and aluminum that have the potential to generate hydrogen on contact with water or steam should not be used inside the containment. If such materials are essential to the design, their use should be limited and the effects of hydrogen generation should be analyzed.

#### **4.9.3. Soft sealing materials**

~~4.168~~~~4.169~~. Soft sealing materials are commonly used in multiple containment applications, such as in the sealing of ventilation valves or the inflatable sealing of air locks. Although these materials contribute to a very high leaktightness of the containment under normal conditions, their behavior in accidents should be properly

demonstrated. Potentially damaging effects for soft sealing materials include embrittlement and cracking due to high temperatures and irradiation, dissolution due to moisture and steam, and swelling or shrinkage due to temperature fluctuations. Specific consideration should be given to the protection of these materials from the direct effects of hydrogen burning and/or the accumulation of radioactive aerosols. In extreme conditions such materials may degrade to the extent that their mechanical properties are altered.

~~4.169.4.170.~~ The anticipated lifetimes of soft sealing materials and the ageing mechanisms that affect their performance should be assessed, and appropriate replacement intervals should be established. Sealing components should be designed to be easily inspectable and replaceable.

#### 4.9.4. Covering, thermal insulation and coating materials

The following recommendations provide guidance to fulfil the requirement 6.30 of [2].

~~4.170.4.171.~~ Covering, ~~cushioning~~, thermal insulation and coatings materials should not compromise any safety functions in the event of their deterioration. They should be installed and affixed to prevent loosening and the possible clogging of sieves and valves as a consequence.

~~4.171.4.172.~~ In particular, materials used to insulate pipes and tanks inside the containment should be selected and designed to achieve the following:

- To minimize the production of debris that can accumulate on containment floors and clog the sump ~~screen or strainer~~ filter or damage recirculation pumps;
- To ensure easy decontamination if the need arises;
- To avoid giving rise to fire hazards;
- To minimize the release of toxic gases during their heating at the plant start up.

~~4.172.4.173.~~ The amount of ~~insulation~~ debris generated in the event of high energy pipe breaks and transported to the sumps should be assessed and the surface of filters sized accordingly in order not to compromise the normal operation of the pumps necessary to mitigate the consequences of accidents.

Moreover, the installation of a cleaning system of the filters should be established taking into account the large uncertainties on the types and the amount of debris susceptible to clog the filters.

~~4.173.4.174.~~ If organic liners are applied to increase the leaktightness of the containment structure, they should be selected to withstand the thermal loads and pressure loads, as well as the environmental conditions in the containment, without losing their safety function. Provision for managing the ageing of these organic liners should be made, including provision for maintenance and surveillance.

~~4.174-4.175.~~ Painting and coating materials should be selected so as not to pose a fire hazard.

~~4.175-4.176.~~ In the selection of painting and coating materials, consideration should be given to the effect of the dissolution of their solvents in the sump on the volatility of iodine.

~~4.176-4.177.~~ Ageing mechanisms that affect covering, cushioning, thermal insulation and coating materials should be assessed and appropriate replacement intervals should be established.

#### 4.10. INSTRUMENTATION ~~AND CONTROL SYSTEMS~~

The following recommendations provide guidance to fulfil Requirement 59 of [2].

~~4.177-4.178.~~ To support the implementation of the defence in depth concept and to enhance the reliability of the containment systems, instrumentation should be provided for the purposes of:

- Monitoring of the stability of the containment structure;
- Detection of deviations from normal operation;
- Periodic testing;
- Monitoring of the availability of the containment systems;
- Initiation of automatic operation of systems;
- Post-accident monitoring.

~~4.178-4.179.~~ As those different purposes can need measurements of the same parameters for different levels of defence, the consequences of sharing of sensors for different purposes should be considered in order to preserve adequate independence between the different levels of defence in depth and the following recommendations should be implemented to the extent possible:

- Not sharing the same sensors for the automatic actuation of the operation of the systems and the accident monitoring of the plant;
- Implementing different and dedicated sensors for the mitigation of accidents with core melting;
- Not sharing the same sensors for the automatic actuation of the reactor scrams or operation of the safety systems and their back up implemented to reinforce the prevention of accidents with core melting.

4.180. Instrumentation should be qualified under seismic and environmental conditions that might prevail prior to or during its operation until its mission be completed.

4.179-4.181. Test sequences for equipment qualification should be consistent with well proven international practices. General principles and adequate practices are indicated in [19].

#### **4.10.1. Monitoring the stability of the containment structure**

4.180-4.182. Appropriate instrumentation should be incorporated inside the containment in order to monitor closely any deformation (radial, vertical or circumferential) or movement of the containment structures or the containment walls.

4.181-4.183. For pre-stressed concrete walls, means to detect loss of the pre-stressing should be provided. The concrete compression and rigidity parameters (such as Young's modulus) should be defined, and they should be verified by such means as acoustic measurements. The temperature in concrete singularities should also be measured to aid the interpretation of the results of pressure proofing tests.

4.182-4.184. Appropriate instrumentation for measurements relating to earthquakes should be installed at suitable places (e.g. on and/or the basemat of the containment ~~at or on~~ suitable floors).

#### **4.10.2. Detection of deviations from normal operation**

4.183-4.185. Appropriate instrumentation should be incorporated inside the containment for an early detection of:

- Leaks of radioactive material (as airborne activity, activity in the sumps)
- Abnormal radiation levels
- High energy leaks
- Leaks,
- Fire,
- Failure of components.

4.184-4.186. Instrumentation sensitivity necessary to detect a developing deviation should be estimated by appropriate analytical methods.

4.185-4.187. For an adequate detection of the different abnormal conditions, information provided by the instrumentation can be used alone or in combination with others. Parameters typically monitored include:

##### *4.10.2.1. Containment atmosphere temperature*

Monitoring of containment atmosphere temperatures is necessary to check whether temperatures are within the ranges specified for the normal operation.

- A sufficient number of temperature sensors should be installed to measure the containment atmosphere temperatures;
- In/out containment air coolers may be used to complete and confirm temperatures inside the containment.

~~4.186~~4.188. The containment atmosphere temperatures should be recorded to show trends.

#### 4.10.2.2. *Containment Pressure*

- Monitoring of containment pressure should be established to check whether the pressure is within the range specified for the normal operation (small variations of the pressure may be caused by the operation of the air operated valves, changes in the containment temperature or by leakages of fluids such as compressed air, nitrogen);
- For ~~the Secondary Containment or Primary containment with double walls containment~~, monitoring of the pressure inside the Secondary containment or the annulus between the two walls should be established to check whether the pressure is within the range specified for the normal operation (a small negative pressure should be maintained in the annulus).

~~4.187~~4.189. The containment pressure should be recorded to show trends.

#### 4.10.2.3. *Humidity at different locations,*

~~4.188~~4.190. Humidity is a highly significant factor for the detection of leaks from a water reactor cooling system in operational states. Different techniques can be used to measure the humidity such as:

- The dew point temperature of the containment atmosphere,
- Electrical parameters (such as impedance or resistance) of sensors,
- The amount of condensate in the air coolers of the containment building.

Measurements should be recorded to show the trends.

#### 4.10.2.4. *Water levels in the drain storage tanks and sumps*

~~4.189~~4.191. Drain storage tanks and sumps of each safety system as well as the condensate collector of each air cooler should be provided with a water level indicator.

#### 4.10.2.5. *Radiation levels and radio activity measurements*

~~4.190~~4.192. Radiation levels at different locations inside the containment should be measured for the radiation protection of the workers and for an early detection of any anomalies with harmful effects caused by an excess of radiation.

~~4.191-4.193.~~ Airborne and water (drain storages and sumps) activity measurements should be implemented as [a diverse mean for ~~redundant and~~](#) complementary detection of leaks.

#### 4.10.2.6. *Visible abnormalities,*

~~4.192-4.194.~~ A video monitoring should be installed inside the containment to detect anomalies at the more relevant locations where leaks or other malfunctions can be expected and/or where personnel access is difficult (e.g. Reactor Coolant pumps, equipment hatch, personnel airlocks, reactor pools, etc.).

~~4.193-4.195.~~ Mobile cameras should be available for use if and when the demand for them arises.

#### 4.10.2.7. *Noise and vibrations,*

~~4.194-4.196.~~ The use of audio signals from the containment building for the detection of abnormalities should be considered (e.g. the use of spectral and Fourier transform analyses for acoustic noise signals).

#### *Fire.*

~~4.195-4.197.~~ Smoke and flame detectors should be installed as [additional complementary](#) means of an early departure of a fire in each compartment where there may be a risk of fire.

### **4.10.3. Periodic testing**

~~4.196-4.198.~~ Appropriate instrumentation should be incorporated inside the containment for conducting the periodic leak tests. Measurements of temperature, pressure and humidity and flow rates should be combined for the periodic calculation of the mass of the containment atmosphere and for the estimate of the leak rate.

~~4.197-4.199.~~ For steel containments, the temperature of the steel should also be measured.

### **4.10.4. Monitoring of the availability of systems**

~~4.198-4.200.~~ Appropriate instrumentation should be used to monitor the availability of the containment systems used for energy management, management of combustible gases or for the control of radionuclides.

~~4.199-4.201.~~ The availability of the systems should be verified by means of the following:

- By continuous monitoring and display in the main control room of the main parameters important to safety (a single integrated monitor for critical safety parameters is recommended );

- By conducting the periodic tests and inspections as required;
- For the systems for energy management, by monitoring the positions of valves, the status of components in operational states and flow rates;
- For the systems for radionuclide management, by monitoring the positions of isolation valves, air locks and doors, the pressure of inflatable airlock seals and water levels in the different water tanks necessary to the operation of those systems;

#### 4.10.5. Initiation of automatic operation of systems

In the event of a significant release of energy or of radioactive material into the containment different information is necessary for a complete and effective management of the energy, radionuclides and combustible gases release inside the containment. The requested management can be initiated automatically or by the operator provided that time for implementing operator actions is sufficient.

[4.200-4.202.](#) Information should be elaborated from the monitoring of parameters giving evidence that a large release of energy or a significant release of radioactive material has occurred inside the containment. Depending on the reactor technology or the design the following parameters may be relevant:

- High pressure inside the containment,
- High radiation levels inside the containment atmosphere,
- Low pressure in the reactor coolant system,
- Small sub cooling margin in the reactor coolant system [\(PWR\)](#),
- Low water level in the reactor pressure vessel.

[4.201-4.203.](#) In addition to conditions which require a complete and effective management of energy, gases and radioactive material releases inside the containment, there are other events for which only the individual isolation of the affected lines is necessary to limit the release of radioactive material from the containment to the environment. This is the case for a break occurring outside of the containment of a pipe crossing the containment and carrying radioactive material, or for the failure of an interface between two associated systems (e.g. rupture of a heat exchanger tube of the component cooling water system) that leads to a release of radioactive material from a system inside the containment to a system outside. The actuation of the isolation devices should be derived from the values of appropriate parameters, such as:

- Levels of radiation or of airborne contamination,
- Pressure changes in the affected system
- Temperature changes in the affected system,
- Water level in the affected system.

#### 4.10.6. Post-accident monitoring

~~4.202-4.204.~~ For the management of accidents, appropriate instrumentation displays and records should be available in the MCR [and the Emergency Control Center](#) to allow personnel to make a diagnosis and to decide and to take the manual protection actions specified in the Emergency Operating Procedures on in the Severe Accident Management Guideline. Such instrumentation should provide information about:

- Conditions inside the containment (containment pressure and temperatures, radiation levels, airborne activity, [steam](#), oxygen or hydrogen concentration if relevant);
- Process parameters to check that the required safety actions are in progress and to indicate the operations of the required safety systems and safety features for DEC's (flow rates, water levels in tanks and sumps, operating pressures in the systems, etc.);
- Process parameters to indicate the potential for degradation or loss of the containment leaktightness (containment isolation valves position, status of hatches and doors, containment pressure, airborne activity in the surrounding buildings etc.);
- Process parameters to implement actions specified in the emergency procedures or severe accident management guidelines (process parameters to control the pressure and to maintain the conditions inside the containment below the specified limits);
- Instrumentation for assessing in a timely manner the radiological consequences and for assisting in decisions on long term actions for the protection of the population (off-site emergency measures). Measurement for assessing radiological consequences may include:
  - Dose rate meters and airborne activity sensors in the containment and in peripheral buildings;
  - Sensors for monitoring conditions in the containment sump water (e.g. temperature and pH);
  - Activity monitors for noble gases, iodine and aerosols in the stack(s) and in the containment venting line;
  - Position indicators of containment venting valves.
- Dedicated instrumentation should be implemented to allow personnel in the MCR to initiate long term actions necessary to maintain the containment integrity in the event of an accident with core melting. Such instrumentation should provide information about:
  - Process parameters to initiate the fast depressurization of the Reactor Coolant System (before core melting) and to confirm the open position of the valves;

- Process parameters to confirm the flooding of the reactor cavity (for in vessel strategy), or the flooding of the [ex-vessel retention structure spreading area](#) (for ex-vessel retention strategy);
- Process parameters for the localization of the corium (for ex-vessel retention strategy);
- Process parameters to initiate and confirm the operation of the containment spray;
- Process parameters to initiate and confirm the operation of the containment heat removal system;
- Process parameters to initiate the venting of the containment (if relevant);
- Process parameters for the hydrogen risk management.

#### 4.10.7. Sampling

[4.203-4.205.](#) A monitoring or sampling system should be provided inside the containment to enable assessment of the risks of explosion from combustible gases. The design of the system should take into account the following factors:

- Possible sources of combustible gases such as interaction between clad material and water, or interaction between molten core and concrete, radiolysis;
- Presence or not of oxygen and inert gases;
- [Presence of noble gases and aerosols](#);
- Presence of devices aimed at recombining hydrogen as produced, and type of these devices (passive or active)
- Sufficient mixing or not of the containment atmosphere to avoid local possibilities of hydrogen accumulation.

The monitoring can be achieved by direct gas concentration measurement or sampling. Alternative possibility is to measure the recombining activity of the recombiners by temperature measurement.

[4.204-4.206.](#) Provisions should be made in the design for sampling of the containment atmosphere and the sump water at suitable locations. The sampling devices used should be qualified for the expected containment conditions and should be installed so as to avoid a containment bypass in the event of their rupture. They should be designed to ensure that occupational radiation dose limits are not exceeded for the personnel who operate them.

[4.205-4.207.](#) Monitoring or sampling lines that could transport radionuclides outside the containment should be considered as extensions of the containment and should be subject to specifications for structural integrity and leaktightness comparable with those applied to containment structure itself.

## 5. TESTS AND INSPECTIONS

In order to demonstrate that the containment and the associated systems meet design and safety requirements, commissioning and in-service tests and inspections should be conducted as outlined in the following.

The following recommendations provide guidance to fulfil Requirement 29 of [2]. Recommendations given by [11] should also be considered.

### 5.1.COMMISSIONING TESTS

- 5.1. Commissioning tests for the containment should be carried out prior to the first criticality of the reactor to demonstrate the containment's structural integrity, to determine the leak rate of the containment envelope and to confirm the performances of systems and equipment.

#### 5.1.1. Structural integrity test

- 5.2. A pressure test should be conducted to demonstrate the structural integrity of the containment envelope (including extensions and penetrations) and of the pressure retaining boundary of systems.
- 5.3. The pressure test should be conducted at a specified pressure for which account is taken of the applicable codes for the material used, and which is at least the design pressure. The value of the test temperature should not be close to the ductile brittle transition temperature for the metallic material.

#### 5.1.2. Integrated leak tests (of the containment envelope)

- 5.4. A leak test should be conducted to demonstrate that the leak rate of the containment envelope does not exceed the specified maximum leak rate. The test should be conducted with the components of the containment in a state representative of the conditions that would prevail following an accident, to demonstrate that the specified leak rate would not be exceeded under such conditions.
- 5.5. To establish a point of reference for future in-service leak tests, the leak test performed during commissioning should be conducted at a test pressure or pressures consistent with the pressure selected for in-service leak tests:
  - At values of pressures between the pressure selected for in-service leak testing and the positive design pressure, if the in-service tests are to be conducted at a pressure lower than the design pressure; or
  - At the design pressure of the containment, if the in-service tests are to be conducted at this pressure.

5.6. The need to validate reliably the leak rate assumed in the safety analysis over the entire plant operating lifetime for the entire range of pressures calculated should be taken into consideration in the choice of test pressure(s).

5.7. The need for initial and periodic testing should be considered in the design, and all the components that might be damaged during testing should be identified. The necessary means to pressurize and depressurize the containment and appropriate instrumentation for testing should be included in the design.

5.8. One way of determining leak rates is the absolute pressure method, in which the leakage flow is determined by measuring the decrease in pressure or the dry air mass as a function of time. In this method, the temperature and pressure of the containment atmosphere, the external atmospheric temperature and pressure, and the humidity of the containment atmosphere should be measured continuously and factored into the evaluation. Means should be provided to ensure that the temperature and humidity of the containment atmosphere are uniform.

5.9. Appropriate instrumentation should be provided in the containment, appropriately positioned and installed either permanently or as needed, to determine representative atmospheric conditions in the different zones of the containment.

5.10. For double wall containments, one way to determine the direct leak rate from the containment to the environment (i.e. if the leaked water or gas does not collect in the annular space between the inner and the outer containment walls) is by calculation. This calculation should determine the difference between (a) the total leak rate from the inner containment as determined by the leak test for the inner containment (this consists of both flow from the inner containment into the annulus and flow from the inner containment to the atmosphere) and (b) the leak rate from the inner containment wall to the annulus, obtained after ventilation of the annulus has been stopped (this is typically calculated by subtracting the normal flow out of the annulus vent from the flow out of the annulus vent during the leak test).

### **5.1.3. Local leak tests of isolation devices, air locks and penetrations**

5.11. Leak tests should be performed to establish a baseline leakage measurement for each isolation device, air lock and penetration. The following components are the most sensitive parts of the containment envelope, and special attention should be paid to them:

- Isolation devices in systems open to the containment atmosphere;
- Isolation devices in fluid system lines penetrating the containment;
- Penetrations that have resilient or inflatable seals and expansion bellows, such as:
  - personnel air locks,

- equipment air locks,
- equipment hatches,
- Fuel transfer tube
- spare penetrations with bolted closures,
- cable penetrations with resilient seals,
- pipe penetrations with flexible expansion bellows in the connections to the containment.

#### **5.1.4. Functional tests of equipment and wiring in the containment**

5.12. Tests should be carried out to verify that the equipment in all associated systems is functional unless the tests would have a detrimental effect on safety.

5.13. Tests should be carried out on all electrical wiring associated with the containment systems to demonstrate that there are no deviations from the design and that all connections are in accordance with the design.

### **5.2. IN-SERVICE TESTS AND INSPECTIONS**

5.14. Periodic in-service tests and inspections should be performed to demonstrate that the containment systems continue to meet the requirements for design and safety throughout the operating lifetime of the plant.

5.15. The test methods and intervals for in-service tests should be specified so as to reflect the importance to safety of the items concerned. In devising test methods and determining the frequency of testing, consideration should be given to the necessary levels of performance and reliability of the containment systems individually and as a whole.

5.16. Appropriate features should be provided for performing commissioning and in-service testing for containment pressure and leaktightness, and the correlated loads should be considered for the purposes of structural design.

5.17. General guidance on in-service inspection is provided in [11].

#### **5.2.1. Structural integrity tests**

5.18. Periodic structural tests should be conducted to demonstrate that the containment structure continues to perform as intended in the design. The test pressure should be the same as in the pre-operational test and as required by the applicable design codes. In the design, attention should be paid to the additional stresses imposed by the tests, and test pressures should be established to prevent the tests from causing excessive stresses to the containment structure. A leak test should be performed during any structural integrity test.

### 5.2.2. Integrated leak tests (of the containment envelope)

5.19. The design should provide the capability for periodic in-service testing of the leak rate to prove that the leak rate assumed in the safety analysis is maintained throughout the operating lifetime of the plant. The in-service leak rate tests may be made at either:

- A pressure that permits a sufficiently accurate extrapolation of the measured leak rate to the leak rates at the accident pressures considered in the safety analysis; or
- The containment design pressure.

5.20. There are also methods available to provide a continuous estimate of the overall containment leak rate during plant operation and to derive rough indications of containment leak rates in accident conditions. Such approaches are generally based on variations in the containment pressure or the mass balance during normal operation of the plant. In some cases, the use of these methods together with extensive local leak rate tests during shutdown for refueling may justify a reduction in the frequency of the global tests.

5.21. The design should permit leak tests of isolation devices, air locks, penetrations and containment extensions.

5.22. The design should facilitate local testing by providing access to penetrations and incorporating necessary connections and isolation valves.

5.23. In containment with a pressure suppression pool, features should be provided for periodically assessing any leakage that might lead to bypassing of the pool, so as to ensure that the bypass rate of the pool is consistent with the value considered in the safety analysis.

5.24. The testing method of the containment integrated leak test should be qualified.  
~~5.22.~~

### 5.2.3. Visual inspection

~~5.23-5.25.~~ Where it is technically feasible, the design should provide for a complete visual inspection of containment structures (including the tendons for pre-stressed concrete containments), penetrations and isolation devices.

~~5.24-5.26.~~ Visual inspection of the containment envelope, including appurtenances and penetrations, should be made in conjunction with each of the tests specified in paras 5.18–5.23. Visual inspections are important for the monitoring and detection of ageing effects, detection and evolution of cracks.

#### **5.2.4. Periodic tests**

[5.25.5.27.](#) The design should provide a capability for testing safety systems and systems implemented to cope with DEC's at intervals that reflect their importance to safety, or for otherwise demonstrating the necessary reliability for the containment systems individually or as a whole.

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Field Code Changed

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## ABBREVIATIONS

AC	Alternating current
ASME	American Society of Mechanical Engineers
BWR	Boiling Water Reactor
CCF	Common cause failure
DBA	Design basis accident
DC	Direct current
DEC	Design extension condition
I&C	Instrumentation and control
LOCA	Loss of coolant accident
MCR	Main control room
NPP	Nuclear power plant
PIE	Postulated initiating event
PSA	Probabilistic safety assessment
PWR	Pressurized water reactor
RCPB	Reactor coolant pressure boundary
RCS	Reactor coolant system
SSCs	Structures, systems and components
SG	Steam generator

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