

SAFETY GUIDES

safety series

Design of Spent Fuel Storage Facilities



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**DESIGN OF SPENT FUEL
STORAGE FACILITIES**

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FOREWORD

Nuclear power is becoming an ever more significant part of the energy programmes of many countries. The spent fuel resulting from reactor operations must be safely stored and managed pending its reprocessing or disposal. The International Atomic Energy Agency recognizes the increasing need for such interim spent fuel storage and has consequently established a programme to provide guidance to its Member States on the key safety aspects of safe storage. This programme complements the IAEA's Nuclear Safety Standards (NUSS) programme.

The IAEA has prepared and issued a series of related Safety Series publications addressing the design, operation and safety assessment of interim spent fuel storage facilities. This Safety Guide has been prepared for use by organizations or firms in the nuclear power industry, supporting organizations and related Regulatory Bodies in identifying and managing all relevant issues on the design aspects for the safe interim storage of spent fuel from nuclear power plants.

This Safety Guide has been developed through a series of Advisory Group Meetings, Technical Committee Meetings and Consultants Meetings from 1990 to 1994, and presents an international consensus on useful design principles. These principles incorporate features which will be effective in maintaining fuel subcritical, removing residual heat, providing radiation protection and containing radioactive materials for the lifetime of the facility.

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1. INTRODUCTION

BACKGROUND

101. This Safety Guide was prepared as part of the IAEA's programme on safety of spent fuel storage. It reflects the standards of the IAEA's Nuclear Safety Standards (NUSS) programme relating to nuclear power plants, and, in particular, the IAEA Code on the Safety of Nuclear Power Plants: Design [1].

102. The Safety Guide is related to two other Safety Series publications on the subject of spent fuel storage: Operation of Spent Fuel Storage Facilities [2] and Safety Assessment for Spent Fuel Storage Facilities [3].

OBJECTIVE

103. The purpose of this Safety Guide is to provide details on the design of interim spent fuel storage facilities. Such guidance is required to define and control the extent and quality of the facility, and will assist the designer in preparing technical documentation.

104. Good design is crucial to the safe operation of spent fuel storage facilities because spent fuel must be received, handled, stored and retrieved without undue risk to health and safety, or to the environment. To achieve this, the design shall incorporate features which will be effective for the lifetime of the facility under normal operating conditions, anticipated operational occurrences and design basis accident conditions in maintaining fuel subcritical, removing spent fuel residual heat, providing radiation protection and maintaining containment of radioactive material.

SCOPE

105. This Safety Guide is for interim spent fuel storage facilities that are not an integral part of an operating nuclear power plant. Interim spent fuel storage facilities provide for the safe storage of spent nuclear fuel after it has been removed from the reactor pool and before it is reprocessed or disposed of as radioactive waste. The facilities may be either co-located with nuclear facilities (such as a nuclear power plant or reprocessing plant) or sited independently of other nuclear facilities.

106. The type of spent fuel considered in this Safety Guide is typically that derived from water moderated reactors. The Safety Guide can also be applied to other fuel types such as those from gas cooled reactors, and fuel assembly components can also

be considered. Other items, such as canistered failed fuel, may also be considered if an adequate safety analysis is prepared.

107. The Safety Guide on Fuel Handling and Storage Systems in Nuclear Power Plants [4] provides guidance on the design of fuel storage systems that are an integral part of an operating nuclear power plant. Similarly, publications on the design of high level waste facilities and spent fuel disposal facilities are included in the Radioactive Waste Safety Standards (RADWASS) series.

108. Transport requirements are provided in IAEA Regulations for the Safe Transport of Radioactive Material [5], and in related IAEA publications (e.g. the TECDOC entitled Interfaces between Transport and Geological Disposal Systems for High Level Radioactive Waste and Spent Nuclear Fuel [6]). The interface between storage and transport is discussed in this Safety Guide.

STRUCTURE

109. Following this introduction, Section 2 describes the general safety requirements applicable to the design of both wet and dry spent fuel storage facilities; Section 3 deals with the design requirements specific to either wet or dry storage. Recommendations for the auxiliary systems of any storage facility are contained in Section 4; these are necessary to ensure the safety of the system and its safe operation. Section 5 provides recommendations for establishing the quality assurance system for a storage facility. Section 6 discusses the requirements for inspection and maintenance that must be considered during the design. Finally, Section 7 provides guidance on design features to be considered to facilitate eventual decommissioning.

2. GENERAL GUIDANCE

SPENT FUEL STORAGE FACILITIES

201. Interim spent fuel storage facilities provide for the safe, stable and secure storage of spent nuclear fuel before it is reprocessed or disposed of as radioactive waste. Like other engineered systems, the safe operation and maintenance of spent fuel storage facilities depends in part on adequate design and construction. The most important design features of such facilities are those which provide the necessary assurances that spent fuel can be received, handled, stored and retrieved without undue risk to health and safety, or to the environment.

202. To achieve these objectives, the design of spent fuel storage facilities shall incorporate features to maintain fuel subcritical, to remove spent fuel residual heat,

to provide for radiation protection, and to maintain containment over the anticipated lifetime of the facilities as specified in the design specifications. The features shall also provide for all anticipated operational occurrences and design basis accidents in accordance with the design basis as approved by the Regulatory Body.

203. Various designs of wet and dry spent fuel storage facilities are in operation or under consideration in Member States. Although designs differ, all consist of relatively simple, often passive systems, which are intended to provide adequate safety over several decades. Associated handling and storage operations are relatively straightforward.

204. Spent fuel is usually transferred to interim spent fuel storage facilities only after an initial period of storage at the reactor station. This initial period of storage allows a considerable reduction in the quantity of volatile radionuclides, the radiation fields and the production of residual heat. Hence, the development of conditions which could lead to accidents at spent fuel storage facilities will generally occur comparatively slowly, allowing ample time for corrective action before limiting conditions are approached. The safety of spent fuel handling and storage operations can thus be maintained without relying on complex, automatically initiated protective systems.

205. As noted above, different designs of spent fuel storage facilities are possible and, indeed, exist in Member States. These designs are normally developed on the basis of a design specification, through the application of an iterative process which seeks to accommodate all the requirements relevant to fundamental safety, operation, regulatory criteria, site characteristics and/or limitations, monitoring, maintenance, operational states, design basis accidents, quality assurance, decommissioning and costs. The scope and details of the design are compiled in a technical design specification document, and reviewed and approved by representatives or parties interested in the installation of the storage facility. Such interested parties might include the future facility owner, the facility operating organization and the Regulatory Body of the Member State.

206. Various technical and performance requirements are relevant to facility designs for both wet and dry modes of spent fuel storage. These basic design requirements, together with the classification of storage types, are discussed below.

DESIGN PROCESS

207. In the design process, appropriate analytical methods, procedures and tools should be used in conjunction with suitably selected input data and assumptions for both normal operational states and credible deviations. Only verified methods are acceptable for predicting the consequences of operational states and design basis

accidents. Similarly, input data should be selected so as to be conservative, albeit realistic, and these data should address both the normal and abnormal states of operation. Where uncertainties in input data, analyses or predictions are unavoidable, appropriate allowances should be made to compensate for such uncertainties, and the sensitivity of the results to them should be tested.

208. As part of the overall process leading to an acceptable design, its evolution and the supporting rationale should be clearly and adequately documented and kept readily available for future reference. The exact content of this documentation, which is likely to be of particular interest to all those involved in the construction, licensing, operation and eventual decommissioning of the facility, may vary somewhat due to facility specific factors. The supporting documentation shall include a full Safety Analysis Report (SAR).

209. The SAR should demonstrate that the design and all potentially significant related issues have been adequately analysed and appropriately addressed. It should describe the performance assessment models and methodologies used and the resulting conclusions. Thus, for any design proposed, the SAR should demonstrate that the facility can, within the bounds of existing technology, be safely constructed, commissioned, operated and decommissioned in accordance with the design specifications and the requirements of the owner and the Regulatory Body.

210. The procedures related to the control of design modifications during subsequent stages should also be defined. Such modifications might be required to take into account the results of the SAR. The systems, structures and components of the design which are relevant to safety should be identified and classified according to their relative importance. The Technical Report on Grading of Quality Assurance Requirements: A Manual [7] provides information on such classification and grading.

211. It should be recognized that in some Members States the general public is involved in the decision making process on the acceptability of proposed interim spent fuel storage facilities.

212. In addition to the general applicability of the iterative design process described above, there exist various technical, administrative and safety requirements which are also relevant to all designs of spent fuel storage facilities. These requirements are discussed below.

SUBCRITICALITY

213. A fundamental safety objective of all designs for spent fuel storage facilities shall be to ensure that subcriticality of the entire system can always be maintained.

214. The subcriticality of fuel may be ensured or influenced by a number of design factors and precautions. The physical layout and arrangement of the spent fuel storage facility shall ensure, through geometrically safe configurations, that subcriticality will be maintained during operational states and accident conditions. Where spent fuel cannot be maintained subcritical through configuration alone, the design shall specify additional means, such as fixed neutron absorbers or the use of a credit for burnup, to ensure subcriticality.

215. Subcriticality can be influenced by internal and external hazards which have the potential to reconfigure the pre-existing spent fuel assembly array in a manner to increase the potential for criticality. For operational states and accident conditions, the sequences of events leading to such abnormal fuel configurations shall be evaluated. The probability and possible consequences of such occurrences should be evaluated using reliable data and methodologies and, if warranted, appropriate mitigating measures should be provided to ensure that subcriticality will be maintained under all such conditions.

216. When calculating the infinite multiplication factor, which may be used as a conservative estimate of k_{eff} , the following rules shall be adhered to:

- (a) An adequate subcriticality margin shall be maintained which is acceptable to the Regulatory Body. Typically a 5% margin after inclusion of the uncertainties in the calculations and data is considered acceptable.
- (b) If the enrichment within individual fuel assemblies is variable, exact modelling shall be used or a pessimistically calculated, representative enrichment of the fuel assembly shall be assumed.
- (c) If the enrichment of the fuel assemblies differs, the design of the facility should generally be based on the enrichment value corresponding to that of the maximum enriched fuel assembly. However, in situations involving only small amounts of fuel of higher enrichment, assessments may be made on a case by case basis taking into account the specific parameters of the fuel in question.
- (d) Where uncertainties exist in any data relating to the fuel (design geometries, nuclear data, etc.) representative values which are pessimistically calculated should be used in all subcriticality calculations. If necessary, sensitivity analysis should be performed to quantify the effects of such uncertainties.
- (e) Neutron reflection shall be considered.
- (f) The inventory of the storage facility shall be assumed to be at the maximum capacity of the design.
- (g) Credit shall not be claimed for neutron absorbing parts or components of the facility unless they are fixed, their neutron absorbing capabilities can be determined, and they are unlikely to be degraded by any postulated initiating events.
- (h) Consideration of the neutron absorbing characteristics of the fuel assembly may be included.

- (i) No allowance for the presence of burnable absorbers shall be made unless on the basis of justification acceptable to the Regulatory Body. This shall include consideration of the reduction of neutron absorption capability with burnup.
- (j) Those geometric deformations to the fuel and storage equipment which might be caused by any postulated initiating events shall be taken into account.
- (k) Appropriate pessimistic moderation should be assumed for anticipated operational occurrences.
- (l) All fuel shall be assumed to be at a burnup and applicable enrichment value resulting in maximum reactivity unless credit for burnup is assumed on the basis of justification acceptable to the Regulatory Body. Such justification may include an appropriate measurement which directly or indirectly confirms calculated values for fissile content or depletion level prior to storage of fuel.
- (m) Assumptions of neutronic decoupling of different storage areas shall be substantiated by appropriate calculations.

STRUCTURE AND LAYOUT

217. Design requirements associated with the layout of irradiated fuel handling and storage systems are as follows:

- (a) Handling and storage areas for irradiated fuel shall be secure against unauthorized access or unauthorized removal of fuel.
- (b) The area used for storage shall not be part of an access route to other operating areas.
- (c) The transport routes for handling should be as direct and short as practical so as to avoid the need for complex or unnecessary moving and handling operations.
- (d) The layout shall minimize requirements for moving heavy objects above stored fuel and safety systems.
- (e) The layout shall reflect application of the ALARA ('as low as reasonably achievable') principle regarding all fuel handling operations, storage and required personnel access.
- (f) The layout shall provide for decontamination and appropriate maintenance of fuel handling equipment and shipping casks.
- (g) Space shall be provided, if necessary, to permit the inspection of fuel and fuel handling equipment.
- (h) Space shall be provided to allow the required movement of the fuel and storage containers and the transfer of these between different handling equipment.
- (i) Space shall be provided for the safe handling of a shipping cask. This can be achieved by using a separate cask unloading area or by including dedicated space within the facility.

- (j) Space should be provided for the storage and use of the tools and equipment necessary for the repair and testing of storage components. Space for the receipt of other radioactive parts may also be required.
- (k) Appropriate arrangements for containment measures and the safe storage of leaking or damaged fuel shall be provided.
- (l) The layout shall provide easy exit for personnel in an emergency.
- (m) The design shall permit access to all parts of the storage facility requiring periodic inspection and maintenance.
- (n) The design should ensure safe storage conditions following postulated external events, i.e. earthquakes, tornadoes, floods, etc.
- (o) Penetrations shall be designed to prevent the ingress of water (e.g. rain), inorganic solutions, organic materials, etc., which could reduce subcriticality margins, impair heat transfer or increase corrosion and degradation of the storage facilities in ways that might prevent inspection or repair.

RADIATION PROTECTION

218. The design of spent fuel storage facilities shall provide for radiation protection of workers and the public in accordance with the principles and requirements described in Refs [8, 9].

219. The radiation protection principles to be adhered to in the design of wet and dry storage facilities for spent fuel are those generally applicable to all nuclear facilities. In their application to spent fuel storage facilities, they may be stated as follows:

- (a) Radiation doses to the public and workers as a consequence of spent fuel handling, storage, inspection and monitoring activities shall not exceed relevant limits as recommended in Ref. [8].
- (b) Spent fuel storage facilities shall be designed to ensure that resulting radiation doses to the public and workers are kept as low as reasonably achievable.
- (c) Spent fuel storage facilities shall be designed to ensure that the possibility and the magnitude of potential exposures are kept as low as reasonably achievable.

220. Adherence to the above principles during the design of spent fuel handling systems in storage facilities requires that:

- (a) Appropriate ventilation, including air filtration systems where necessary, shall be included in the design to limit the concentrations of airborne radioactive materials and related exposures of workers and the public to acceptable levels;
- (b) The design of facilities and areas provides for monitoring of radioactive effluents;

- (c) Spent fuel handling in storage facilities be designed to avoid the buildup of contamination to unacceptable levels and to provide for remedial measures should such contamination occur;
- (d) Handling of spent fuel and containers be carried out in an environment in which important parameters (e.g. temperature, concentration of impurities, intensity of radiation) are controlled;
- (e) Areas where spent fuel is handled or stored be provided with suitable radiation monitoring for the protection of workers. Radiation monitoring shall meet the requirements of Ref. [8].

221. The design shall ensure that, in the operating and adjacent areas of the fuel handling systems, shielding is provided to meet the requirements of Ref. [9].

222. To meet these requirements, the following provisions shall be included:

- (a) For shielding design analysis it shall be assumed that all locations which may contain fuel are full, that the fuel has reached the maximum burnup, and that the post-irradiation cooling interval should be the minimum reasonable.
- (b) Penetrations through shielding barriers (e.g. penetrations associated with cooling systems or penetrations provided for loading and unloading) shall be designed to avoid localized high gamma and neutron radiation fields.
- (c) In the analysis, equipment for transporting fuel shall be assumed to contain the maximum amount of spent fuel.
- (d) Handling equipment shall be designed to prevent inadvertent placing or lifting of irradiated fuel into unshielded positions.
- (e) The radiological impacts of deposits of activation products shall be considered.

CONTAINMENT OF RADIOACTIVE MATERIALS

223. The design of spent fuel storage and handling systems shall provide adequate and appropriate measures for containing radioactive materials so as to prevent uncontrolled release to the environment. The spent fuel cladding shall be protected during storage against degradation that leads to gross ruptures, or the fuel shall otherwise be contained in such a manner that degradation of the fuel during storage will not pose operational safety problems.

224. Ventilation and off-gas systems should be provided where necessary to ensure containment of airborne radioactive particulate materials during operational states and accident conditions. All spent fuel storage containment systems shall be provided with monitoring to enable the licensee to determine when corrective action is needed to maintain safe storage conditions.

HEAT REMOVAL

225. Spent fuel storage facilities should be designed with heat removal systems capable of cooling stored fuel when that fuel is initially loaded into the facility. The heat removal capability shall be such that the temperature of all fuel (and fuel cladding) in a storage facility does not exceed the maximum temperature recommended or approved by the Regulatory Body for the type and condition of fuel to be stored. The heat removal system shall be designed to withstand all design basis accidents.

226. The heat removal system should be designed for adequate removal of heat likely to be generated by the maximum inventory of spent fuel anticipated during operation. In determining the necessary heat removal capability, the post-irradiation cooling interval and the burnup of the fuel to be stored shall be taken into consideration. The design of heat removal systems shall include an additional margin of heat removal capability to account for processes foreseen to degrade or impair the system over time. The design of the heat removal system shall consider the maximum heat capacity of the installation.

227. In the case of certain modular facilities such as vaults, the fact that the heat produced from the decay of fuel fission products decreases with time can be taken into account. For example, in some facilities forced cooling is initially provided, after which natural cooling is adequate.

228. Redundant and/or diverse heat removal systems might be appropriate, depending on the type of storage system used, the potential for fuel overheating over an extended time and the level of conservatism necessary to provide accident mitigation.

229. The design of heat removal systems for spent fuel storage facilities should include any appropriate provisions to maintain fuel temperatures at acceptable limits during the transfer of fuel.

MATERIALS

230. The design of a facility for the storage of spent nuclear fuel should be based upon a specified operational lifetime. This design life should include provision for routine inspection, refurbishment and replacement of parts.

231. Safety related components of a spent fuel storage facility shall be designed to preserve their function during the lifetime of the facility. Where this is not possible, the design shall allow for the safe replacement of such components.

232. The selection of structural materials and welding methods shall be based upon codes and standards acceptable to the Regulatory Body. Consideration shall be given to the potential cumulative effects of radiation on materials likely to be subjected to significant radiation fields.

233. The materials of structures and components in direct contact with the spent fuel assemblies shall be compatible with the fuel assemblies and shall not contaminate the fuel with foreign matter which might significantly degrade the integrity of the fuel during storage.

234. Detailed consideration shall be given to the effects of the storage environment on the fuel and safety components. In particular, the potential for the oxidation of exposed UO_2 to U_3O_8 , with the consequent volume increase and particulate formation, shall be considered. In addition, any effects of changes in storage environment (e.g. wet-dry-wet) shall be assessed.

235. The effects of corrosive agents inside and outside the spent fuel containment (e.g. on fuel cladding, water pool structure, cask, silo or vault wall and sealing) shall be considered. All systems shall have adequate reliability over the design lifetime commensurate with the radiological consequence of their failure.

236. As determined by design specific factors, attaining such reliability might require that the design specify the use of durable construction materials, redundancy of key components, reliability of auxiliary services (e.g. electrical power supply), effective monitoring plans and efficient maintenance programmes (i.e. programmes compatible with normal facility operations), depending upon the storage technology used.

237. The construction shall allow easy decontamination of surfaces. Compatibility of decontamination materials and the operating environments shall be considered for operational states and design basis accidents.

HANDLING

238. Spent fuel handling and transfer equipment and systems might include:

- Fuel handling machines;
- Fuel transfer equipment;
- Fuel lifting devices;
- Fuel dismantling devices;
- Handling devices for all operations associated with transport containers;
- Provision for the safe handling of defective or damaged fuel or containers.

239. Handling equipment shall be designed to minimize the potential for damage to fuel, fuel assemblies, and to storage or transport containers. The following should be considered:

- (a) Equipment should not contain sharp edges or corners which could damage the surfaces of fuel assemblies.

- (b) Equipment should be provided with positive latching mechanisms to prevent accidental release.
- (c) Moving equipment should have defined speed limitations.
- (d) Systems should be designed so that fuel cannot be dropped as a result of loss of power. Consideration should be given to the consequences of a single failure and, where appropriate, redundant load paths should be provided.
- (e) Where it is necessary to ensure that fuel assemblies can be readily placed in a safe location, fuel handling equipment should be designed for emergency manual operation.
- (f) Equipment shall be designed to ensure that the magnitude and direction of any forces that are applied to fuel assemblies are within acceptable limits.
- (g) Equipment should be provided with suitable interlocks or physical limitations to prevent dangerous or incompatible operations. Such interlocks or limitations should prevent travel in some circumstances (e.g. where fuel is incorrectly placed or where the machine is too close to the pool walls), overlifting of fuel assemblies or other components, accidental release of loads or the application of incorrect forces.

240. Where, in the interests of safety, the operating organization of spent fuel handling systems is likely to require information on the non-visible state of the equipment or components, the design shall include provision effectively to transmit such information to the operator through appropriately located indicator systems or alternative means.

241. The design of spent fuel handling equipment shall include provision for the related use of portable manual or power operated tools, provided that the planned use of such tools is consistent with the design objectives and that such use shall not compromise the safety of the fuel handling operations.

242. The design of equipment for transferring spent fuel to a storage facility shall be such that the equipment is capable of withstanding operational states and accident conditions. In the event of an accidental drop, the equipment shall not damage the containment or the shielding of fuel canisters in any manner that makes possible unacceptable radiation exposure to workers or the public. An accidental drop shall also not prevent fuel retrieval or cause significant damage to the fuel unit or storage facility.

SITE

243. The site for an interim spent fuel storage facility shall be approved by the Regulatory Body.

244. Areas selected for spent fuel storage shall be sufficiently large to accommodate the anticipated amount of fuel and all ancillary equipment and facilities, and provision shall be made for any foreseen expansions.

245. The IAEA Code on the Safety of Nuclear Power Plants: Siting [10] and the associated Safety Guides on nuclear power plant siting (50-SG-S1 to 50-SG-S11) contain criteria and methods which could be used effectively in siting spent fuel storage facilities.

246. A site intended for the location of a spent fuel storage facility shall be selected on the basis of an appropriate safety and environmental review. This review should include consideration of site characteristics related to geology, soil bearing capacity, topography, hydrology, hydrogeology and civil design, including accessibility and the potential impact of external hazards.

247. External hazards to be considered should include both natural phenomena (e.g. earthquakes, floods, winds, rain, snow, ice and lightning) and man-made hazards (e.g. aircraft crashes and explosions).

248. A pre-qualified nuclear site (i.e. a nuclear site qualified to the satisfaction of the Regulatory Body) may be considered acceptable for a compatible spent fuel storage facility.

249. If a spent fuel storage facility is to be located on the same site as, or adjacent to, an existing nuclear facility (e.g. power reactor), this will generally require changes to the site licence. The presence of the new storage facility will alter the safety analysis and environmental impact analysis previously submitted to the Regulatory Body.

250. Such a storage facility may share common services (e.g. electricity, water, access) with other facilities if:

- Such sharing does not significantly increase the probability or potential consequences of an accident or malfunction in these facilities;
- Due consideration is given to, and appropriate design allowances are made for, potential impacts as a consequence of interrelationships associated with the nuclear facilities and ancillary equipment and facilities (e.g. site generated missiles, effects of buildings on air flow);
- Such sharing is acceptable to the Regulatory Body.

251. In general, the safety systems and the safety related systems of the storage facility should not be shared with those of the other facilities on the site. In special circumstances, on the basis of a thorough analysis, the Regulatory Body might accept a proposal for some common systems if it is justified and the difference in the life-time of the various facilities is also taken into account.

252. When the spent fuel storage facility is situated within the site area of a nuclear power plant, the design basis for external events should be evaluated using paras 204–206 of the Safety Guide on Seismic Design and Qualification for Nuclear Power Plants [11] and para. 223 of the Safety Guide on External Man-Induced Events in Relation to Nuclear Power Plant Design [12].

SAFEGUARDS AND PHYSICAL PROTECTION

253. The design of a spent fuel storage facility and its relevant systems should take account of safeguards and related requirements for physical protection, and should facilitate their resolution.

254. ‘Safeguards’ refers to the IAEA safeguards system, the objective of which is the timely *detection* of any diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons, other nuclear explosive devices, or for purposes unknown, and *deterrence* of such diversion by the likelihood of early detection. The IAEA safeguards system is based on the use of materials accountancy as a safeguards measure of fundamental importance, with containment and surveillance as major complementary measures. General information on the IAEA safeguards programme and the related technical measures are contained in IAEA publications such as IAEA Safeguards: an Introduction [13] and IAEA Safeguards: Guidelines for States’ Systems of Accounting for and Control of Nuclear Materials [14].

255. The design process and the co-ordination procedures of the designer’s organization shall take into account the Member State’s international obligations relating to safeguards. The designer, in co-operation with the Regulatory Body responsible for the matter, shall ensure full compliance with the safeguards requirements which apply to the design process and to the subsequent operation of the facility itself.

256. The design of spent fuel handling and storage systems and areas shall facilitate the application and maintenance of safeguards requirements as determined by the respective Safeguards Agreements. This design shall provide for the installation, operation and maintenance of appropriate equipment and systems to establish and maintain a safeguards system consisting of adequate elements of physical protection, containment, surveillance and nuclear materials control and accountancy.

257. Physical protection arrangements which permit access only to authorized personnel shall be provided in order to deter and detect unauthorized access to storage structures or to areas where irradiated fuel is handled or stored. The design of spent fuel storage facilities shall include measures or systems to detect and deter any unauthorized diversion of nuclear materials from spent fuel handling and storage areas.

258. General information and the required technical measures are described in The Convention on the Physical Protection of Nuclear Material [15] and The Physical Protection of Nuclear Material [16]. These measures may include security fences, surveillance and intrusion detection systems.

OPERATIONAL ASPECTS

259. The design of spent fuel handling and storage systems shall be such as to ensure safe operation during operational states. Thus assumptions critical to operational safety should be documented at the design stage to facilitate the subsequent development of operational procedures. These assumptions and conclusions concerning the anticipated operational safety of the facility should be justified through detailed analyses using appropriate techniques.

260. A design for safe operation of spent fuel handling and storage systems should include the following:

- Measures to limit radioactive releases and radioactive exposures of workers and the public during normal operation and anticipated operational occurrences in accordance with the philosophy of dose limitation recommended by Ref. [8], with particular consideration being given to use of remote techniques in areas of radiation to reduce worker exposures;
- Measures to prevent anticipated operational occurrences and accident conditions from developing into unacceptable severe accident conditions;
- Provision for ease of operation and maintenance of essential equipment (in particular, safety related systems or equipment);
- Provision through equipment and procedures for retrieving spent fuel from storage.

3. SPECIFIC DESIGN REQUIREMENTS

301. Although many design requirements and considerations are applicable to all types of storage facilities for spent nuclear fuel, there are other design requirements specific to wet or dry storage facilities. These are discussed below.

WET STORAGE OF SPENT FUEL

302. The following sections describe requirements and considerations specific to wet storage of spent nuclear fuel.

Subcriticality

303. Credit shall not be taken for the presence of a soluble neutron absorber in the pool water, unless this credit includes a verification requirement with an appropriately justified frequency and is acceptable to the Regulatory Body.

304. For those designs of wet storage facilities where pool water boiling during abnormal operating conditions is permitted, specific allowances shall be provided in the design evaluations for the change in water moderator density during such operational states and accident conditions.

Structure and layout

305. The boundaries of the storage pool and other components important to the retention of the cooling water shall be designed to withstand operational states and accident conditions (and, in particular, impacts from collisions or dropped loads) without significant leakage of water. Further, the design of facilities utilizing pool storage should provide for detecting leakage and implementing appropriate repairs or remedial actions likely to be required.

306. Water storage pools shall be designed to exclude penetrations below the elevation which corresponds to the minimum water level required for adequate shielding and cooling of stored fuel.

307. The design shall exclude the permanent installation of piping or other equipment which could inadvertently (e.g. by acting as a siphon) lower the pool water elevation below the minimum operating level specified in the interests of radiological safety and protection of the fuel.

308. The pool water make-up system shall be designed to provide water at a rate exceeding the maximum rate of water removal possible as a consequence of losses during operation, including removal of water via the pool water removal system. Conversely, pool water removal (and cleanup) systems shall have capacities less than those of the pool water make-up systems.

309. Where water pools are to be connected by sluiceways, the design of the sluiceways shall afford containment of water, and detection, collection and removal of leakage. Sluice gates shall be designed to withstand anticipated water pressures.

310. The facility design shall provide protection against overfilling of the storage pool.

Radiation protection

311. Where the radiation protection of the public and the workers depends on radiation shielding provided by a water pool, the water level shall be maintained so as

to provide the required degree of shielding. For that reason, the design of a wet storage facility for spent fuel shall include provision for an adequate and appropriately accessible supply of water of a quality acceptable for use in the facility.

312. Wet storage facilities shall be designed to provide effective control of radioactive materials which may be released into the water medium.

313. The design of wet storage facilities shall include the capability to purify the bulk of the pool water. The controlled removal of dissolved and suspended radioactive materials might be necessary to limit radiation fields at the surface of the pool. The provision of equipment to clean the walls of the pool liner should be provided for periodically removing radioactive deposits and sludges from these surfaces.

Heat removal

314. Heat removal systems for spent fuel storage facilities shall be designed to ensure the safe operation of the facility. The primary concern shall be to ensure that no temperature limit set to protect the components, systems and the inventory from damage shall be exceeded. Thus, heat removal systems of wet storage facilities shall ensure that the bulk temperatures of the pool water remains within safe limits during normal operation and anticipated operational occurrences. Accordingly, the design should ensure that variations and rates in change of the temperatures of the pool medium and affected facility components can be maintained within acceptable limits during operations, as identified and specified during the design process.

Materials

315. The materials of:

- the spent fuel containment structures
- the storage racks or containers
- the cooling water containing structures
- handling systems

shall be compatible with the pool water or shall be effectively protected against undue degradation or corrosion. The storage racks or containers shall not contaminate the pool water. Ease of decontamination of equipment exposed or in contact with pool water is related to the surface condition and properties of the materials of component fabrication. The designer shall consider the requirements for decontamination when specifying the materials for such equipment.

316. Pool water chemistry conditions shall be consistent with the protection of fuel cladding, pool structure and processing equipment. The water transparency required for pool operation shall be maintained.

Handling

317. The design of handling systems and equipment should prevent the leakage and escape of lubricants or other fluids or substances in a manner which could degrade the purity of the pool water. Such substances should either be prevented from entering wet storage facilities or, alternatively, should be fully compatible with fuel, equipment and storage structures (i.e. water may be used).

318. Hollow handling tools intended for use under water should be designed so that they fill with water upon submergence (to maintain water shielding) and drain upon removal. Over-raising of fuel or other components shall be prevented by incorporating interlocks designed to inhibit hoist motion in the event that high radiation fields are detected.

DRY STORAGE OF SPENT FUEL

319. The following sections describe requirements and considerations specific to dry storage of spent nuclear fuel.

Subcriticality

320. The design of fuel baskets or canisters intended for use with casks or silos, and the design of the casks and silos within which the fuel baskets or canisters are to be placed, shall ensure that the fuel will remain in a configuration which has been predetermined to be subcritical during loading, storage and retrieval.

321. The design of dry fuel storage facilities should allow for any consequences likely to result from the redistribution or the introduction of a moderator as a consequence of an internal or external event. If subcriticality under these conditions cannot be assured, then arguments should concentrate on why they are unlikely. This requires substantial consideration of site conditions with supporting analysis and/or demonstration that the stored fuel can remain effectively isolated from the external environment.

Structure and layout

322. Casks or silos shall be designed with a closure that can be secured to the body of the cask or silo in a manner which allows safe retrieval of fuels. In vaults, a similar closure shall be provided for the storage tubes or canisters.

323. When casks or silos are equipped with liners, they shall be designed to prevent the accumulation of water between the liner and the external shell. Vaults shall be provided with drainage.

324. The mechanical structure of a fuel basket or canister shall be designed to support, without structural deformity leading to handling problems, the mass of other fully loaded baskets or canisters which may be placed upon it if stacking is proposed. Static, impact and seismic loads shall be considered.

325. Ease of access is required for transfers of spent fuel to or from casks, silos or vault storage positions during normal operations, or during recovery operations after anticipated operational occurrences or accident conditions. Sufficient clearances shall be provided from all directions and on all sides to provide the required access.

326. Where the casks are to be transported off the site, they shall satisfy the requirements of Ref. [5].

327. The design of casks or silos shall be such as to provide stability against accidental upset.

328. In the design of casks or silos, joints shall be fitted with approved waterstops or effectively sealed by other means.

329. The foundation of the cask or silo storage area shall be capable of withstanding the load of the full containers and the handling equipment without excessive settling, which could lead to canister instability.

330. The design of an unenclosed dry storage facility should provide for appropriate collection, monitoring and treatment of surface water runoff.

331. If the storage installation does not have a hot cell or other capabilities for unloading the cask or silo, the cask or silo should be designed for maintenance or repair in a manner acceptable to the Regulatory Body.

332. The layout of any dry spent fuel storage area and of nearby components and pipes shall prevent the ingress of other moderating material to the stored fuel (e.g. water).

Radiation protection

333. The design of casks, silos and vaults shall be such that when they are loaded with fuel, the external radiation fields do not exceed the criteria or limits recommended by Ref. [8].

334. Loading and unloading of spent fuel into casks, silos or vaults in a storage configuration shall be done using equipment and methods designed to limit skyshine and the reflection of radiation towards uncontrolled areas, in accordance with the ALARA principle.

335. The design of concrete or metal casks, silos or vaults shall incorporate containment barriers acceptable to the Regulatory Body. Containment barriers to prevent

the release of radionuclides include liners which might form integral parts of the cask, silo or vault structures.

336. Those areas of vaults affording significant potential for generating or accumulating unacceptable concentrations of airborne radionuclides shall be designed so as provide for the maintenance of sub-atmospheric pressures to prevent the spread of airborne radionuclides to other areas of the storage facility. Alternatively, such areas shall be provided with ventilation and filtration services capable of maintaining concentrations of airborne radionuclides at acceptable levels.

337. The design shall be such as to facilitate monitoring of the spent fuel containment and detecting containment failures. If the design does not provide for continuous monitoring, it shall provide for periodic verification by observation or measurement that the containment systems are performing satisfactorily.

Heat removal

338. The design of the storage facility shall ensure the transfer of residual heat to the surroundings in order to meet specified design requirements for controlling fuel storage temperatures and maintaining the integrity of structural materials.

339. The cask, silo storage area or vault shall be designed so that casks, silos or vaults are placed, constructed in place or maintained in a manner which permits adequate heat dissipation. Design features might include provisions to maintain the effectiveness of cooling mechanisms during adverse weather conditions.

340. To the maximum practical extent, systems for cooling spent fuel stored in casks, silos and vaults should be passive and require minimal maintenance. Examples of such systems are those which rely on natural convection, conduction and radiant heat transfer. Where forced circulation of coolant is used, it shall be demonstrated to be sufficiently reliable to satisfy any requirement of the Regulatory Body.

341. Where the integrity of spent fuel stored in a gas medium within a cask, silo or vault requires that the gas medium be maintained at design conditions, the design of the associated storage facility should include provision for monitoring and maintaining this medium in accordance with the requirements of the Regulatory Body.

Materials

342. The cask, silo or vault shall be adequately constructed of suitable materials, using appropriate design and construction methods, to maintain shielding and containment functions under the environmental and loading conditions expected during its design lifetime unless adequate maintenance and/or replacement during operation can be demonstrated. These conditions should include corrosion caused by exposure

to the atmosphere, internal and external humidity, fission products, temperature variations, the internal buildup of gas and high radiation fields.

343. The casks, silos or vaults and their closures shall be constructed of materials which provide chemical and radiological stability, and appropriate resistance to mechanical impacts and thermal effects.

344. The selection of materials and storage atmosphere shall be based on codes and standards acceptable to the Regulatory Body.

345. Fuel shall be adequately dried in order to attain and maintain the gas environment required to protect the integrity of the fuel and its containment.

Handling

346. The design of casks intended to be portable shall include provision for lifting and handling which shall withstand anticipated loadings and usage during the lifetime of the casks.

347. For those dry storage facility designs incorporating concrete shielded casks with metallic canister provisions, consideration shall be given to transportation needs after loading the spent fuel assemblies into the canister, sealing the canister and placing the canister in the concrete shield enclosure. These transportation requirements might take the form of radiation shielding overpacks for on-site activities, and radiation shielding and impact limiters for off-site transportation in accordance with the requirements of the Regulatory Body.

4. AUXILIARY SYSTEMS

401. To ensure the operation and safety of spent fuel storage facilities, a number of support systems may be required. Design requirements for these auxiliary systems are discussed below.

SERVICES

402. The design of a spent fuel storage facility shall provide for emergency electrical power if the loss of normal electrical supplies could adversely affect safe conditions, physical security or the operation of safeguards equipment.

403. Where the safety of spent fuel storage is dependent upon the supply of utilities (e.g. compressed air or water), adequate sources shall be reliably available.

VENTILATION SYSTEMS

404. Ventilation systems shall be designed to limit the potential release of radionuclides.

405. Ventilation systems should be designed to control the accumulation of flammable or explosive gases (e.g. H_2 formed by radiolysis). The potential for drawing in hazardous gases from external sources should be considered.

406. Ventilation systems shall satisfy the requirements of Ref. [9] and their design shall be compatible with fire protection requirements.

COMMUNICATIONS

407. The design shall provide for adequate communications to satisfy the operational and emergency requirements of the facility.

CONTROL AND INSTRUMENTATION

408. Whenever practicable, control and protection functions shall be mutually independent. If this is not feasible, detailed justification for shared and interrelated systems shall be provided. Ergonomic factors shall be considered when designing provisions for alarms and indications to the operator.

FIRE PROTECTION

409. The design of the fuel handling and storage areas shall meet the requirements of the *Safety Guide on Fire Protection in Nuclear Power Plants* [17]. The design intent of such fire protection measures shall be to limit the risk of damage through fire of safety significance to spent fuel storage areas, spent fuel handling systems and auxiliary systems.

410. Fire protection systems of appropriate capacity and capability should be provided.

411. Precautions which are of particular relevance to this Safety Guide include the limitation and control of combustible materials in fuel handling and storage areas (e.g. combustible packing materials, piping systems carrying combustible materials). The spent fuel storage area shall be so designed that fire suppression cannot cause inadvertent criticality.

WASTE TREATMENT

412. The systems shall be designed to:

- minimize the potential for creating radioactive waste;
- provide safe and adequate means for handling radioactive wastes.

413. Processing methods for wastes should be compatible with the requirements of the receiving facility and acceptable to the Regulatory Body.

LIGHTING

414. Provision shall be made for adequate and reliable illumination in support of inspection and/or physical protection of spent fuel storage areas.

415. For wet storage in pools, the pool area shall be provided with the necessary illumination equipment. The design shall address any requirements for underwater lighting near work areas and provide for replacement of underwater lamps.

416. Materials used in underwater lighting shall be compatible with the environment and, in particular, shall not undergo unacceptable corrosion or cause any unacceptable contamination of the pool water.

AREA AND PERSONNEL MONITORING

417. Area monitoring may include measurements of radiation dose rates, airborne activities and surface contamination. In the controlled areas, fixed continuously operating instruments with local alarm and unambiguous readout should be installed to give information on the radiation dose rates. Any such instruments shall have ranges adequate to cover the expected levels.

418. Portable or mobile dose rate meters shall be provided for monitoring in spent fuel storage areas. Fixed or portable instruments to detect external contamination of workers shall be provided at exits from locations where there is a significant probability of such contamination. Instruments for area and personnel monitoring, whether fixed or portable, shall comply with appropriate Regulatory Body standards.

5. QUALITY ASSURANCE

501. The design of an interim spent fuel storage facility shall be subject to a quality assurance (QA) programme. This programme shall cover the activities, systems, components and materials specified in this guide. It shall be in accordance with the principles and objectives of the IAEA Code on the Safety of Nuclear Power Plants: Quality Assurance [18] and related Safety Guides.

502. The design of safety related systems and components of spent fuel storage facilities shall be subject to QA requirements commensurate with their importance with respect to safety. In this respect, the graded approach specified in Ref. [7] may be taken into account.

503. Verification of the design, fabrication and materials of items and systems important to the safety of spent fuel storage facilities shall be in accordance with the principles and objectives of Ref. [18] and related Safety Guides.

504. The design specifications and analyses pertaining to safety related materials and systems of a spent fuel storage facility shall be documented. The documentation shall be maintained in accordance with the established QA programme.

6. INSPECTION AND MAINTENANCE

601. The design of an interim spent fuel storage facility shall provide for an appropriate programme of inspection and maintenance of safety related components and systems. The design of a spent fuel storage facility shall provide safe access to all systems, areas and components requiring periodic inspection and/or maintenance. The access provided shall be sufficient for the safe operation of all required tools and equipment and for the installation of spares.

602. The design of a spent fuel storage facility shall permit monitoring of the integrity of stored fuel unless a specific justification is given to show that the monitoring is not necessary. Where the facility design requires the storage of fuel in sealed containment, the design shall provide a means of safeguards monitoring or verifying the related sealing operations. Such means shall not impair the integrity of the fuel.

603. Provision should be made in the design for maintenance of hot cell components. This maintenance work can be done either in the cell or externally, and the design should take account of the preferred option.

7. DECOMMISSIONING

701. A spent fuel storage facility shall be designed so that at the time it is decommissioned, the decontamination and dismantling of structures and equipment together with the removal of wastes can be facilitated, the quantities of waste arising can be minimized and occupational exposures can be reduced to as low as reasonably achievable (ALARA). These design provisions shall be consistent with the safe and efficient operation of the facility, and any decommissioning plan required by the Regulatory Body.

702. Design features to assist decommissioning of spent fuel storage facilities may include the following:

- Provisions specifically intended to facilitate the removal of equipment and systems during the decommissioning stage;
- Planning and arranging the storage facility and related operations such that the contamination of those areas and equipment which are not likely to be readily decontaminated is minimized as far as practicable.

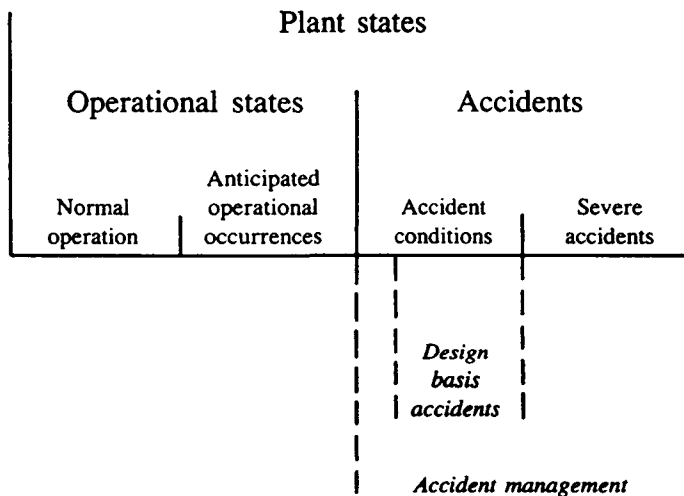
703. Examples of these provisions referred to above include minimizing penetrations through pool walls for piping systems, etc. Alternatively, where such penetrations are necessary or desirable for valid reasons, then conduits, sleeves or connectors may be employed to permit ready decommissioning of the associated systems without massive damage to pool structures.

DEFINITIONS

The definitions below are those specific to this document. Other terms in this document have the meaning as defined in other publications of the IAEA.

The specific definitions of plant states given below are taken from NUSS documents.

The relationships among the following fundamental definitions of plant states are illustrated by the accompanying diagram.



Operational States

States defined under normal operation or anticipated operational occurrences.

Normal Operation

Operation of a spent fuel storage facility within specified operational limits and conditions including fuel handling, storage, retrieval and fuel monitoring, maintenance and testing.

Anticipated Operational Occurrences¹

All operational processes deviating from normal operation which are expected to occur once or several times during the operating life of the fuel storage facility and which, in view of appropriate design provisions, do not cause any significant damage to items important to safety nor lead to accident conditions.

Accident (or Accident State)

A state defined under accident conditions or severe accidents.

Accident Conditions

Deviations² from operational states in which the releases of radioactive materials are kept to acceptable limits by appropriate design features. These deviations do not include severe accidents.

Design Basis Accidents

Accident conditions against which the spent fuel storage facility is designed according to established design criteria.

Severe Accidents

Spent fuel storage facility states beyond accident conditions, including those causing significant fuel degradation.

Accident Management

The taking of a set of actions

- during the evolution of an event sequence, before the design basis of the plant is exceeded, or
- during severe accidents without allowing unacceptable radionuclide releases to the environment

to return the facility to a controlled safe state and to mitigate any consequences of the accident.

¹ Examples of anticipated operational occurrences are loss of normal electric power, malfunction of individual items of a normally running plant and failure to function of individual items of control equipment.

² A deviation may be, for example, a major fuel failure caused by equipment malfunction, operator error, etc.

Other definitions used throughout this document are as follows:

Acceptable Limits

Limits acceptable to the Regulatory Body.

Applicant

The organization that applies for formal granting of a licence to perform specific activities related to siting, design, construction, commissioning, operation and decommissioning of a spent fuel storage facility.

Barrier

A natural or engineered feature which delays or prevents material migration to or from storage components. Facilities may include multiple barriers.

Burnup Credit

The assumption in criticality safety analysis that considers the reduction in reactivity due to changes of fissile material, and/or increase in fission product neutron absorbers in spent fuel that has occurred as a result of use in a nuclear reactor.

Concrete Canister (or Silo)

A concrete canister is a massive container comprising one or more individual storage cavities. It is usually circular in cross-section, with its long axis vertical. Containment and shielding are provided by an inner, sealed liner and the massive concrete of the canister body. Heat removal is accomplished by radiant transfer, conduction and convection within the body of the canister and natural convection at its exterior surface. Canisters may be located in enclosed or non-enclosed areas.

Containment System for Spent Fuel Storage

Systems, including ventilation, that act as barriers between areas containing radioactive substances and the environment.

Dry Storage

In dry storage, spent fuel is surrounded by a gas environment such as air or an inert gas. Dry storage facilities include the storage of spent fuel in casks, silos or vaults.

Fault

A failure of a single device or component to perform its safety function when required to do so by a demand on the safety system.

Fuel Assembly

A grouping of fuel elements which is not taken apart during the handling, storage, retrieval and monitoring activities of the spent fuel storage facility. It may include non-fuel components such as control rod spiders, burnable absorber rod assemblies, control rod elements, thimble plugs, fission chambers, neutron sources and fuel channels that are contained in, or are an integral part of, the fuel assembly but do not require special handling.

Fuel Element

The smallest structurally discrete part of a fuel assembly that has fuel as its principal constituent.

Licence

Authorization issued to the applicant by the Regulatory Body to perform specified activities related to siting, design, construction, commissioning, operation and decommissioning of the spent fuel storage facility.

Licensee

The holder of a licence.

Operating Organization

The organization authorized pursuant to a licence issued by the Regulatory Body to operate the spent fuel storage facility.

Operation

All activities performed to achieve the purpose for which the spent fuel storage facility was constructed, including maintenance, inspection and other associated activities related to spent fuel handling, storage, retrieval and monitoring.

Operational Limits and Conditions

A set of rules which set forth parameter limits, the functional capability and the performance levels of equipment and personnel approved by the Regulatory Body for safe operation of the spent fuel storage facility.

Postulated Initiating Events

Identified events that lead to anticipated operational occurrences or accident conditions and their consequential failure effects.³

Regulatory Body

A national authority or a system of authorities designated by a Member State, assisted by technical and other advisory bodies, and having the legal authority for conducting the licensing process, for issuing licences and thereby for regulating the spent fuel storage facility. The Regulatory Body will consider the siting, design, construction, commissioning, operation and decommissioning or specified aspects thereof.⁴

Residual Heat

The heat originating from radioactive decay in the spent nuclear fuel.

Silo (see Concrete Canister)

Site

The area containing the spent fuel storage facility, defined by a boundary and under effective control of the plant management.

Site Personnel

All persons working on the site, either permanently or temporarily.

³ The primary causes of postulated initiating events may be credible equipment failures and operator errors (both within and external to the spent fuel storage facility), or man induced or natural events. The specification of the postulated initiating events is to be acceptable to the Regulatory Body for the spent fuel storage facility.

⁴ This national authority could be either the government itself, or one or more departments of the government, or a body or bodies specially vested with appropriate legal authority.

Spent Fuel Storage Facility

An installation used for the interim storage of fuel assemblies and related components after their removal from the reactor pool and before reprocessing or disposal as radioactive waste.

Storage Cask, Cask

A storage cask is a massive container which may or may not be transportable. It provides shielding and containment of spent fuel by physical barriers which may include the metal or concrete body of the cask and welded or sealed liners, canisters or lids. Heat is removed from the stored fuel by radiant transfer to the surrounding environment and natural or forced convection. Casks may be located in enclosed or non-enclosed areas.

Vaults

Vaults consist of above- or below-ground reinforced concrete buildings containing arrays of storage cavities suitable for containment of one or more fuel units. Shielding is provided by the exterior structure. Heat removal is normally accomplished by circulating air or gas over the exterior of the fuel-containing units or storage cavities, and subsequently exhausting this air directly to the outside atmosphere or dissipating the heat via a secondary heat removal system.

Wet Storage

Wet storage facilities for spent fuel are those facilities which store spent fuel in water. The universal mode of wet storage consists of storing spent fuel assemblies or elements in water pools, usually supported on racks or in baskets, and/or in canisters which also contain water. The pool water surrounding the fuel provides for heat dissipation and radiation shielding, and the racks or other devices ensure a geometrical configuration which maintains subcriticality.

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