

Chapter 10

Planning, Construction, Operation, and Decommission of Nuclear Power Plants

Michiya Kuno and Masanori Hamada

Abstract Nuclear power plants must maintain important safety functions in the event of earthquakes and tsunamis. It is thus vital that strict quality control is implemented in all project stages including planning, construction, operation, and decommissioning to ensure that performance requirements are met. This chapter describes the planning and construction of nuclear power plants, maintenance/management activities during their operation, and decommissioning. The detailed flow of the decommissioning of a nuclear power plant is explained; the flow includes the transportation of spent fuel away from the plant, removal of radioactive substances from equipment inside the reactor and reactor building, and disposal of nuclear waste from decommissioning.

Keywords Planning · Design · Construction · Operation · Decommissioning · Inspection · Integrity evolution · Aging · Seismic reinforcement · Nuclear waste disposal

10.1 Flow of Regulatory Actions for Nuclear Power Plants

This section explains the flow of regulatory actions for nuclear power plants in the four project stages: planning, construction, operation, and decommissioning. Figure 10.1 shows the flow of regulatory actions for nuclear power plants that are taken in Japan at different times starting with the application for a reactor establishment license in the planning stage and ending with decommissioning.

M. Kuno (✉)
Chubu Electric Power Company, Nagoya, Japan
e-mail: kuno.michiya@chuden.co.jp

M. Hamada
Waseda University, Shinjuku, Tokyo, Japan

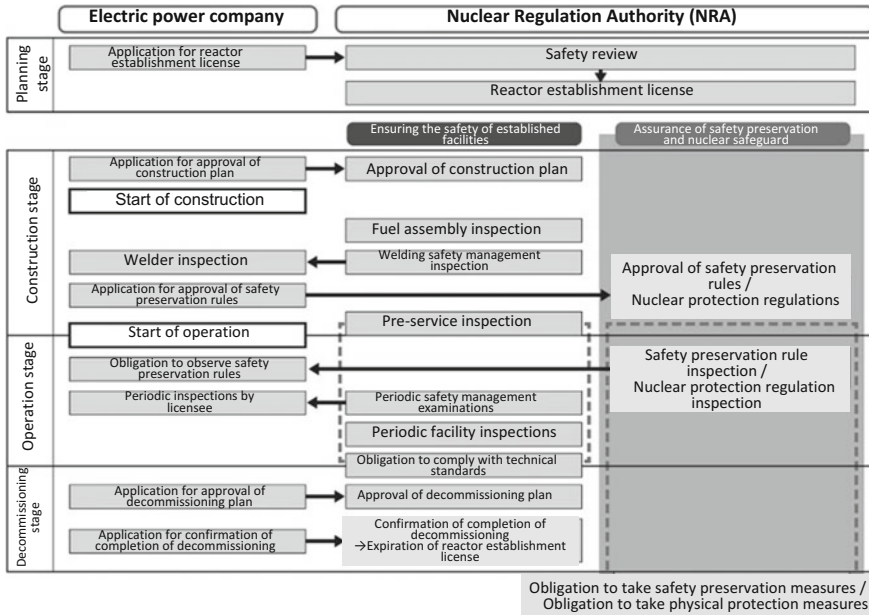


Fig. 10.1 Flow of regulatory actions for nuclear power plants [1]

10.1.1 Planning Stage

In the process of selecting a site for building a nuclear power plant, investigations and assessments are performed from diverse angles, giving attention not only to the safety of the nuclear power plant but also to effects on the lives of nearby residents and other industries. The electric power company produces three documents and submits them to the Ministry of Economy, Trade and Industry (METI) for examination: *Statement on the Consideration of Environmental Impact Assessment*, *Statement on the Method of Environmental Impact Assessment*, and *Statement on the Preparation for Environmental Impact Assessment*. In consideration of feedback from the examination process, the electric company produces an environmental impact assessment report and submits it to METI. After the contents of the environmental impact assessment report are finalized, the electric power company submits an application for a reactor establishment license to the Nuclear Regulation Authority (NRA). The NRA performs safety reviews on the application for reactor establishment and performs a safety examination to determine if the application satisfies the licensing criteria as per the Act on the Regulation of Nuclear Source Materials, Nuclear Fuel Materials and Reactors (hereinafter “Reactor Regulation Act”), and, subject to the satisfaction of these criteria, issues the reactor establishment license.

10.1.2 Construction Stage

After receiving the reactor establishment license, the electric power company applies for the approval of the construction plan to have the detailed plant design approved by the NRA before starting construction. The commercial power reactor facility constructed following the approval of the construction plan receives a pre-service inspection prior to commissioning. The pre-service inspection reviews the construction stage by means of material inspection, dimensional inspection, and appearance inspection. In addition, a welder inspection, fuel assembly inspection, and safety preservation rules are examined.

10.1.3 Operation Stage

During the operation stage after commissioning, the safe and stable operation of the nuclear power plant is ensured by periodic inspections made by the licensee (i.e., the electric power company) and statutory periodic facility inspections. In addition, an integrity assessment (i.e., an examination of equipment integrity), periodic safety reviews, and aging management activities are performed as parts of long-term facility maintenance programs.

10.1.4 Decommission Stage

The dismantling and removal of a nuclear power plant after the end of operation involves processes such as decontamination (i.e., the removal of radiological contamination by nuclear fuel materials) and the disposal of contaminated materials that must be carried out strictly in compliance with applicable laws. Before decommissioning a nuclear power plant, the licensee must produce a decommissioning plan and have it approved by the NRA. At the end of decommissioning, the licensee applies for confirmation of the completion of decommissioning by the NRA. Upon the confirmation of decommissioning by the NRA, the reactor establishment license expires and the given nuclear power plant ends its mission.

10.2 Construction of Nuclear Power Plant

This section describes the flow of construction activities from preparatory work to commissioning with explanations on particularities of different types of works involved.

10.2.1 Nuclear Power Plant Construction Works

The following are the particularities of nuclear power plant construction works:

- (1) The construction works involve aggressive testing, inspection, and quality control.
- (2) Construction takes a long time to complete. Notably, building work, mechanical work, and electrical work are conducted concurrently over a long period.
- (3) The work volume is enormous. For example, a large site has to be developed through civil engineering work.

10.2.2 Construction Project Flow

This subsection explains the entire construction project flow after the completion of rock formation testing. A nuclear power plant construction project generally takes a little more than 4 years from the rock test under the reactor building foundation to the start of commercial operation. However, the exact period varies depending on site conditions, the reactor type (e.g., boiling water reactor or pressurized water reactor), and volume of electricity generation.

The erection of major facilities inside the reactor building is identified as a critical path that strongly affects the scheduling of the entire construction project. Because the work volume is enormous, it is important to ensure that works are conducted reliably according to schedules, and individual work processes are planned with emphasis given to concurrent execution, labor savings, rationalizing, quality control, and labor safety.

Figure 10.2 gives an overview of construction schedules for major plant buildings.

10.3 Construction of Reactor Building

This section describes the construction of the reactor building of an advanced boiling water reactor plant. The entire workflow from the start of construction to the beginning of operation starts with preparatory work, continues with construction work and mechanical/electrical work, and ends with tests and trial operation. The start of construction work is declared upon the commencement of foundation excavation work for the reactor building for example, after the approval of the construction plan. Figure 10.3 shows the workflow of the reactor building construction.

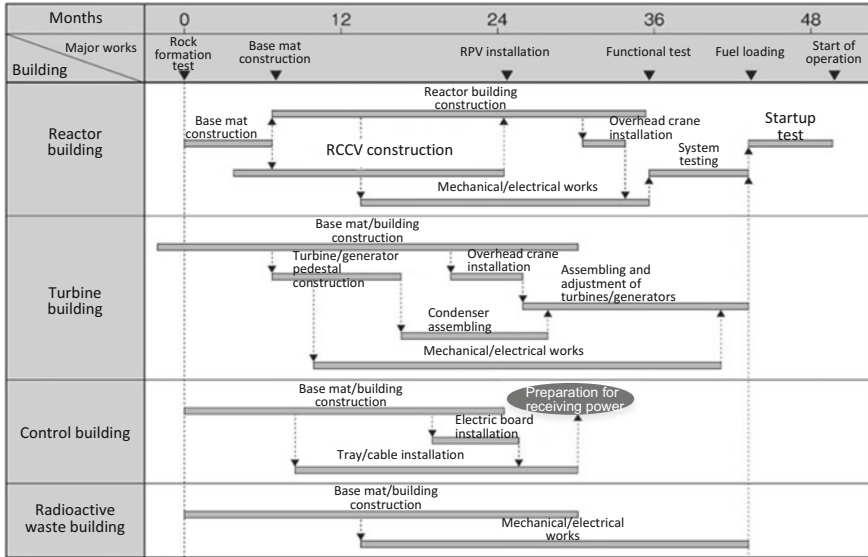


Fig. 10.2 Overview of construction schedules for major plant buildings [2]

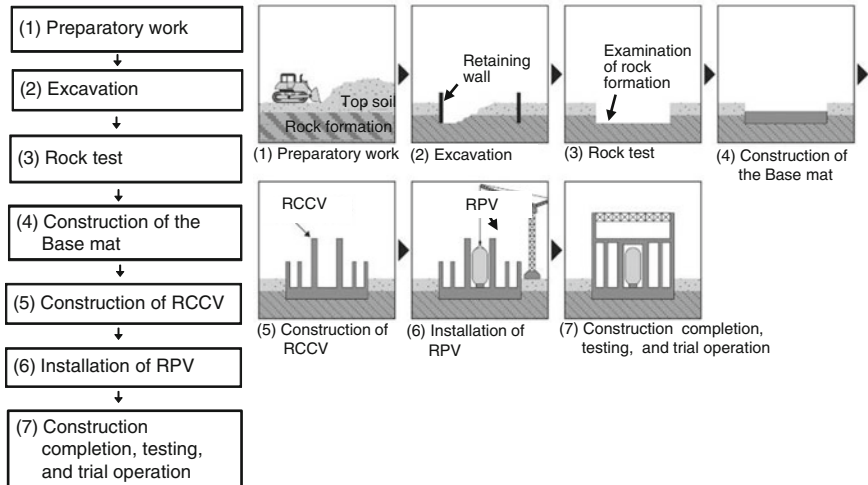


Fig. 10.3 Workflow of reactor building construction

10.3.1 Preparatory Work

The preparatory work includes the setup of temporary storage yards, shore protection work, and site development (e.g., excavation of ground landfill, soil disposal, and ground grading).

10.3.2 Excavation

The foundation excavation work begins for the reactor building, the turbine building, and water storage facilities.

To facilitate excavation work, earth-retaining walls, such as soldier pile retaining walls, soil mixing continuous walls, and underground continuous walls, are constructed. The volume of soil in a major excavation work lasting several months is in the order of 10^6 m³. Throughout the excavation work, environmental considerations are made along with strict quality control, taking measures to reduce noise, vibration, and dust, because of the frequent traffic of large dump trucks. As a general rule, the excavated soil is reused for site development.

10.3.3 Rock Test

The rock test is performed in pursuant to the Reactor Regulation Act and other laws. The construction work starts after the completion of the rock test. Figure 10.4 shows a scene from a rock test.

The purpose of the test is to verify that the rock is strong enough to serve as the foundation of the reactor containment building. The test is performed in the



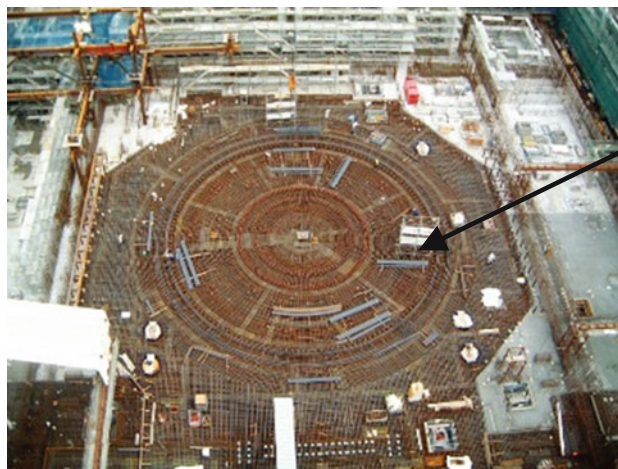
Fig. 10.4 Rock formation test (Photograph Chubu Electric Power Co., Inc.)

presence of NRA personnel and includes the examination of related documents. The test includes the examination of the foundation rock elevation, information about rock types/qualities and their distribution, rock test results, information about groundwater inflow and drainage facilities, and the cleanliness of the rock surface. It must be verified that the actual states of the foundation rock formation do not differ significantly from their descriptions examined in relation to the approval of the reactor establishment license and construction plan. Excavation is performed carefully for the foundation rock, and it has to finish with manually conducted finishing excavation and cleanup. Prior to the rock test, a tent is stretched over the rock surface to keep it clean and to ensure the test is unaffected by weather.

10.3.4 Construction of the Base Mat

After the completion of the rock test, the construction of the reactor building foundation begins with the setting of base mat reinforcement bars and the casting of concrete. Figure 10.5 shows the construction of base mat reinforcement bars. The base mat, 70–80 m long on each side, is composed of large-diameter reinforcement bars, laid out not only in the two horizontal rectangular directions but also radially, and a large quantity of concrete.

The construction of the reactor building involves the daily casting of a large volume of concrete (500–1,000 m³/day). The foundation base mat of the reactor building is often of extra-large thickness (more than 4 m in thickness) and requires the use of large quantities of large-diameter reinforcement bars. From the assembling of reinforcement bars to the completion of concrete casting, the whole process



Large-diameter reinforcement bars (laid out radially and cylindrically at the bottom of the Reinforced Concrete Containment Vessel (RCCV))

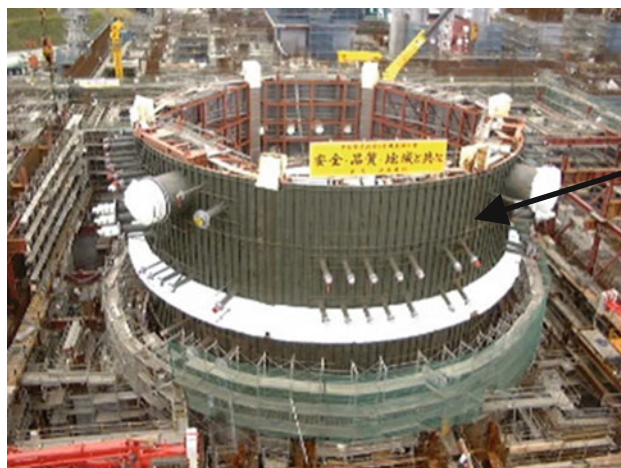
Fig. 10.5 Construction of base mat concrete reinforcement bars (Photograph Chubu Electric Power Co., Inc.)

takes about half a year. The strict control of concrete quality is practiced in the casting of base mat concrete. The time required for concrete casting is shortened by the use of block casting.

10.3.5 Construction of Reinforced Concrete Containment Vessel

After the production of base mat concrete, the construction of the RCCV begins. In the course of concrete works, the control of concrete quality and the management of work schedules depend largely on coordination among different works, such as the fixing of equipment supports and the installing of pipes. It is necessary to produce a work plan carefully, deciding on the division of work areas and the placement of heavy construction machinery in consideration of overlaps among construction work, mechanical work, and electrical work. Moreover, large and heavy construction machineries such as tower cranes operate in a confined construction area. To support the smooth and safe execution of reactor building construction work, it is important that the placement of construction machinery is planned carefully, appropriately considering the rotation radius of the tower crane boom and appropriately positioning work pedestals. Once the reactor building is constructed, RCCV pressure leakage testing is performed to confirm the structural integrity of the reactor containment vessel.

Figure 10.6 shows a scene from RCCV construction work. To the exterior of cylindrical steel liner plates, a reinforced concrete wall of about 2 m in thickness is constructed.



Liner plates (covered externally by a reinforced-concrete wall of about 2m in thickness)

Fig. 10.6 RCCV construction (Photograph Chubu Electric Power Co., Inc.)



Fig. 10.7 RPV hoisting (Photograph Chubu Electric Power Co., Inc.)

10.3.6 Installation of Reactor Pressure Vessel

After the construction of the RCCV, the RPV is installed. Figure 10.7 shows an RPV being hoisted for installation. The RPV is hoisted carefully while avoiding the operation zones of the tower cranes for reactor building construction.

The RPV, brought to the site from the factory by sea and land transportation, is hoisted for installation using a crane specially provided for this purpose. The hoisting is done carefully to avoid the reactor containment vessel, the reactor vessel, and pre-installed piping. The installation of major equipment and piping ends with the hydraulic testing of main systems.

10.3.7 Construction Completion, Testing, and Trial Operation

After the installation of the RPV, the top story is constructed and the roof is added as the final major step in the construction of the reactor building. The construction of other buildings and structures, such as the turbine building and exhaust stack, proceeds concurrently with the construction of the reactor building and is completed around the same time, putting an end to the construction work of the nuclear power plant. After the completion of construction work, functional testing of various systems (e.g., equipment, piping, electrical installations, instruments, etc.) is performed, followed by a trial operation. After fuel loading, the reactor output is gradually increased to 100 % while monitoring the performance of various facilities at different output levels before the commencement of the commercial operation of the nuclear power plant.

10.4 Operation of Nuclear Power Plant

In relation to activities conducted at a nuclear power plant during its operation, this section explains maintenance management, aging assessment techniques, and seismic safety improvement measures.

10.4.1 Maintenance Management

The purpose of the maintenance management of a nuclear power plant is to ensure the integrity of plant facilities and to increase the assurance of safe and stable plant operation. Maintenance management activities performed at nuclear power plants either during operation or during scheduled outages (periodic inspections) include the following.

- (1) Inspections are performed by the operators while the reactor is in operation, including the surveillance testing of components important to safety (approximately once a week) and daily walk-through and routine inspections.
- (2) A statutory periodic facility inspection is performed while the reactor is in outage approximately once per year in pursuant to the Reactor Regulation Act. During the inspection period, the operation data of different facilities and the records from past periodic inspections are examined. In addition to this statutory inspection, there are periodic inspections performed by the electric power company according to their programs that ensure the integrity of plant facilities. Particular emphasis is placed on detecting the symptoms of aging (i.e., degradation due to long use) during periodic inspections. A plant integrity evaluation program has been introduced to collect data on the aging trend, on the basis of which repairs and replacements are performed before the performance of facilities drops below the predefined reference level,
- (3) Following the amendment of the Electric Enterprise Law on October 2003, the Japan Electric Association issued the Code of Quality Assurance for Safety of Nuclear Power Plants (JEAC4111) and the Rules of Maintenance Management of Nuclear Power Plants (JEAC4209) under the Reactor Regulation Act. With guidelines on maintenance management established by these publications, the Japanese government monitors the states of maintenance management at nuclear power plants. Government-appointed nuclear safety inspectors periodically conduct examinations to determine how safety preservation rules, dictating practices to be followed to ensure safe plant operation, are observed at nuclear power plants. The inspection of certain facilities prescribed by law has to be covered by periodic inspection by the licensee. The Japan Nuclear Energy Safety Organization examines the state of implementation of such periodic inspections by licensees, and the examination result is reviewed by the Nuclear and Industrial Safety Agency of METI.

- (4) In trying to maintain and improve the reliability of plant facilities, repairs and improvements need to be performed systematically, considering lessons from nuclear power plant operating experiences in Japan and abroad, and taking advantage of technological development. The aging of the RPV due to neutron irradiation embrittlement is addressed by inspections, but the replacement of the RPV in the reactor building is difficult.
- (5) Every 10 years or more, the implementation of safety preservation activities and the incorporation of the latest technical knowledge during the given period are examined in a periodic safety review. Moreover, within 30 years of the commencement of commercial operation (and every 10 years thereafter), an aging technical evaluation is performed to address the aging of components and structures that are important to safety. The licensee is obliged to establish a long-term maintenance management policy based on the results of these evaluations and incorporate it into the safety preservation rules.

Figure 10.8 shows the flow of maintenance management of a power plant. The paragraphs that follow offer more information about periodic facility inspections, integrity evaluation, periodic inspections by licensees, and periodic safety reviews.

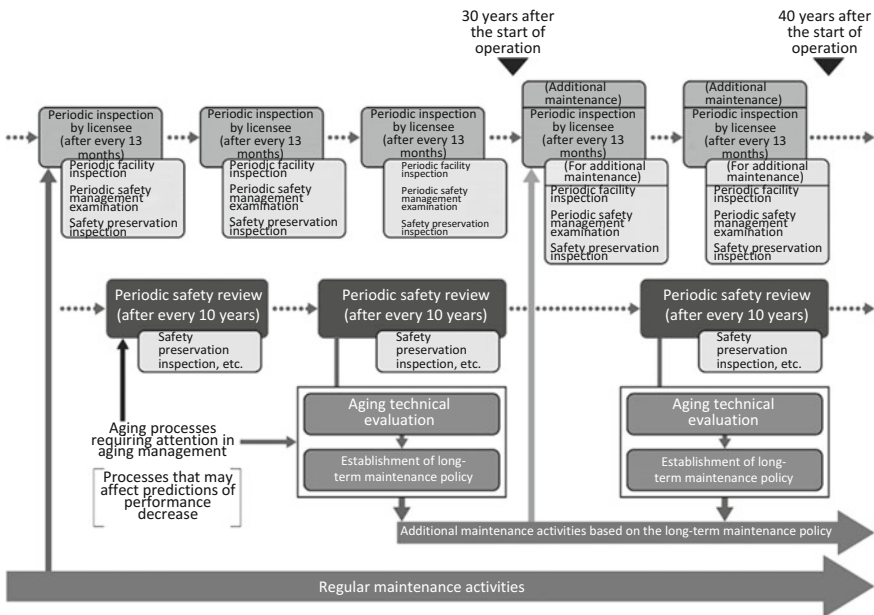


Fig. 10.8 Flow of the maintenance management of a nuclear power plant [3]

10.4.1.1 Periodic Facility Inspection

The Reactor Regulation Act requires that each commercial power reactor facility is inspected periodically every 13 months as a general rule. Conducted for the purpose of verifying the integrity of plant facilities, this inspection involves the testing of the operating performance of main facilities, facility inspection by overhaul, and leakage testing. This periodic inspection is combined with the checking and taking care of the parts of facilities that resemble or correspond to the parts that caused an accident or failed in other nuclear power plants.

The licensees (i.e., electric power companies) are responsible for conducting these periodic inspections. The inspection of important facilities is conducted in the presence of inspectors from the government. The inspection activities include the overhaul inspection of pumps and valves (e.g., the in-service inspection of containers, pipes, and support structures) and the leakage testing of the RCV and main steam isolation valve.

10.4.1.2 Integrity Evaluation Program

The integrity evaluation program gives attention to flaws discovered by periodic inspections and technically predicts their further development for evaluating future plant integrity. If a flaw such as cracking is found in the shroud inside the RPV or in a facility or component in a system that handles the reactor coolant, for example, the cause of the flaw is identified, and technical evaluation is performed to find out how far the flaw may develop during the lifecycle of the facilities.

Figure 10.9 shows the flow of integrity evaluation. In the past, each detected flaw used to be addressed by repair or replacement irrespective of the greatness of its effect on safety in reference to the design and manufacturing standards applicable to new components. In the current integrity evaluation program, however, the facilities and components in which flaws have been discovered may continue to be used as they are under enhanced monitoring or with the observation of further developments provided that they still meet their maintenance standards. According to a prediction of the gradual decrease in strength due to crack development or wearing, for example, a component may continue to be in service as long as it satisfies the safety standard. When it no longer meets the safety standard, it has to be repaired or replaced.

As standards concerning the maintenance of reactor facilities, *Codes for Nuclear Power Generation Facilities: Maintenance Standards* (JSME S NA1-2010) published by the Japan Society of Mechanical Engineers is referred to. Electric power companies are obliged to report the results of these evaluations on plant maintenance and inspection activities to the national government and preserve the records.

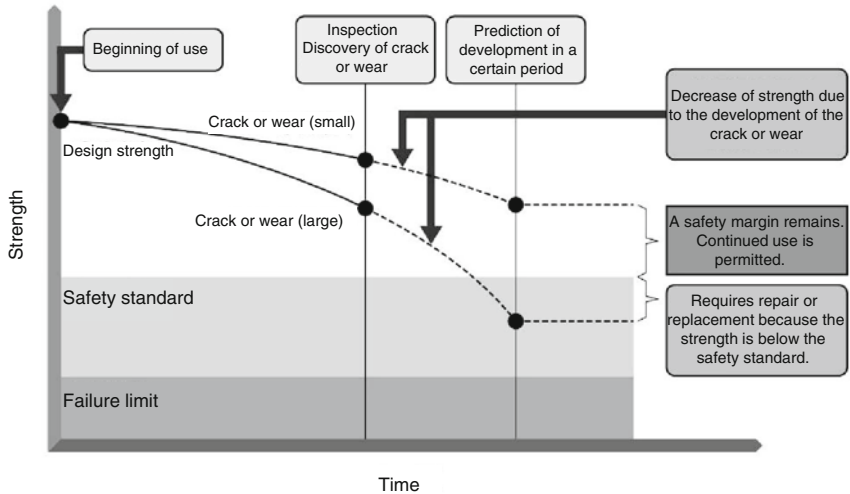


Fig. 10.9 Method for evaluating the integrity of plant facilities [3]

10.4.1.3 Periodic Inspection by Licensee

Periodic inspections by licensees were institutionalized in October 2003. Formerly, Article 54 of the Electric Enterprise Law stipulated the roughly annual execution of periodic inspections, and the licensees were also obliged to perform voluntary inspections. However, because the scope of voluntary inspections had not been clearly defined by law, Article 55 of the Electric Enterprise Law stipulated a periodic inspection by the licensee. Regarding these inspections performed by electric power companies periodically (every 13 months), the law stipulates the scope of inspection and the obligations of record keeping and reporting. Each periodic inspection by the licensee is performed together with the periodic inspection required by the Electric Enterprise Law, and their records are reviewed by the national government's periodic safety management examinations and safety preservation inspections.

10.4.1.4 Periodic Safety Review and Aging Technical Evaluation

Apart from periodic inspections, a periodic safety review is performed at intervals of less than 10 years for the implementation of safety preservation activities and the incorporation of the latest technologies during the given period, and the results are checked during safety preservation inspections. Moreover, within 30 years of the commencement of commercial operation (and every 10 years thereafter), an aging technical evaluation for extended plant operation is performed. The licensee establishes a long-term maintenance management policy based on the result of these evaluations and incorporates it into the safety preservation rules.

10.4.2 Aging Evaluation

Aging technical evaluation addresses the aging of buildings, structures, equipment, and piping systems that fulfill safety functions. The evaluation results are used in the planning of the long-term maintenance management of reactor facilities.

This subsection gives examples of aging technical evaluation performed at a nuclear power plant. Aging processes include neutron irradiation embrittlement, stress corrosion cracking, low-cycle fatigue, pipe thinning, insulation deterioration, concrete weakening, and decreasing shielding capability. Figure 10.10 shows chief contributors to the aging of reactor facilities. Table 10.1 gives an example of an aging technical evaluation performed for pumps. Aging processes affecting pumps include the corrosion of the pump shaft and casing, fatigue cracking of the casing, and fatigue cracking by fretting (i.e., repeated sliding motions at a very small amplitude between two objects that are pressed against one another).

Figure 10.11 shows an example of the parts of buildings and structures that receive attention in the evaluation of concrete weakening and decreasing shielding capability. Table 10.2 gives an example of the evaluation performed on concrete weakening. Factors contributing to concrete weakening include heat, neutron irradiation, neutralization, chloride penetration, the alkali–aggregate reaction, and mechanical vibration.

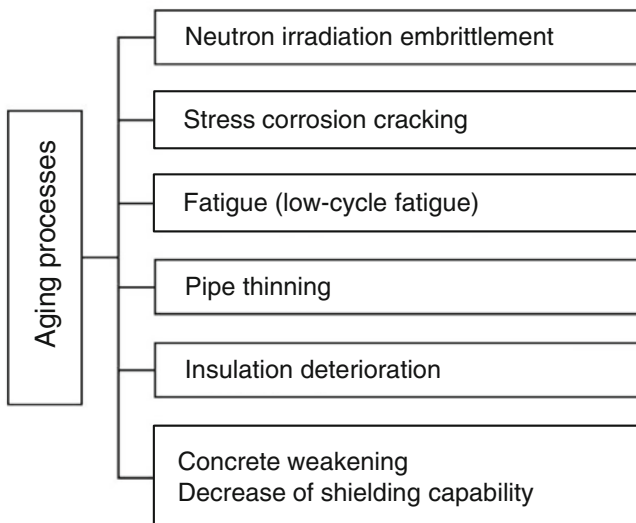
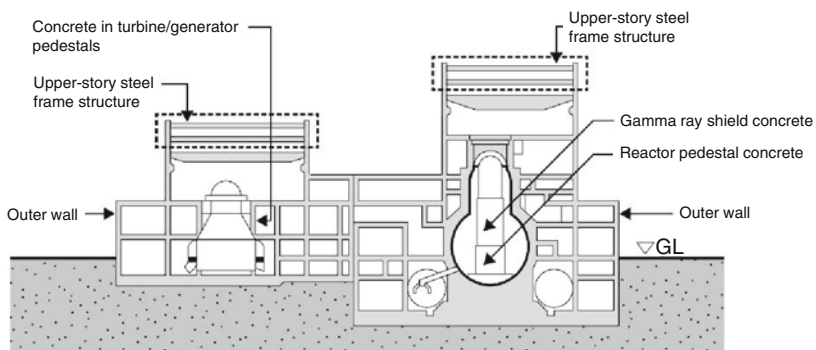


Fig. 10.10 Contributors to the aging of reactor facilities

Table 10.1 Example of an evaluation performed for processes contributing to the aging of pumps (at Hamaoka NPP) [4]

Aging process	Example of evaluation result
(a) Corrosion of shaft, casing, etc.	<ul style="list-style-type: none"> Any significant corrosion can be easily found by sight. A visual inspection is performed during overhaul to find any corrosion and address it as required by replacement, etc.
(b) Fatigue cracking of casing (reactor recirculation pump)	<ul style="list-style-type: none"> A fatigue life evaluation, performed in consideration of the number of thermal transient that happen due to plant startup and shutdown in the period of 60 years from the commissioning, gives an assurance that the fatigue accumulation factor will not go above the allowable limit. During the overhaul of pumps, the absence of any significant flaw is verified by the visual inspection of the casing interior, etc.
(c) Fatigue cracking due to fretting	<ul style="list-style-type: none"> In the case of a pump in which the vane rotor is shrunk-fit to the shaft, the shaft is inspected after removing the vane rotor in order to confirm the absence of fatigue cracking due to fretting



Ageing process	Factors contributing to aging		
Weakening	<ul style="list-style-type: none"> Heat Neutralization Mechanical vibration Drying shrinkage 	<ul style="list-style-type: none"> Neutron irradiation Chloride penetration Chemical penetration Creep 	<ul style="list-style-type: none"> Alkali-aggregate reaction Freezing and thawing Fatigue Wear
Decrease of shielding capability	<ul style="list-style-type: none"> Neutron irradiation (generation of heat by gamma ray) 		

⊙: Factors contributing to aging required by the standards for a light-water reactor

Fig. 10.11 Example of inspection targets [4]

Table 10.2 Example of an evaluation performed on concrete weakening (at Hamaoka NPP) [4]

Factors contributing to aging	Evaluation target	Example of evaluation result
Heat	Reactor pedestal	<ul style="list-style-type: none"> It is confirmed that the highest temperature determined by temperature distribution analysis is below the maximum allowable temperature (65 °C generally, 90 °C locally)
Neutron irradiation	Reactor pedestal	<ul style="list-style-type: none"> An analysis performed on neutron and gamma ray irradiation expected in the period of 60 years from the commissioning assures that the cumulative levels of irradiation will not be large enough to cause any significant weakening of concrete
Neutralization	Whole structure	<ul style="list-style-type: none"> An estimation performed on the depth of neutralization after 60 years from the commissioning at the evaluation target points, selected in consideration of contributors such as carbon dioxide and temperature, assures that the depth of neutralization will not be large enough to initiate the corrosion of reinforcement bars
Chloride penetration	Whole structure	<ul style="list-style-type: none"> An estimation performed on the thinning of reinforcement bars due to corrosion in the period of 60 years from the commissioning assures that the degree of thinning will be sufficiently lower than the level at which the cracking of the cover concrete may occur
Alkali–aggregate reaction	Whole structure	<ul style="list-style-type: none"> The measurement of the total swelling ratio, performed on core samples of concrete structures in which the alkali–aggregate reaction proceeded, demonstrated that the swelling ratio was sufficiently lower in view of the requirement of “less than 0.1 % when 6-month old”
Mechanical vibration	Turbine/generator pedestals	<ul style="list-style-type: none"> The average compressive strength, determined by a compressive strength testing of core samples, was sufficiently higher than the design strength

10.4.3 Seismic Reinforcement

As examples of seismic reinforcement implemented at a nuclear power plant, the following explains two projects launched by the Chubu Electric Power Company, at the Hamaoka Nuclear Power Plant: (1) the Seismic Safety Margin Improvement Project; and (2) Actions Taken in Consideration of Lessons from Damage Inflicted by the 2007 Niigata-Ken Chuetsu-Okai Earthquake on the Kashiwazaki Kariwa Nuclear Power Plant of Tokyo Electric Power Company.

10.4.3.1 Seismic Safety Margin Improvement

The Hamaoka Nuclear Power Plant exists in an area that is likely to be affected by the Tokai earthquake. To increase the seismic safety margin of the nuclear power plant, Chubu Electric Power Company launched a reinforcement project assuming that the seismic ground motion acceleration at the bedrock level may reach as high as $1,000 \text{ cm/s}^2$. As examples of the measures taken, the following explains exhaust stack reinforcement, ground improvement around a piping duct, and support improvement for piping and cable conduits.

(1) Exhaust stack reinforcement

During normal plant operation, the exhaust stack serves as an outlet of air from the reactor building. In an emergency, air from the secondary containment is released from the exhaust stack after passing through a charcoal filter. The exhaust stack structure must maintain its ability to support the shaft that goes through it.

The exhaust shaft is a cylindrical steel structure 100 m in height and about 8 m in diameter at the bottom. It is held by a concrete foundation that is about 20 m deep. The exhaust shaft was reinforced for seismic safety. This was done by building a steel tower around the exhaust shaft and joining this supporting steel tower with the exhaust tower via oil dampers. Figure 10.12 shows an example of exhaust shaft reinforcement.

(2) Ground improvement around a piping duct

To reduce the forces that act on a piping duct from the surroundings, the ground soil was improved by injecting a cement-based material into the ground and by mixing the material with soil. Figure 10.13 shows an example of ground improvement around the piping duct.

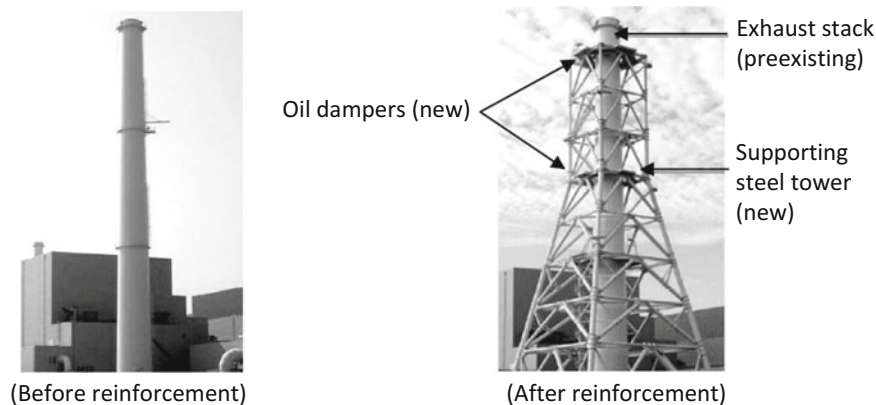


Fig. 10.12 Example of exhaust stack reinforcement [5]

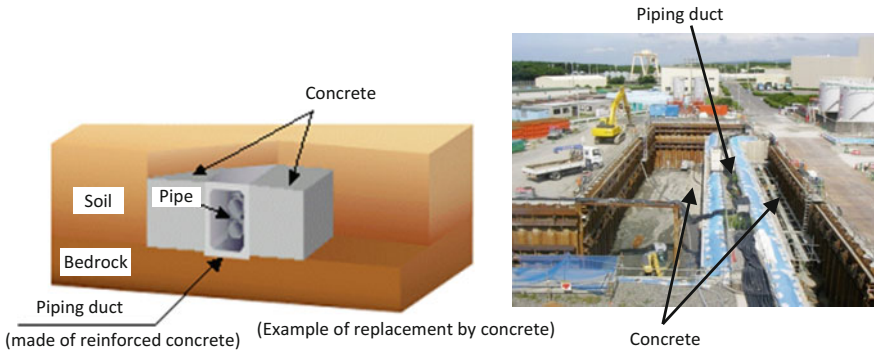


Fig. 10.13 Ground improvement around a piping duct [5]

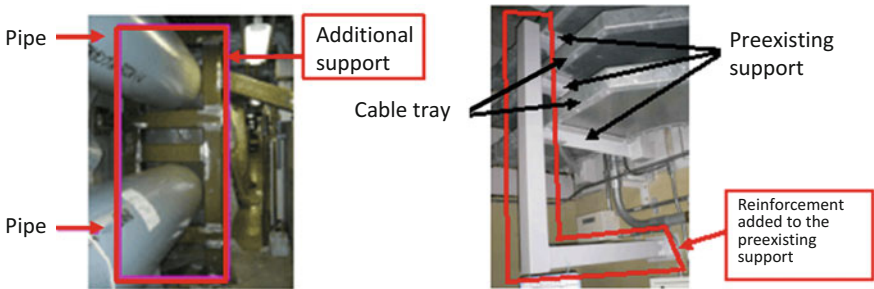


Fig. 10.14 Support improvement for piping and cable conduits [5]

(3) Support improvement for piping and cable conduits

Supports were added to reduce the horizontal and vertical displacements that can happen for piping and cable conduits inside the reactor building and some other plant buildings. The required seismic strength was determined by performing numerical analyses using models of piping and supports. After performing a seismic evaluation on piping supports at about 6,000 points in total, reinforcement was made at about 200 of the 6,000 points. In addition, cable conduit supports were reinforced at about 1,300 points. Figure 10.14 gives an overview of support improvement for piping and cable conduits.

10.4.3.2 Actions Taken in Response to the 2007 Niigata-Ken Chuetsu-Oki Earthquake

In consideration of the damaged inflicted by the 2007 Niigata-Ken Chuetsu-Oki Earthquake on the Kashiwazaki Kariwa Nuclear Power Plant of Tokyo Electric Power Company and emergency measures taken after the earthquake, Chubu

Electric Power Company, reexamined seismic safety measures for the Hamaoka Nuclear Power Plant and built a seismically isolated office building in which to facilitate initial responses to earthquake and to support the distribution of reliable information.

The seismically isolated building has four storeys above the ground with a single-storey penthouse with dimensions of about 30×40 m. A seismic isolation system is placed between the first storey level and the foundation to dampen earthquake motion. The seismic isolation system improves the reliance on the plant personnel’s capability to make initial responses and to distribute information. Figure 10.15 shows the appearance of the seismically isolated office building.

Furthermore, in view of the need to ensure the availability of access roads used in initial responses, precast concrete plates were installed over underground constructions to prevent the collapsing of roads due to the failure of underground constructions. Figure 10.16 shows an example of access road reinforcement.



Fig. 10.15 Seismically isolated office building (*Photograph Chubu Electric Power Company*)

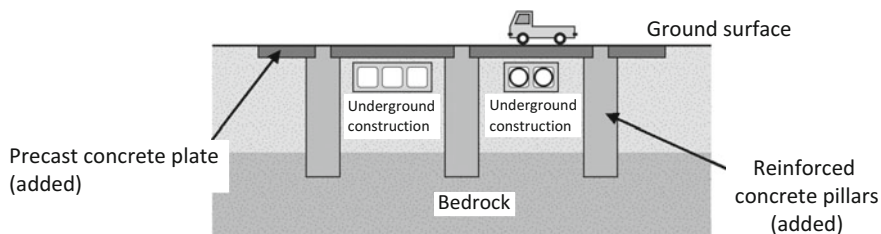


Fig. 10.16 Example of access road reinforcement

10.5 Decommissioning of Nuclear Power Plant

Nuclear power plants are dismantled and removed following the termination of their operation. This section describes the decommissioning of nuclear power plants and the disposal of the waste produced by decommissioning.

10.5.1 Decommissioning Flow

The Reactor Regulation Act stipulates “When terminating the use of a nuclear power plant, it is necessary to take measures specified by the rules of the NRA such as the dismantling of reactor facilities, the transfer of nuclear fuel materials, the removal of contamination by nuclear fuel materials, and the disposal of components contaminated by nuclear fuel materials.”

In pursuant to the Reactor Regulation Act, the licensee has to prepare in advance a decommissioning plan and have it approved by the NRA. A document titled *Decommissioning of Commercial Nuclear Power Reactors* (July 15, 1985) from the Nuclear Power Committee of the Advisory Committee for Energy, the Ministry of International Trade and Industry (now METI), along with a few other documents, prescribes a standard decommissioning workflow. Figure 10.17 illustrates this standard workflow for nuclear power plant decommissioning.

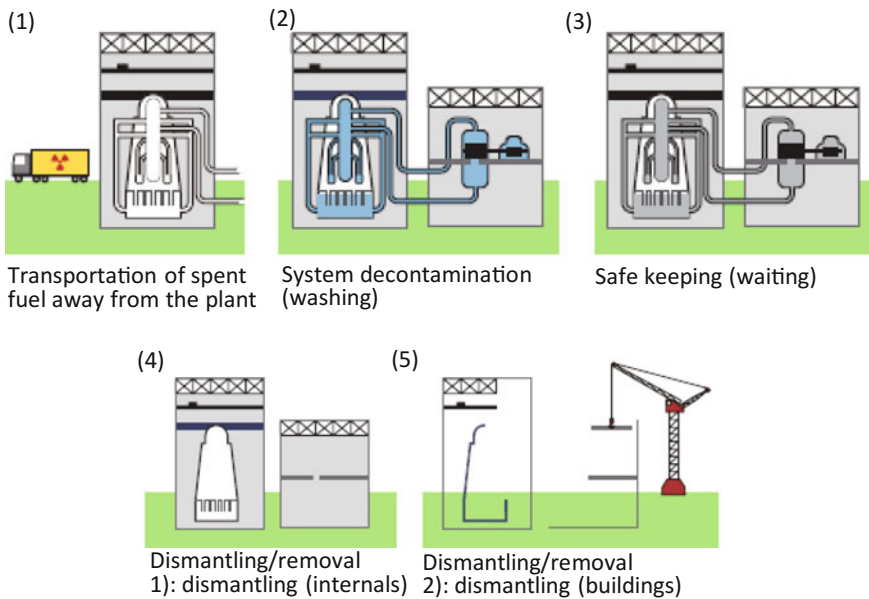


Fig. 10.17 Flow of the decommissioning of a nuclear power plant [3]

The standard workflow is as follows;

- (1) Transportation of spent fuel away from the plant
- (2) Removal of radioactive substances from inside the piping and containers using chemicals (i.e., system decontamination)
- (3) Safekeeping for a period of 5–10 years to wait for the decrease in radioactivity by decay
- (4) Dismantling and removal of piping, containers, and other components from inside the reactor and the reactor building
- (5) Dismantling and removal of buildings.

10.5.1.1 Transportation of Spent Fuel from Plant

The spent fuel is transported away from the nuclear power plant. The spent fuel removed from the plant has to be properly controlled and disposed of. Before the spent fuel is removed, the nuclear power plant has to maintain safety functions that protect it from the risk of an earthquake and tsunami.

The spent fuel is put into special transportation containers (canisters) before it is carried away. Figure 10.18 shows spent fuel being transported away from a nuclear power plant. The transportation canisters must meet statutory design requirements so that they may withstand accidents such as dropping and fire without having any radiological effect on the environment. Until the transportation of spent fuel is completed, the plant facilities providing cooling and containment capabilities, as well as radioactive waste disposal facilities and radiation control facilities (e.g., radiation monitors), are periodically inspected.

Fig. 10.18 Spent fuel transported away from a nuclear power plant
(*Photograph* Chubu Electric Power Company)



10.5.1.2 System Decontamination

To minimize the dose to workers who will be engaged in dismantling activities, piping, containers, and other components are washed using chemicals to clean them of radioactive substances adhering to them. During system decontamination activities, the release of radioactive substances is prevented by measures such as the restricting of work areas. Throughout the period of system decontamination, the plant facilities providing the containment capability, as well as radioactive waste disposal facilities and radiation control facilities (e.g., radiation monitors), are maintained.

10.5.1.3 Safe Keeping

The quantity of radioactive substances decreases with the passage of time. During the safekeeping period of a certain duration, determined according to the measurement and evaluation of the radioactivity of reactor components, the plant is left alone with necessary maintenance and control provided to wait until the quantity of radioactive substances decrease sufficiently to permit the easier execution of dismantling/removal activities. For the assurance of safety during the safekeeping period, the piping and containers are emptied of liquid and all valves and openings are closed at the plant to prevent the outflow of radioactive substances. Furthermore, the plant facilities providing the containment capability, as well as radioactive waste disposal facilities and radiation control facilities, are maintained.

10.5.1.4 Dismantling and Removal

To prevent the external release of radioactive substances, facilities and components inside the plant buildings are dismantled and removed first. After that, building floors and interior wall surfaces are cleaned of radioactive substances. After confirming the removal of radioactive substances from inside, the plant buildings are dismantled and removed. The work areas are covered to prevent the scattering of radioactive substances. Furthermore, the plant facilities providing the containment capability, as well as radioactive waste disposal facilities and radiation control facilities, are maintained.

10.5.2 Waste Produced by Decommissioning

In the case of a 1.1-GW-class nuclear power plant (i.e., a light water reactor plant), the waste produced by its decommissioning is expected to amount to approximately 500–550 thousand tons. Most of these wastes are nonradioactive or not radioactive enough to require treatment as radioactive waste. Figure 10.19 shows the breakdown of decommissioning waste.

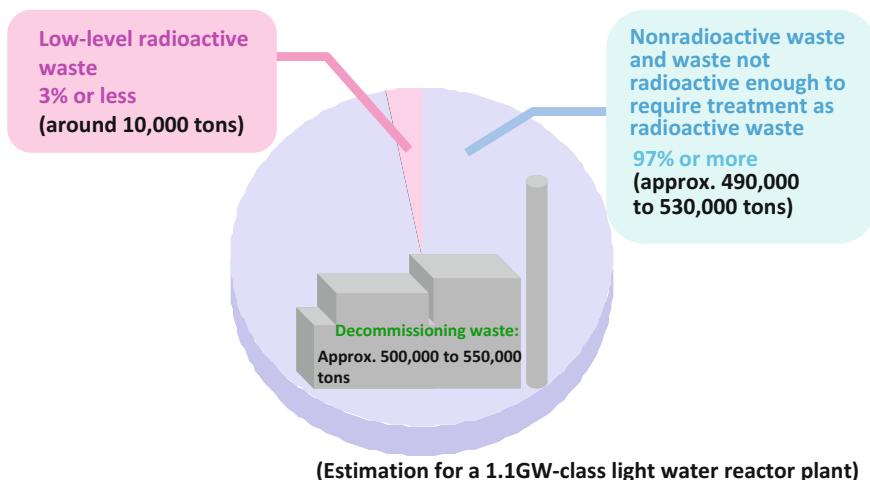


Fig. 10.19 Decommissioning waste

The nonradioactive waste and the waste not radioactive enough to require treatment as radioactive waste are recycled as resources or disposed of like typical industrial waste. Low-level radioactive waste is classified by the type of radioactive nuclides it contains and the level of radioactivity, and disposed of appropriately according to the classification.

10.5.3 Classification and Disposal of Waste from the Decommissioning of a Nuclear Power Plant

Figure 10.20 shows the classification and disposal of waste from the decommissioning of nuclear power plants. Low-level radioactive waste is classified by the types of radioactive nuclide it contains. It is then buried at a determined depth and protected by an artificial barrier such as that of a concrete pit as required.

10.6 Examples of Nuclear Power Plant Decommissioning

In Japan, four reactor units are now undergoing decommissioning: Tokai Power Station (a carbon dioxide-cooled reactor) of Japan Atomic Power, Fugen (an advanced thermal reactor) of Japan Atomic Energy Agency and Fugen Decommissioning Engineering Center, and Hamaoka Units 1 and 2 of Chubu Electric Power Company. In addition, a decision has been made to decommission Units 1–6 at Fukushima Daiichi Nuclear Power Plant of Tokyo Electric Power Company.

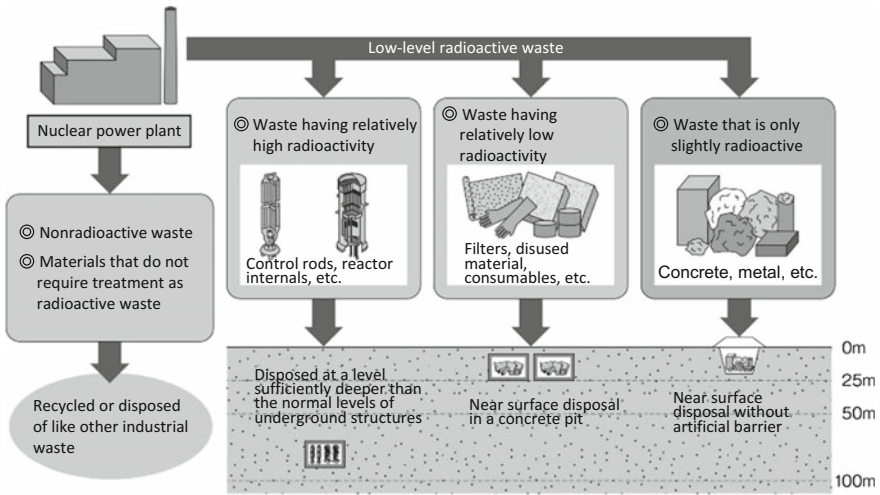


Fig. 10.20 Classification and disposal of waste from the decommissioning of a nuclear power plant

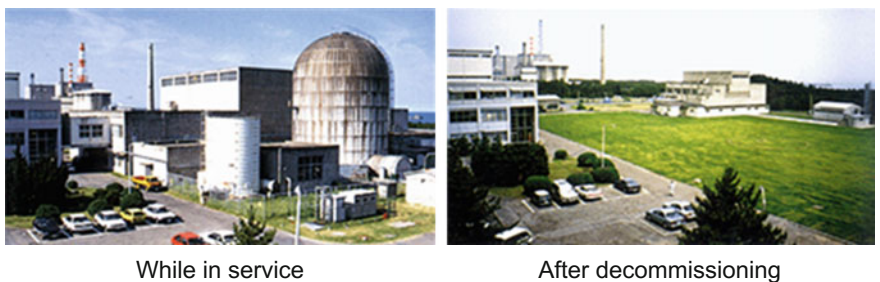


Fig. 10.21 Example of the decommissioning of a nuclear power plant in Japan [6]

Figure 10.21 shows an example of nuclear power decommissioning in Japan. The power demonstration reactor, which is called JPDR (Japan Power Demonstration Reactor) and used to be run by the Japan Atomic Energy Agency (formerly known as Japan Atomic Energy Research Institute), underwent all decommissioning processes, including dismantling, by October 2002.

As of April 2012, out of 138 commercial power reactors outside of Japan that have terminated their operation, 17 units, including Maine Yankee (0.9 GW) and Haddam Neck Nuclear Power Plant (0.6 GW) in the United States, have completed the decommissioning process.

As for the decommissioning of Hamaoka Units 1 and 2 of Chubu Electric Power Company, the first phase of the project, which continued to the end of the 2014 fiscal year, was dedicated to preparations before dismantling. Activities that have been completed or started are the carrying away of the spent fuel, the evaluation and

analysis of contamination, system decontamination, and the dismantling/removal of facilities and components outside the radiation control area. The decommissioning process is scheduled to be completed in the 2036 fiscal year.

References

1. “Graphical Flip-chart of Nuclear & Energy Related Topics 2012”, The Federation of Electric Power Companies of Japan, 2012
2. “*Kagenkyoukai Kouza 22; Hatsudensho no Kensetsu, Shiunntenn to Untenhoshu* (TENPES Lecture 22 Building, Commission, Operation and Maintenance of Power Plants)”, Thermal and Nuclear Power Engineering Society
3. “Graphical Flip-chart of Nuclear & Energy Related Topics 2013”, The Federation of Electric Power Companies of Japan
4. “*Hamaoka Genshiryoku Hatsudensho 2 gouki Koukeinenrekka Gijutsu Hyouka nado Hokokusho* (Evaluation Report of Aging Management of Hamaoka Nuclear Power Plant Unit 2)”, Chubu Electric Power Co., Inc
5. Chubu Electric Power website
6. Japan Atomic Energy Agency website

Further Readings

7. “Code of Quality Assurance for Safety of Nuclear Power Plants (JEAC4111)”, The Japan Electric Association
8. “Rules of Maintenance Management of Nuclear Power Plants (JEAC4209)”, The Japan Electric Association
9. “JSME Codes for Power Generation Facilities; Maintenance Codes”, The Japan Society of Mechanical Engineers