Form10/00

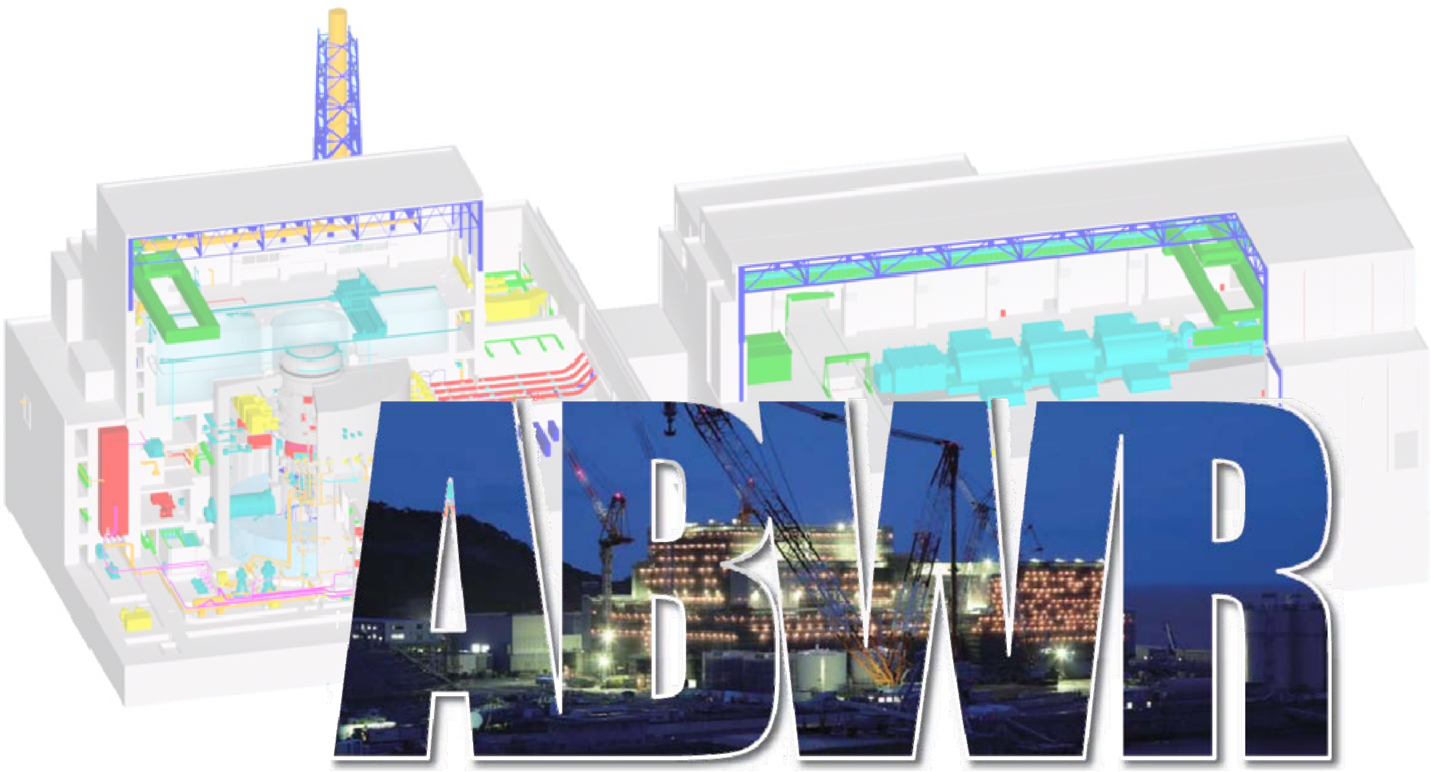
UK ABWR

HITACHI

Document ID	:	GA91-9901-0039-00001
Document Number	:	XE-GD-0150
Revision Number	:	A

UK ABWR Generic Design Assessment

Preliminary Safety Report on Radiation Protection Section 1 Definition of Radioactive Sources



Hitachi-GE Nuclear Energy, Ltd.

DISCLAIMERS

Proprietary Information

This document contains proprietary information of Hitachi-GE Nuclear Energy, Ltd. (Hitachi-GE), its suppliers and subcontractors. This document and the information it contains shall not, in whole or in part, be used for any purpose other than for the Generic Design Assessment (GDA) of Hitachi-GE's UK ABWR. This notice shall be included on any complete or partial reproduction of this document or the information it contains.

Copyright

Table of Contents

Acronyms

Abbreviations and Acronyms Description	Description
ABWR	Advanced Boiling Water Reactor
ALAP	As Low As Practicable
ALARP	As Low As Reasonably Practicable
BWR	Boiling Water Reactor
CD	Condensate Demineralizer
CIV	Combined Intermediate Valve
CP	Corrosion Product
CST	Condensate Storage Tank
CUW	Reactor Water Clean-Up System
CW	Circulating Water System
DF	Decontamination Factor
ES	Extraction Steam System
FDW	Feedwater System
FP	Fission Product
FPC	Fuel Pool Cooling and Cleanup System
HCW	High Conductivity Waste System
HPCF	High Pressure Core Flooder System
HPCP	High Pressure Condensate Pump
HPDP	High Pressure Heater Drain Pump
LCW	Low Conductivity Waste System
LPCP	Low Pressure Condensate Pump
MS	Main Steam System
MSIV	Main Steam Isolation Valve
MSR	Moisture Separator Reheater
MSV	Main Stop Valve
PCV	Primary Containment Vessel
PSA	Probabilistic Safety Analysis
RCIC	Reactor Core Isolation Cooling System
RFP	Reactor Feed Pump
RHR	Residual Heat Removal System
RPV	Reactor Pressure Vessel
SFP	Spent Fuel Pool
SJAE	Steam Jet Air Ejector
SPCU	Suppression Pool Cleanup System
SRV	Safety Relief Valve

1 General Description

During normal operation and outage as well as transport/storage of radioactive/contaminated items, the radiation arises from activity within the systems and components and/or from surface contamination, which leads to measurable dose rate in the surrounding areas. It has to be taken into account for radiation protection purposes.

The radioactive sources, which mean the nuclide inventory composition, vary depending on operational phases or different systems and components. Consequently, radiological impact is also different and so shielding provision needs to be fit for purpose.

The radiological impact of nuclides with a short half-life such as nitrogen-16 (N-16) and nitrogen-17 (N-17), 7 seconds and 4 seconds respectively, becomes totally negligible after a few minutes due to radioactive decay after shutdown and therefore during outages. Their contribution is not negligible during operation and has to be taken into account.

The alpha and beta particles emitted by nuclides such as tritium or carbon-14 has sufficiently low energy hence they can be prevented by the containment structures of piping and equipment etc. As a result, their contributions are negligible for the shielding design.

Systems and components which are connected to the primary circuit and contain or transport primary fluid (reactor water and main steam) are identified as the main radioactive sources in the plant. Also radioactive waste systems and the off-gas system are understood as radioactive sources in this sense.

During the reactor’s operating life, activated materials transported by the primary water have been deposited on the inner surfaces of the piping and equipment in contact with the primary water. This accumulation of contamination, especially corrosion products, is under a continuous process that depends mainly on the physical and chemical conditions of the primary system in the different reactor states.

During outages, cobalt-60 (Co-60) as an activated corrosion product accumulated on inner surfaces delivers the largest contribution to the whole radiation dose.

The radioactive sources are used as a design parameter for UK ABWR shielding provisions and they are conservative compared with operating experiences. Radioactive sources for shielding design do not necessarily include all radionuclides which may be detectable or theoretically predicated to be present. Overall, these radioactive sources can be regarded as included in the shielding design since fundamental radioactive sources of reactor coolant are conservative.

Radioactive source data for boiling water reactors have been incorporated in “Source Term and Radiation Zoning for Shielding Design of BWR” The Federation of Electric Power Companies of Japan [1-1], “Review for Scope of ALAP Provision” Tokyo Electric Power Company Inc., Toshiba Corporation and Hitachi Ltd. [1-2] and “Technical Derivation of BWR 1971 Design Basis Radioactive Material Source Term” NEDO-10871 [1-3]. These guidelines provide bases for estimating typical radioactive concentrations of the principal radionuclides which may be anticipated over the lifetime of a BWR plant.

The radioactive source data are based on the cumulative industry experience at operating BWR plants, including measurements at several stations through the 1970’s. It therefore reflects the influence of a number of observations made during the transition period from operation with fuel of older designs to operation with fuel of current essentially improved designs.

2 Scope

The aim of this section is to define the radioactive source terms in the reactor water and steam which serve as shielding design bases for the gaseous, liquid and solid radioactive waste management systems during normal operation and outage including maintenance as well as transport and storage of radioactive and/or contaminated items including spent fuel.

For the shielding design, the radioactive sources during each operating condition are divided into three scopes shown in Figure 2-1. The emissions of gamma rays and neutrons are considered because these are much more relevant for external radiation than alpha or beta particles.

During normal operation, this includes start-up conditions, steady-state and shutdown conditions. The radioactive source terms and radiation dose vary depending on operational phases such as the above.

During start-up and shutdown conditions, an activity spike occurs, which is a phenomenon to fluctuate radioactive concentration transiently. However, it is not considered for shielding design because it is identified as a temporary fluctuation and it can be mitigated by the operational control, which is discussed in a field of reactor water chemistry. Therefore, it is defined that normal operation can be represented as steady-state for the shielding design.

For reactor water and reactor, turbine and radioactive waste management system, fission products, activation products including corrosion products are considered. In addition, for reactor core, neutron and gamma ray by nuclear fission, fission products are considered. The radioactive sources are defined conservatively in the shielding design. The radioactive sources during normal operation are discussed in sub-section 3.1.

During outage, the radioactive sources consist of activation products including corrosion products. However, activation products, N-16 and N-17, are nuclides with a short radioactive half-life. These nuclides become totally negligible after a few minutes. As a result, the radioactive sources during outage consist of only corrosion products, which are discussed in sub-section 3.2.

During transport and storage of radioactive and/or contaminated items, the radioactive sources of the spent fuel assembly consist of fission products, actinides and activation products which originate in reaction of the neutrons and the structure materials of the fuel. Also the radioactive sources of the other radioactive and/or contaminated items consist of activation products such as the control rods and corrosion products from the reactor water. These are described in sub-section 3.3.

The radioactive sources during accident and fault conditions are discussed in a field of fault studies / PSA assessment. In addition, the radioactive sources under decommissioning are discussed in a field of decommissioning.

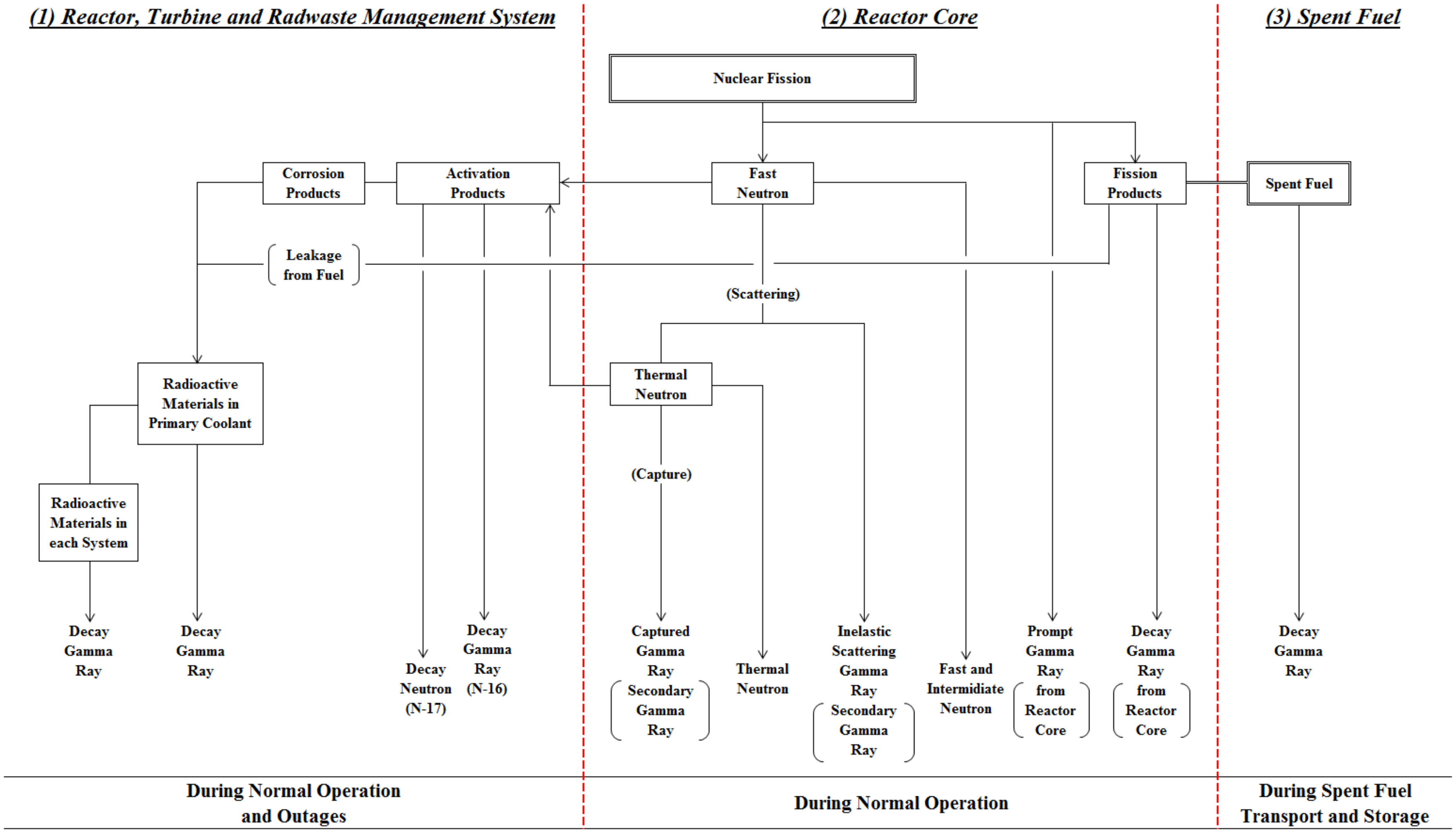


Figure 2-1 Emission Process of Neutrons and Gamma Rays

3 Radioactive Sources

3.1 Radioactive Sources during Normal Operation

In this sub-section, three scopes regarding radioactive sources during normal operation are discussed below.

(1) Reactor Water
(2) Reactor, Turbine and Radioactive Waste Managemet System
(3) Reactor Core

3.1.1 Reactor Water

(1) Primary Radioactive Sources

The primary radioactive sources in reactor water consist of fission products based on noble gas release rate, activation products and corrosion products.

(a) Fission Products based on Noble Gas Release Rate

The noble gas release rate for shielding design basis is selected 3.7×10^{9} Bq/s as evaluated at 30-minute decay, which has historically been used for the design in BWR plants.

Operation at higher release rates can be tolerated for reasonable periods of time with respect to shielding considerations. Consequently, continued application of the same design basis of 3.7×10^{9} Bq/s provides increased safety margin relative to expected release rates.

The radioactive concentration of fission products in reactor water is 5.8×10^{4} Bq/g calculated based on noble gas release rate by using the method described in NEDO-10871 [1-3].

(b) Activation Products (N-16 and N-17)

The most important activation products are N-16 and N-17. However, the dose contribution of N-17 is sufficiently small compared with N-16. Consequently the consideration of N-17 is negligible and so only N-16 is considered for the shielding design.

N-16, which is produced by an (n,p) reaction with oxygen-16 (O-16), is the primary radioactive source in the equipment containing reactor coolant and main steam under operation in BWRs.

The radiological impact of radionuclides with a short radioactive half-life such as N-16 becomes totally negligible after a few minutes simply due to radioactive decay in outages. However, it has an impact during normal operation. Therefore the influence of N-16 decay with the transport time to arrive at respective equipment from the reactor is considered in the shielding design.

The radioactive concentration of N-16 in reactor coolant leaving the reactor vessel is 1.8×10^{6} Bq/g calculated by reactor thermal power, flow-rate, decay time and so on.

In addition, the radioactive concentration of N-16 in main steam leaving the reactor vessel calculated by a similar approach as that in reactor coolant leaving the reactor vessel was used. However, it was reconsidered in comparison to measured data of BWRs.

As a result, the radioactive concentration of N-16 in main steam is **[ ]*** Bq/g based on operating experiences.

(c) Corrosion Products

The corrosion products are defined considering maximum values for each nuclides based on operating experience.

The radioactive concentration of corrosion products is **[ ]*** Bq/g, which is determined based on operating experiences of the radioactive concentration in the reactor water in Japanese BWRs [1-2].

*: This information is removed intentionally.

(2) Reactor Water Chemistry

The radioactive sources in reactor water vary depending on operational phases in reality, which means that radioactive sources have relationship to reactor water chemistry.

However, the control of reactor water chemistry does not have much influence on the radioactive sources during normal operation because one of the main scopes of water chemistry control is to minimise the contribution of corrosion products, which is a primary radioactive source during outages. This is discussed in sub-section 3.2 in detail.

This means that radioactive sources during normal operation depend heavily on fission products based on the conservative noble gas release rate. As a result, the fluctuation of the radioactive concentrations for corrosion products, including Co-60 which is a major radioactive source of occupational exposure, is covered in the shielding design.

The detailed methods of reactor water chemistry control are described in a field of reactor water chemistry.

3.1.2 Reactor, Turbine and Radioactive Waste Managemet System

< Reactor Building >

The primary radioactive sources of main systems in the reactor building for shielding design are shown in Figure 3.1.2-1. The considerations for each of these systems are described as follows:

(1) Main Steam System (MS)
The primary radioactive source is N-16. The transport time to arrive at respective equipment from the outlet nozzle of the Reactor Pressure Vessel (RPV) is considered when calculating radioactive concentration in this system.

(2) Reactor Water Clean-Up System (CUW)

(a) As far as inlet of CUW Filter Demineraliser
The primary radioactive sources are fission products and N-16 at the piping and the CUW heat exchangers. For N-16, transport time to arrive at these equipments from the outlet nozzle of the Reactor Pressure Vessel (RPV) is considered.

(b) CUW Filter Demineraliser
Accumulation just before backwash is considered and Decontamination Factor (DF) of the CUW filter demineraliser to reduce radioactivity is considered.

(c) Outlet of CUW Filter Demineraliser
The primary radioactive sources are fission products passing through the CUW filter demineraliser and noble gas emitted by decay of halogens accumulated in the CUW filter demineraliser.

(3) Residual Heat Removal System (RHR) [Shutdown Cooling Mode]
The mode that radioactive concentration is the highest of all modes in this system (Shutdown Cooling Mode) is considered.

(4) Reactor Core Isolation Cooling System (RCIC)
The primary radioactive source is N-16 since main steam is used as the steam to drive the RCIC turbine. The decay time is considered when calculating the radioactive concentration of steam in the RCIC turbine.

(5) Fuel Pool Cooling and Cleanup System (FPC)
The radioactive concentrations of piping and the heat exchangers of the FPC are based on the operating experience of BWR plants because the dose contribution by accumulation would be larger than expected in this area.

Decontamination Factor (DF) is considered when calculating the radioactive concentration of the FPC demineraliser to reduce radioactivity.

(6) Suppression Pool Cleanup System (SPCU) and High Pressure Core Flooder System (HPCF)
The radioactive concentration in the suppression pool described in (9) is used for these systems related to the suppression pool.

(7) Spent Fuel Pool (SFP)
The concentration of radioactivity in the SFP consists of reactor water, suppression pool and Condensate Storage Tank (CST) water is based on the following assumptions:

(a) The specific radioactivity in the SFP is based on the radioactive concentration of reactor water after 4 days from reactor-shutdown and CUW system shutdown because it takes about 4 days to start injection of water into the reactor well and the SFP after Reactor Pressure Vessel (RPV) head off.

(b) In addition, attenuation effect of dilution in the SFP is considered because suppression pool and CST water is flowed into the SFP.

(8) Spent Fuel
The radioactive sources of spent fuel considered are fission products, activation products and actinides.

(a) Spent Fuel Transport

For spent fuel transport, the considerations below for the shielding design are assumed.

- Irradiation time of fuel is 10^6 hours, which is selected as time leading to saturated source strength.
- Decay time of fuel is 5 days, because injection of reactor water, suppression pool water and CST water into the SFP is expected to be completed after 5 days from shutdown. Subsequently, spent fuel is transported to the SFP from the reactor core.

(b) Spent Fuel Storage

For spent fuel storage, the considerations below for the shielding design are assumed.

- Irradiation time of fuel is 10^6 hours, similar to consideration of spent fuel transport.
- Decay time of fuel is 20 days, because refueling is expected to be completed and SFP gate is expected to be closed after 20 days from shutdown.

Source strength of fuel assembly per generating power is based on “REACTOR HANDBOOK, Second Edition, Vol.III Part.B, SHIELDING” [3.1.2-1].

(9) Suppression Pool
The suppression pool is used for the injection to the reactor well, dryer/separator pit or spent fuel pool depending on plant systems and operation.

Therefore the radioactive concentration in the suppression pool is based on operating experience because the properties of the suppression pool water would be different for each operational phase and so it is difficult to assume the radioactive concentration in the suppression pool.

(10) Drywell
The radioactive concentration in the drywell is based on operating experience because the radioactive concentration would be different for each operational phase and so it is difficult to assume the radioactive concentration in the drywell.

This information is removed intentionally.

Figure 3.1.2-1 Primary radionuclides in Reactor Building for the shielding design

< Turbine Building >

The primary radioactive sources for main systems in the turbine building for shielding design are shown in Figure 3.1.2-2. The considerations for each of these systems are described as follows:

(1) Main Steam System (MS)
The primary radioactive source is the same as the MS System in < Reactor Building > (1) MS.

(2) Extraction Steam System (ES)
The primary radioactive source is N-16. The radioactive concentrations in the piping are assumed at their inlets.

(3) Circulating Water System (CW) and Feedwater System (FDW)

(a) As far as inlet of Condensate Filter and Demineraliser
The primary radioactive sources are fission products transferred to the turbine from reactor water with main steam and the daughter nuclides produced by the radioactive decay of noble gas.

(b) Condensate Filter and Demineraliser
Accumulation just before backwash or resin disposal is considered and the Decontamination Factor (DF) of the condensate filter and demineraliser to reduce the radioactivity are considered.

(c) From outlet of Condensate Demineraliser
The primary radioactive sources are fission products passing through the condensate demineraliser and noble gas produced by radioactive decay of halogens accumulated in the condensate demineraliser.

This information is removed intentionally.

Figure 3.1.2-2 Primary radionuclides in Turbine Building for the shielding design

< Liquid Radioactive Waste Management System >

The primary radioactive sources in the liquid radioactive waste management system for shielding design are mainly fission products and corrosion products. The radioactive concentration in this system is calculated under the following considerations:

(a) The nuclides in this system are based on those in the reactor water.

(b) The decay time in piping and equipment which does not have the function to accumulate activity is not considered.

(c) When there are more than 2 inlets, mixture is considered.

(d) When there are more than 2 inlets but no mixture, the system which has the highest radioactive concentration is considered.

(e) Decontamination Factor (DF) of filter, demineraliser and evaporator such as the Low Conductivity Waste System (LCW) filter and demineraliser, the High Conductivity Waste System (HCW) demineraliser and evaporator to reduce radioactivity are considered.

< Off-Gas Radioactive Waste Managemet System >

The primary radioactive sources for off-gas radioactive waste management system for shielding design are shown in Figure 3.1.2-3. The radioactive concentration in this system is calculated under the following considerations:

(a) The radioactive sources in this system are N-16 and noble gas from condenser and N-16 included in the Steam Jet Air Ejector (SJAE).

(b) For N-16 radioactive concentration of respective equipment, the transport time to arrive at these equipments from the outlet of the Reactor Pressure Vessel (RPV) is considered.

(c) Pressure and temperature of respective equipment are considered when calculating the radioactive concentration of off gas up to the off-gas condenser.

(d) The period to hold up xenon (Xe), 30 days, and krypton (Kr), 40 hours, in the off-gas hold-up system is considered to maximize the accumulation.

(e) The daughter and granddaughter nuclides produced by radioactive decay of noble gas in respective equipment are considered from the outlet of the off-gas condenser up to the off-gas hold-up system (charcoal adsorber).

< Solid Radioactive Waste Management System >

The primary radioactive sources for the solid radioactive waste management system for shielding design are mainly fission products and corrosion products. The radioactive concentration in this system is calculated under the following considerations:

(a) The nuclide composition in this system is based on that in the reactor water.

(b) The decay time of storage in tank and pool is considered.

(c) The radioactive concentration of decant water in the waste sludge storage tank and spent resin tank is assumed from the amount of radioactivity flowing in. These ratios are based on the measured data.

This information is removed intentionally.

Figure 3.1.2-3 Primary radionuclides in Off Gas System for shielding design

3.1.3 Reactor Core

The primary radioactive sources around the reactor core for shielding design are:

- Neutrons and gamma rays emitted by the fission in the reactor core
- Gamma rays emitted by the reaction between neutrons and the components in and out of the reactor core
- Gamma rays emitted by fission products

The emission process of these neutrons and gamma rays are shown in Figure 2-1.

(1) Neutrons

The neutron source strengths of fission per unit volume of reactor core are shown in the following:

$$S_{vi} = \frac{\nu \cdot N_f \cdot P}{\pi \cdot R^2 \cdot H} \cdot x_i$$

where S_{vi} is the source strength of fission neutron for energy group i per unit volume of reactor core ($cm^{-3} \cdot s^{-1}$), ν is the average number of emissions of neutrons per nuclear fission ($fission^{-1}$), N_f is the amount of nuclear fission per watt and second ($fission \cdot W^{-1} \cdot s^{-1}$), P is core thermal power (W), R is core effective radius (cm), H is core effective height (cm), x_i is fission neutron spectra of energy group i for U-235.

(2) Gamma Rays

(a) Fission Product Gamma Rays
The source strength of the gamma rays emitted by decay of fission products is based on “REACTOR PHYSICS CONSTANTS” ANL-5800 Second Edition, Argonne National Laboratory [3.1.3-1].

(b) Other Gamma Rays
Capture gamma rays, inelastic scattering gamma rays and prompt gamma rays are evaluated in the process of transport calculation since these emission probabilities are incorporated in the appropriate cross section data in transport calculation code.

3.2 Radioactive Sources during Outage

During outages, the primary radioactive source is corrosion products attached to the internal surface of equipment or piping in the primary coolant and adjacent systems, especially Co-60. The radiation dose of Co-60 is dominant in the plant during outage, which accounts for the majority of the whole radiation dose according to operating experience in BWRs in Japan and overseas.

The radioactive sources during outages are related to the reactor water chemistry which is discussed in a field of reactor water chemistry in detail.

3.3 Radioactive Sources during Transport and Storage of Radioactive and/or Contaminated Items

From the aspect of transport and storage into the interim storage facility outside the reactor building or the radwaste building, the spent fuel and the other radioactive and/or contaminated items are considered as radioactive sources.

The radioactive sources of the spent fuel consist of fission products and activation products and actinides. In addition, the radioactive sources of the other radioactive and/or contaminated items consist of activation products including corrosion products.

4 References

[1-1] Source Term and Radiation Zoning for Shielding Design of BWR, The Federation of Electric Power Companies of Japan

[1-2] Review for Scope of ALAP Provision, Tokyo Electirc Power Company Inc., Toshiba Corporation and Hitachi Ltd.

[1-3] Technical Derivation of BWR 1971 Design Basis Radioactive Material Source Term, NEDO-10871

[3.1.2-1] REACTOR HANDBOOK, Second edition, Vol.III Part.B, SHIELDING, E.P.Blizard and L.S.Abbott ed, New York, London

[3.1.3-1] REACTOR PHYSICS CONSTANTS, ANL-5800 Second Edition, Argonne National Laboratory