2. Measurement and Evaluation of Radioactive Corrosion Product Behaviour in Primary Sodium Circuits of JOYO

K. ITO, K. IIZAWA, K. TAKAHASHI*
M. A. ZULQUARNAIN**, S. SUZUKI and K. KINJO

O-arai Engineering Center
Power Reactor and Nuclear Fuel Development Corporation
4002 Narita, Oarai-machi, Ibaraki-ken, 311-13 JAPAN

ABSTRACT

In the experimental fast reactor JOYO, the radioactive corrosion product (CP) measurement has been conducted in the primary sodium circuits during each annual inspection. The measured data has been analyzed by the computer code "PSYCHE", which has been developed by PNC. Main results obtained from the measurements and/or calculations are as follows;

(1) The dominant CP nuclide is ^{54}Mn followed by ^{60}Co and ^{58}Co.

(2) Average surface gamma dose rate around the primary piping system at the 8th annual inspection is 0.96 mSv/h. The increasing rate of this value is 0.25 (mSv/h)/EFPY.

(3) The calculated deposition densities of ^{54}Mn and ^{60}Co agree with measured ones within a factor of 0.7 ~ 1.7.

INTRODUCTION

Radiation exposure of plant personnel during maintenance and repair works in an LMFBR plant mostly comes from the radionuclides of the radioactive corrosion product(CP) deposited on the inner surfaces of primary piping and components after sodium drain. Radioactive CPs are produced, transported and deposited in the primary sodium components and piping of an LMFBR plant as shown schematically in Fig.1. These radionuclides are produced in a fast reactor core mostly by (n,G) and (n,p) reactions on the constituent elements and impurities present in the stainless steel of fuel cladding, wrapper tube and other supporting structure of the core. These CP radionuclides are released into the circulating sodium either by bulk corrosion (i.e., surface loss) of the activated core materials or by diffusion of the radionuclides from the interior of steel. The released CP radionuclides are transported by the sodium coolant and then deposited on walls of primary piping, components and also the core subassemblies.

Therefore, dose rate from the radioactive CP deposited in the primary sodium circuits of JOYO has been measured. The computer code PSYCHE(2) developed

*On leave from Energy Research Laboratory, Hitachi,LTD.
**On leave from Reactor Operation and Maintenance Unit of Bangladesh Atomic Energy Commission

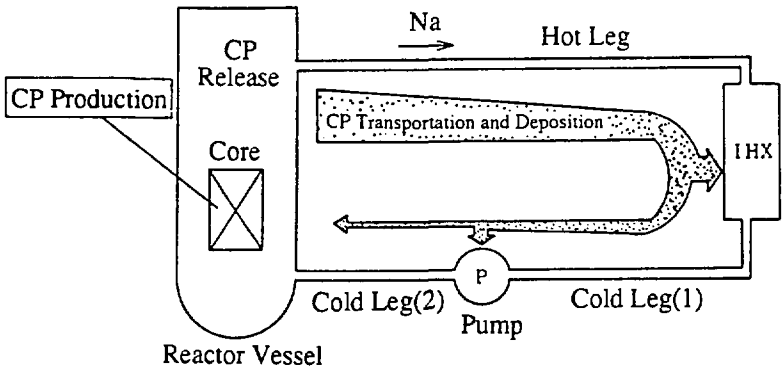


Fig.1 Schematic Diagram of CP Production, Transport and Deposition in an LMFBR Primary System

by PNC to evaluate CP behaviour in an LMFBR is validated with these measurement data.

Measurements were conducted by using both a pure germanium detector and calcium sulfate ($CaSO_4$(Tm)) thermo-luminescence dosimeters (TLDs) for CP deposition and surface dose rate in the primary sodium piping and components, after the sodium had been drained from the primary piping and components into the dump tank, except the reactor vessel.

This report presents the CP measurement and evaluation in the primary cooling system of JOYO.

DESCRIPTION OF JOYO

JOYO is a liquid sodium-cooled fast reactor of loop type with the power output of 100 MWt. JOYO achieved the first criticality in April, 1977. From the first criticality through the 23rd duty cycle, the accumulated reactor output reached 150 GWd.

JOYO consists of primary and secondary systems. Each system has two main cooling

Table 1 Specifications of Pure Ge Solid State Detector (SSD)

Item	Specifications
Detector Type	Coaxial Type of Pure Ge
Energy Resolution	1.75keV FWHM at 1332 keV of ^{60}Co G-ray
Photo peack to Compton Ratio	Peack/Compton=47.8
Detection Efficiency	13.7%

Table 2 Specifications of Themoluminescence Dosimeter (TLD)

Item	Specifications
TLD Type	UD-200S; $CaSO_4$(Tm)
Energy Response	±40% (> 30 keV)
Useful Range	0.1mR ~ 20 R

Table 3 Average Values of Deposition Densities within Different Regions (μCi/cm²)

	Hot Leg	Cold Leg(1)	Cold Leg(2)
^{54}Mn	0.89	2.18	4.46
^{60}Co	0.24	0.08	0.17
^{58}Co	0.07	0.04	0.06

Hot Leg : from the outlet of the reactor vessel to the inlet of IHX
Cold Leg(1) : from the outlet of IHX to the inlet of main pump
Cold Leg(2) : from the outlet of the main pump to the inlet of the reactor vessel

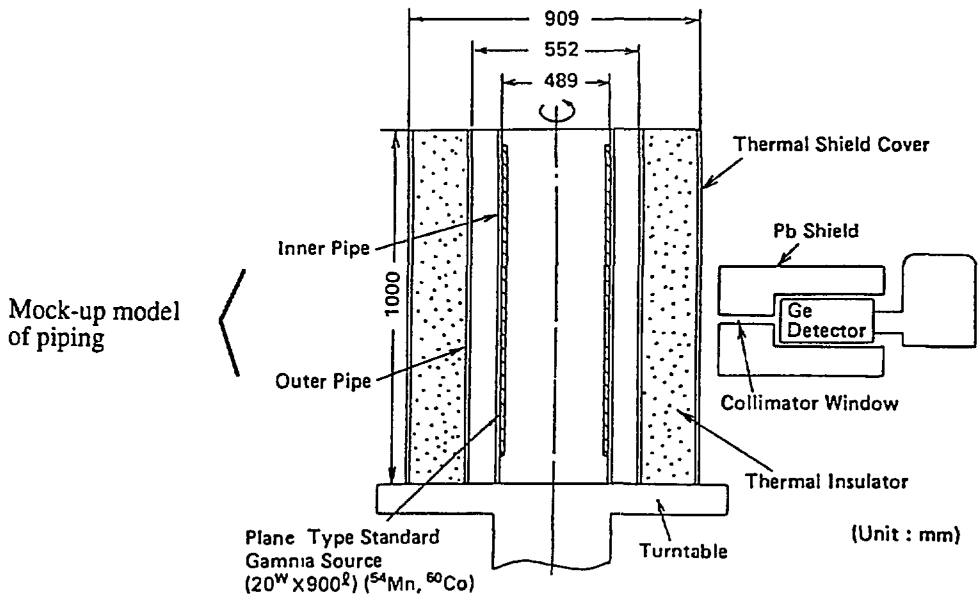


Fig.2 Calibration Arrangement for Ge-SSD System

loops (A and B), and one loop for auxiliary cooling of core and sodium purification with cold trap, respectively. The secondary sodium coolant is separated from the highly activated primary sodium coolant via intermediate heat exchangers (IHXs). Components in each main primary circuit are an IHX, a main pump, piping, the reactor tank itself and so on. Here the primary sodium enters the reactor vessel at temperature of 370 ^{0}C and flow rate of 1260 m^3/h/loop and comes out at 500 ^{0}C through the double-tubed piping. In order to facilitate the identification of different regions of primary piping, they have been designated as follows; Hot Leg is located from the outlet of the reactor vessel to the inlet of IHX, Cold Leg(1) from the outlet of IHX to the inlet of the primary pump and Cold Leg(2) from the outlet of the primary pump to the inlet of the reactor vessel. These piping designations are used to identify piping regions in this report. The sodium temperatures are 500 ^{0}C, 370 ^{0}C and 370 ^{0}C for Hot Leg, Cold Leg(1) and Cold Leg(2) regions, respectively. The sodium velocities are 1.9m/s, 2.3m/s and 4.8m/s along nominal inner diameter of piping of 20^B, 18^B and 12^B for Hot Leg, Cold Leg(1) and Cold Leg(2) regions, respectively.

MEASUREMENT METHODS

To ascertain the radioactive CP behaviour in JOYO two types of measurements have been made; gamma-ray spectroscopy from deposited CP radionuclides and the resulting dose rate measurement. Some additional measurements were made to calibrate TLDs and determine the effective decay constants for dose rate at some measurement points.

(1) Measurement of CP deposition density

Gamma spectra were measured at 16 locations to identify the deposited CP radionuclides and their deposition densities at the inner surfaces of the piping. A pure Ge solid state detector (SSD) system and a suitable collimator assembly were used for this spectrum measurement. Table 1 indicates the specifications of the detector.

The CPS(counts per second) reading at each measurement point was converted into corresponding deposition density ($\mu Ci/cm^2$). The conversion factors ($\mu Ci/cm^2/CPS$) were determined earlier by the piping mock-up arrangements with plane type standard sources of ^{54}Mn and ^{60}Co in a way as shown in Fig.2 (1).

(2) Measurement of surface gamma dose rate

For determination of spatial dose rate distributions along the main primary piping, 93 locations have been marked and numbered in each loop at one meter intervals. At each location four TLDs were placed around the thermal insulator cover of the piping at 90 deg. intervals. TLDs were also placed around the IHXs, main primary pumps and over flow columns at different points in heights and angles in order to determine the gar ..a dose rate distribution at the surfaces of these components. The specifications of the TLD used in this measurement are given in Table 2. The effective decay constants of radioactive CP deposits were evaluated from two measurements of dose rates with time intervals.

RESULTS AND DISCUSSION

Results obtained from the measurement of radioactive CP deposit and gamma dose rate distribution during the 8th annual inspection are as follows;

(1) Deposition densities of CP radionuclides

In Fig.3 deposition densities of the CP radionuclides for Loop-A have been plotted v.s. distances along the piping measured from the outlet of the reactor vessel. From this figure it can be seen that ^{54}Mn is the most dominant CP radionuclide followed by ^{60}Co and ^{58}Co.

The average values for the deposition densities of these CP radionuclides within different regions of the primary circuit piping are given in Table 3. It may be shown from the above result that about 75% of the total accumulation of CPs in the Hot Leg region is rated for ^{54}Mn, 19% for ^{60}Co and the rest 6% for ^{58}Co. In the Cold Leg(1) region these percentages for ^{54}Mn, ^{60}Co and ^{58}Co depositions are rated about 95%, 3% and 2% and in the Cold Leg(2) region about 95%, 4% and 1%, respectively. From this table it can be seen that ^{54}Mn was found to be transferred and deposited dominantly in the Cold Leg regions, particularly in the Cold Leg(2). On the other hand, ^{60}Co and ^{58}Co are transferred and deposited dominantly in the Hot Leg region and also in the Cold Leg(2). It can be seen that these enhancements of CP deposition rates in the Cold Leg(2) are resulted from the sodium flow rate within its region being about two times as large as that within the Cold Leg(1). Deposition rates of CPs are enhanced as increasing sodium flow rate in the main piping.

(2) Gamma dose rate distributions along the main primary piping

In Fig.4 gamma dose rate distributions along the main primary sodium piping have been plotted v.s. distances measured from the outlet of the reactor vessel. This figure shows that the dose rate distribution patterns have that the patterns obtained from the previous measurements, except with some little deviations. In these distributions the peaks at the inlet and the outlet of the reactor vessel come from streaming gamma-rays from the core. Those around the piping near components come from radioactive CP deposits in the components of correspondence. The surface gamma dose rate averaged over the cold and the hot

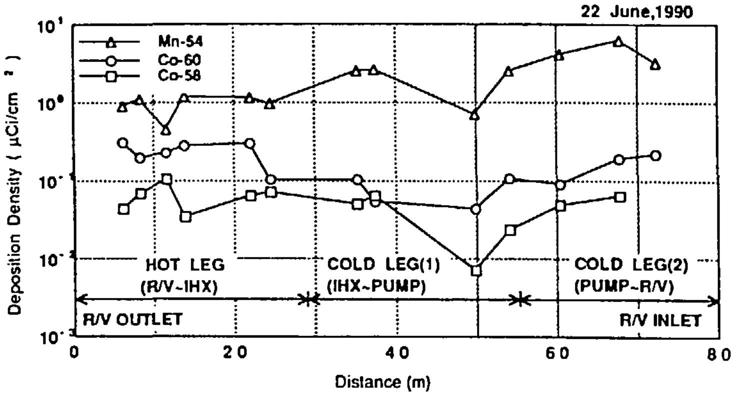


Fig. 3 Deposition of Corrosion Products Along the Main Primary Piping (Loop-A) Just after Reactor Shutdown of MK-II 20th Duty cycle operation (Cumulative Reactor Output: 131GWd)

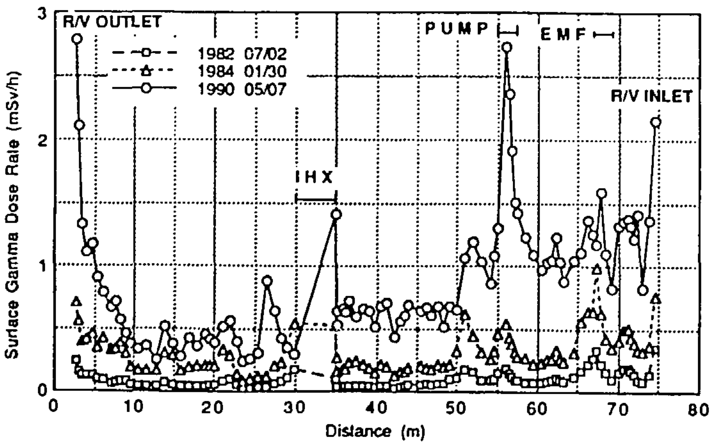


Fig. 4 Surface Gamma Dose Rate Distribution along Main Primary Piping (Loop-A) during Annual Inspections

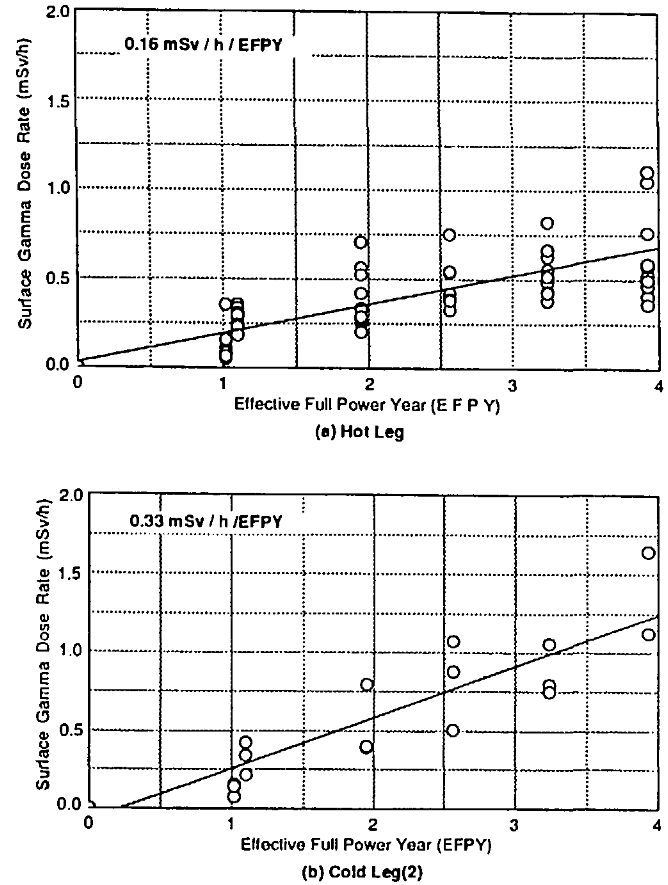


Fig.5 Increasing Rate of Surface Dose Rate at Main Primary Piping (Loop A and B Combined) with EFPY

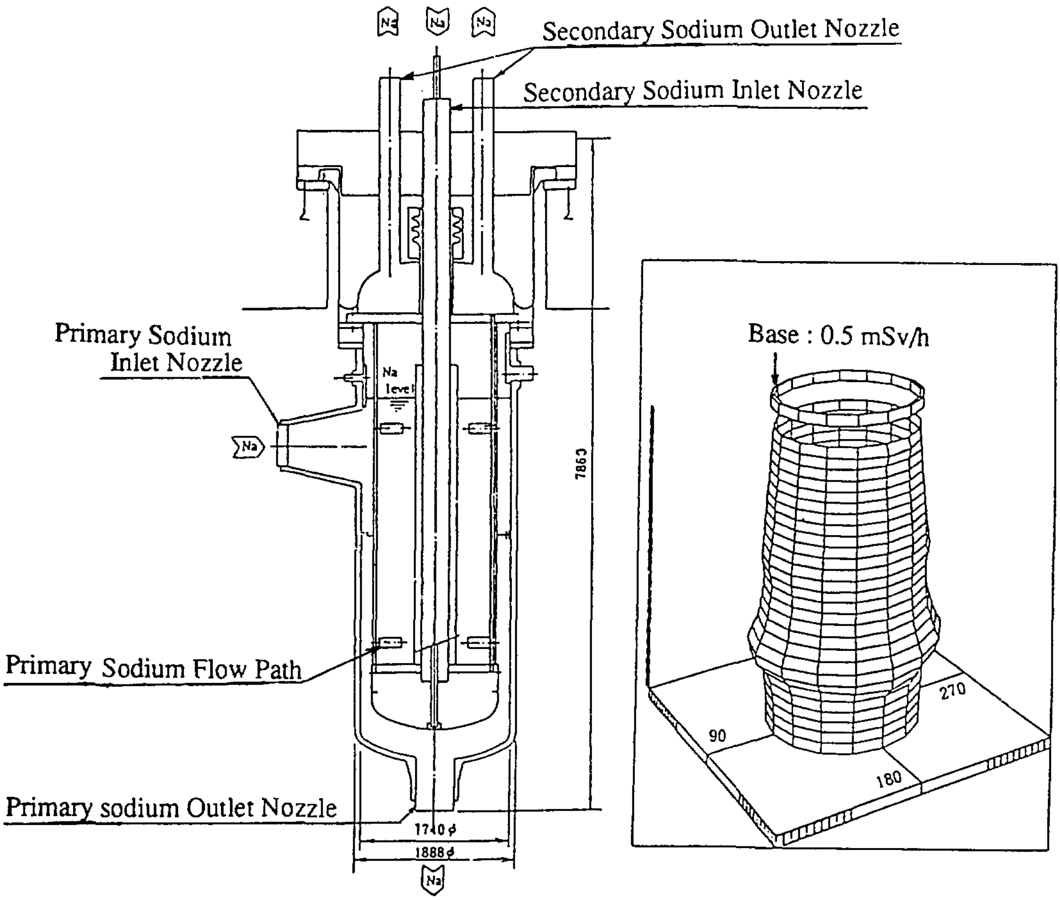


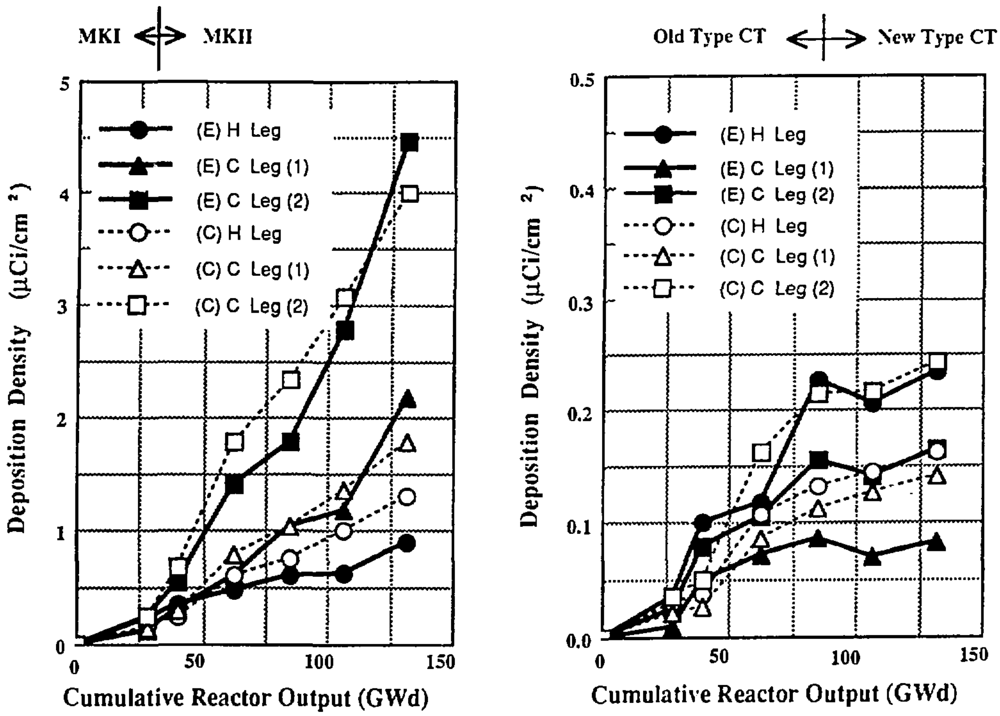
Fig.6 Surface Gamma Dose Rate Distribution around IHX(A)

legs of the primary cooling loops of A and B are 1.1 and 0.73 mSv/h, respectively, while that over the entire length (combined all cold and hot legs of both the loops) is 0.96 mSv/h.

The increasing rates of the averaged surface gamma dose rates for different regions of main primary piping, Hot Leg and Cold Leg(2), are shown in Fig.5 as a function of effective full power years (EFPY). Applying the least square curve fitting technique, increasing rates of dose rates per EFPY are obtained. These values are 0.16 (mSv/h)/EFPY and 0.33 (mSv/h)/EFPY for Hot Leg and Cold Leg, respectively. It means that the rate of build-up of gamma dose rate within the Cold Leg region is about twice as much as that within the Hot Leg region. These dose rates distribution and build-up are corresponding to ^{54}Mn deposition behaviour.

(3) Gamma dose rate distribution at the surfaces of primary components

The surface dose rate distribution around components during the 8th annual inspection has been measured. Figure 6 shows the dose rate distribution for IHX-A. From this figure it can be seen that maximum dose rate is found near the flow path of exit. This distribution is compared with the previous and found to be of similar nature.



(a) Deposition Density of Mn-54 (b) Deposition Density of Co-60

Fig.7 Comparison of Measured (E) and Calculated (C) Values of CP Buildup in Main Primary Loop Piping (A)

(4) Comparison of measured and calculated values of CP radionuclides behaviour

Deposition densities of ^{54}Mn and ^{60}Co measured within different piping regions of Loop-A are compared with the calculational results, using PSYCHE, which predicts build-up and distributions of CP radionuclides, and associated gamma dose rate distribution in LMFBR primary circuits. The calculated value (C) for deposition density of ^{54}Mn was found to agree very well with the measured value(E) for Cold Leg(2) of the piping. Here the C/E ratio is 0.9. For Cold Leg(1) this ratio is 0.8, while for Hot Leg it is 1.5. For ^{60}Co the C/E ratio is 0.7 for Hot Leg, while for Cold Leg(1) and Cold Leg(2) these are 1.7 and 1.6, respec

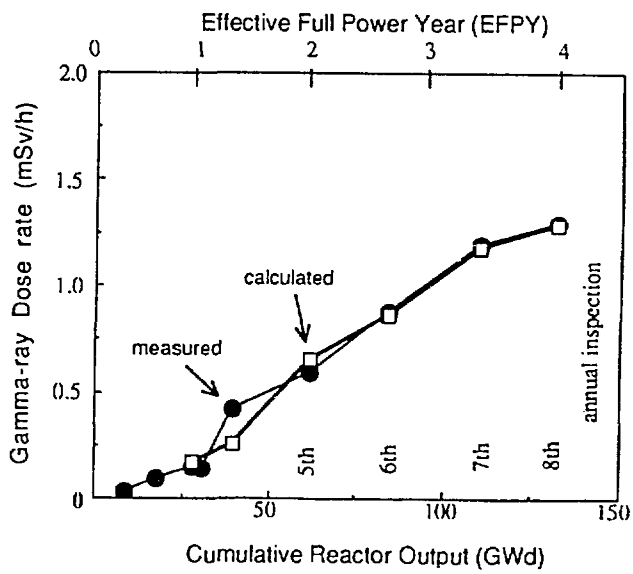


Fig.8 Comparison of Measured (E) and Calculated (C) Values of Surface Gamma-ray Dose Rate Build-up within Cold Leg(2) During Annual Inspections

tively. The above results show graphically in Fig.7.

In Fig.8 the calculated result for the surface gamma dose rate at the Cold Leg(2) of Loop-A is also compared with the corresponding measured result. The C/E ratio is 1.1.

CONCLUSION

· The dominant CP radionuclide is ^{54}Mn followed by ^{60}Co and ^{58}Co. ^{54}Mn deposits mostly in the Cold Leg region, particularly in the Cold Leg(2) region. On the other hand, ^{60}Co and ^{58}Co deposit preferentially in the Hot Leg region and Cold Leg(2) region. These CP deposition rates are enhanced by increasing the sodium flow rate.

· The surface gamma dose rates averaged over the primary loops are 1.1 mSv/h for the Cold Leg region and 0.73 mSv/h for the Hot Leg region , while that over the entire length (all cold and hot legs of both the loops combined) is 0.96 mSv/h.

The increasing rate of surface gamma dose rate for Cold Leg region is 0.33 (mSv/h)/EFPY. The rate of build-up of gamma dose rate in the Cold Leg region is about twice as high as that in the Hot Leg region.

The surface gamma dose rate distribution in IHX-A shows the maximum value near the flow path of exit and its patterns follows the previous measurement works.

· The calculated deposition densities agree with measured ones within a factor of 0.8 ~ 1.5 for ^{54}Mn and with in a factor of 0.7 ~ 1.7 for ^{60}Co. On the other hand, the calculated surface gamma dose rate at the primary piping agrees with measured one within a factor of 1.1.

REFERENCES

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