Master's Thesis

Worker Exposure Dose Evaluation of the Steam Generator Decommissioning Process in the Kori-1

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ABSTRACT

On the 19th of June 2017, the first domestic commercial reactor Kori-1 in Korea was shut down after 40 years of operation since April 1978. Nuclear decommissioning of the Kori-1 will proceed for at least 15 years in the future, and according to the current plan proposed, fuel cooling will be performed during 2018~2022, decontamination and dismantling of reactor will be performed during 2022~2028, and site restoration will be done by 2032. The Kori-1 reactor is largely composed of a primary system and a secondary system. The primary system is composed of a nuclear reactor which operates fission reactions, a steam generator which delivers generated heat from the nuclear reactor to the coolant, a pressurizer, and a coolant pump. The secondary system is composed of a turbine, a generator, a condenser, and a feed water pump. Among the diverse devices and parts, the steam generator was selected for research. The reasons as to why are listed as follows:

1) It is a huge structure with a height of about 20 m, a top diameter of 6m and weighing about 700 tons.

2) It is a large metal waste, which changes in value depending on its dismantling and decontamination methods.

3) There is a relatively low level of radioactivity compared to reactors, which makes it possible for workers to work directly.

4) It is difficult to secure the data, the situation, and the environment since the contents such as the arrangements and specifications of the equipment inside the nuclear power plant are confidential. However, in 1998, the steam generator of the Kori Unit 1 was replaced, and further research, calculation, and evaluation could be conducted. Considering these four points in a comprehensive manner, the steam generator in the first line of Kori Unit 1 was selected as the main analysis and evaluation subject.

Necessary information such as the radioactive nuclides and nuclide radioactivity contamination level to calculate exposure dose of worker, was secured with reference to the ‘surface radiation dose rate evaluation of steam generator in Kori-1 for replacement’. Another necessary information to calculate the external and internal exposure dose, working hours and working distance between contamination object and worker, was secured from a steam generator replacement plan and steam generator replacement operation licensing documents and from the real decommissioning operation, proceeding in the V1 reactor in Slovakia. Based on these materials, I postulated the working hours and working distance for each working process. The Kori-1 steam generator nuclear decommissioning work is largely divided into 3 parts, which includes decomposition, cutting, and decontamination of the fixed steam generator. External and

internal exposure dose of workers about each virtual operation was calculated, and in the case of external exposure, VISIPLAN produced by SCK·CEN in Belgium was used, and in the program, the geometry of the steam generator was described and needed information such as the 13 nuclides' radioactivity and worker's working time and distance for every operation was included.

Using a simulation function in VISIPLAN, the external exposure dose result was calculated for each work operation. Internal exposure dose was calculated by using information like the internal exposure dose calculation formula for cases of inhalation and ingestion, provided by the IAEA safety guide. Radioactivity level change of nuclide in cutting or decontamination process was also reflected in exposure dose calculation. For the cutting operation, consideration to additional exposure by inner tube contamination was set with reference in radioactivity measurement of collected tube sample in steam generator of Dampierre 1 reactor in 1992, France. Applying the same ratio radioactivity contamination and assuming tube inner contamination level, worker exposure dose calculation was conducted for the cutting operation. For the decontamination operation, using the decontamination factor by each decontamination technologies and process, and radionuclide partitioning factors, the radioactivity level was postulated per radionuclides.

Through these processes, the expected kori-1 steam generator decomposition, cutting, and the decontamination operation was set, and worker external and internal exposure dose and radioactivity contribution rate per radionuclide was calculated. By doing these, understanding the upcoming steam generator decommissioning operation process was possible, and utilization of worker exposure calculation and evaluation could be helpful to an uncertain decommissioning operation plan establishment, operation risk evaluation, possible operation classifications, worker participation rate control and so on. Finally, I hope the first domestic nuclear power plant decommissioning would be successful, and taking the head of the world nuclear decommissioning market by outstanding techniques and safety measures.

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I. Introduction

1.1 General background

On June 19th in 2017, first domestic commercial reactor Kori-1 in Figure 1 [2] was shut down after 40 years operation since April 1978. Nuclear decommissioning of Kori-1 will proceed, spent fuel cooling in 2018~2022, decontamination and dismantling of reactor in 2022~2028, site restoration by 2032 [1].

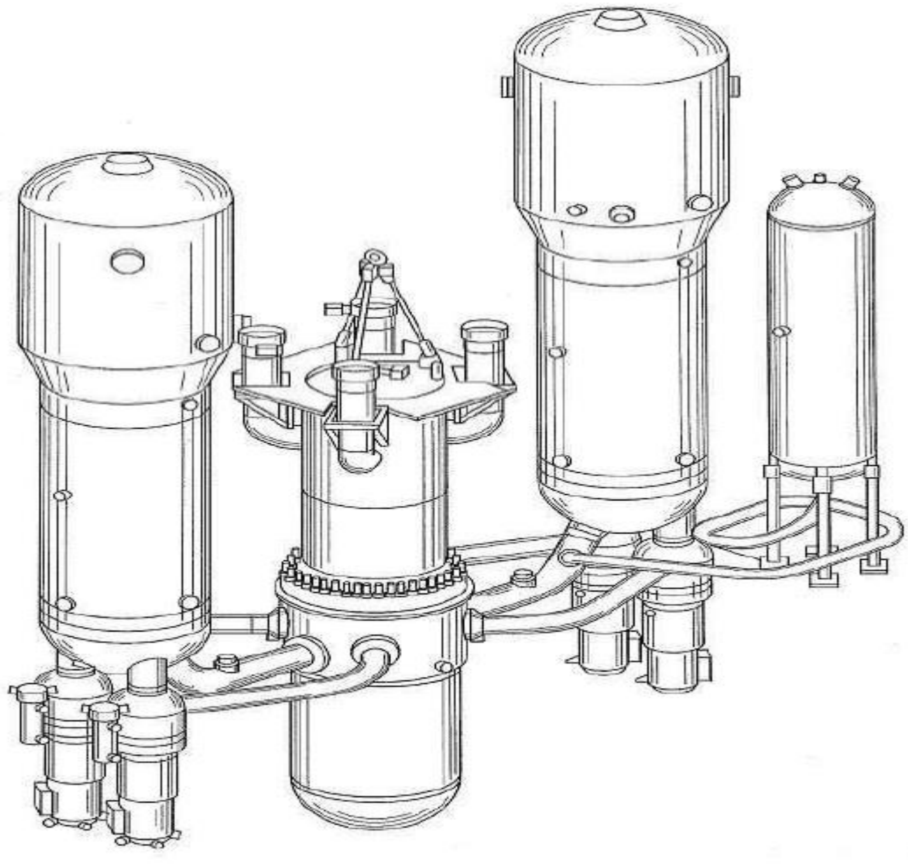

Figure 1. Steam generator in Kori-1 NPP [2]

Primary system of Kori-1 reactor is largely composed of nuclear reactor, steam generator which delivers generated heat from nuclear reactor to coolant, pressurizer, coolant pump like Figure 2 [2]. Steam generator is a massive structure, it has high value as large metallic waste, inner structure of steam generator is described in Figure 3 [2]. Direct work accessibility by worker could be possible compared to nuclear reactor because of relative low radioactivity level. Concerned contents about steam generator in Kori-1 was secured by replacement of steam generator in 1998 through various research thesis or report. By overall consideration, steam generator of primary system in Kori-1 was selected as main research object.

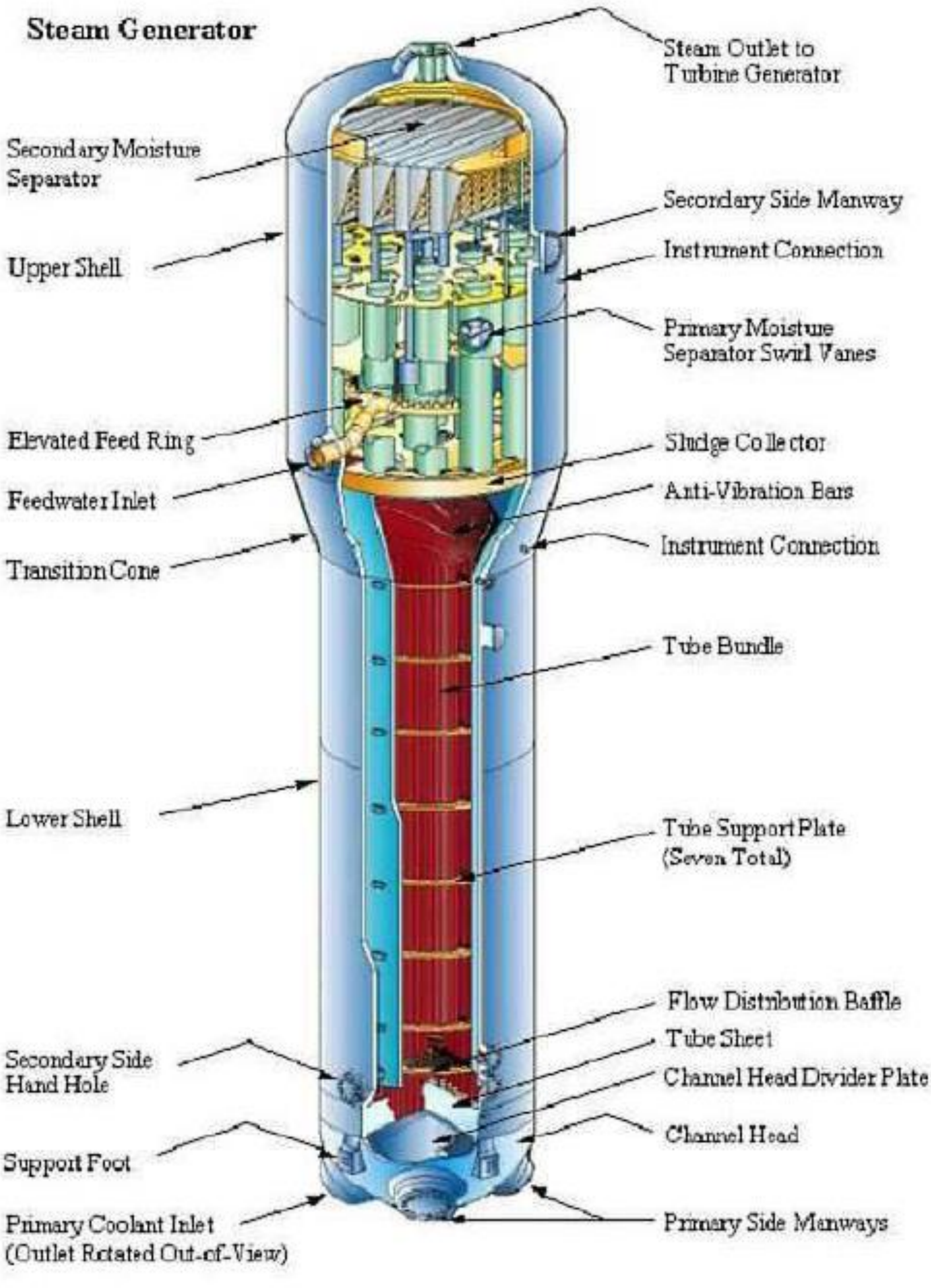

Figure 2. Steam generator component composition [2]

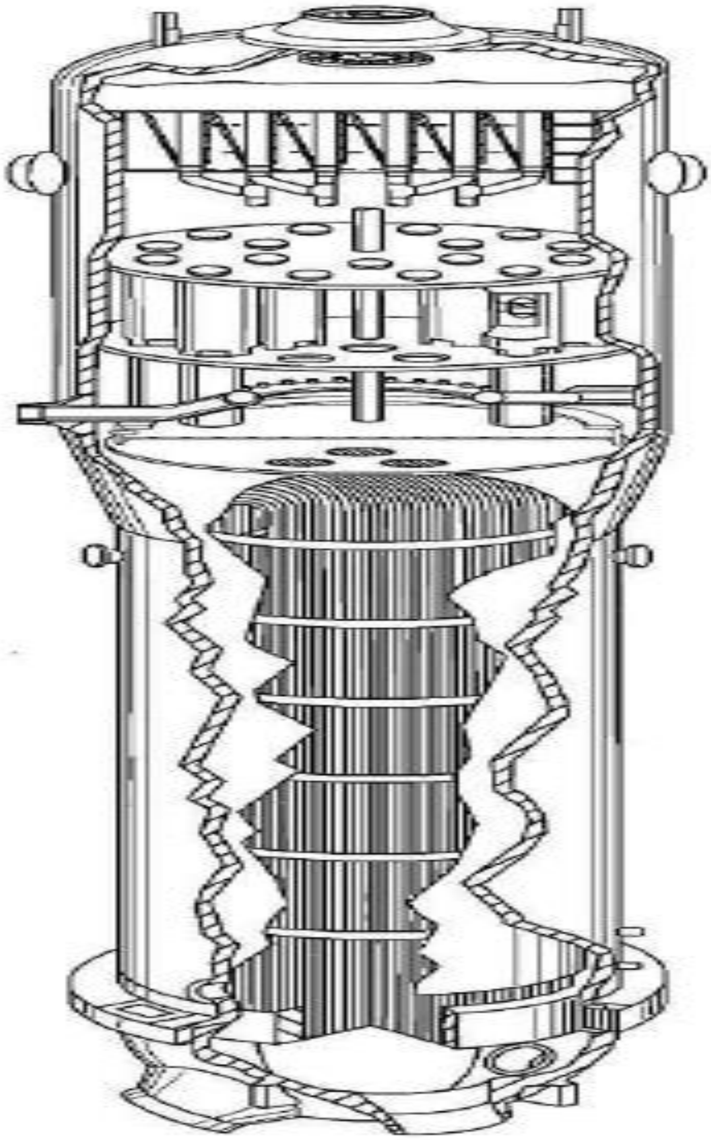

Figure 3. Inner structure of Steam generator [2]

1.2 The goal of this study:

For approaching nuclear decommissioning industry market, preliminary worker radiation dose exposure evaluation about actual nuclear decommissioning process to nuclear instrument or component would be needed. Content in this thesis would be helpful to consider actual decommissioning operation composition, modification and additional exposure reduction method or evaluation for various another nuclear instrument or component. Use of this exposure evaluation method and result would contributes actual decommissioning operation designing and planning. Though this thesis, abroad nuclear decommissioning information such as operation name and procedure and condition like working time and distance to decommissioning object would be proposed.

Ⅱ. Literature study

2.1 Steam generator in Kori-1

Steam generator makes steam from secondary system coolant using coolant heat of primary system from nuclear reaction to drive turbine generators. PWR power plant has 2~4 steam generator in a power plant, one steam generator has a few thousands to over ten thousand heat transfer tube. Especially, heat transfer tube has possibility of damage, breakage or material deterioration. Leakage or rupture of tube happens, pollution of spilled primary coolant makes higher radiation level in reactor system, possibility of leakage to environment is high, that's why integrity of heat transfer tube is important.

Steam generator is large component and contamination level is different depending on which part of steam generator, most parts are not contaminated seriously, however, inner tube bundle shows high contamination level because it is directly contact with reactor coolant [3]. Of course, data of steam generator changes depending on model or capacity, on average, steam generator has about 20 m height, 6 m upper diameter, 12~17 cm of vessel wall thickness, 700 ton of weight. Steam generator in Kori-1 was made from Westinghouse(WH) company, model of steam generator changed from OPR 1000 to APR 1400 after replacement of steam generator [4]. Material of main component in steam generator is variously used. Steam generator heat transfer tube uses Alloy 600, 690, 800 as a component material, they are made of stainless steel containing 13% Cr [5]. Shell of steam generator uses Mn-Mo-Ni low alloy steel, cladding and buttering uses 308I, 309I, Alloy 600, 690, feed water nozzle uses Alloy 600, 690, SA541, SS [4].

Globally, approximately 150 steam generators were changed in about 50 nuclear plant. Domestic replacement of steam generator was executed in Kori-1 reactor in 1998 after 20 years-commercial operation [6]. When steam generator was changed, radioactive contamination level was measured that's why worker exposure dose in decommissioning process of steam generator was executed using VISIPLAN for external exposure dose and direct calculation for internal exposure dose. Among steam generator replacement operations, RCS pipe inside and outside welding operation is especially classified into high exposure operation.

Steam generator tube failure makes leakage of contaminated primary coolant to secondary system, it also causes leakage of radioactive contamination substances to outer of steam generator, temporarily, tube plugging was executed, however, when it is over fixed ratio, replacement or steam generator happens [7]. In case of replacement of steam generator in Surry unit 2 in united states, it takes 320 days for replacement of steam generator, radiation exposure dose of worker was 21.4 man·Sv [6]. For reference, effective dose limit of radiation worker by enforcement regulation of atomic energy law is 100 mSv for 5 years, not exceeding over 50 mSv per year.

2.2 Decommissioning plan

Massive waste like steam generator goes though process as in the followings. First, contamination level was measured and pre-treatment decontamination would be carried out. After that, cutting and re-contamination level measurement would be carried out, re-use decontamination and re-contamination level measurement to determine which smelting decontamination or self-disposal/recycling would be proper. Residual radioactivity measurement and treatment process of metal waste proceed in the beginning of surface dose measurement and surface contamination level measurement, sampling and radionuclide analysis to final exposure dose evaluation to classify radioactive waste, limited-use waste and non-radioactive waste.

2.2.1 Decommissioning stage

Decommissioning of spent steam generator proceeds by decomposition and dissolution. Non-pollution part would be recycled and activated part by radiation would be executed of additional decontamination and segmentation. Expansion of non-pollution part makes maximized amount of recycling and reduction of polluted part would be stored in temporary storage site or permanent disposal in radioactive waste drum. Ended lifespan or happened important flaw to generating equipment would be recycled or disposed in demolition waste dismantling site.

A certain article classifies radiation exposure job related to steam generator in PWR plant according to main job such as steam generator manway job, ECT job, tube job, nozzle dam job, lancing job. Each job is divided again into several detailed jobs, steam generator manway job is divided into preparatory job, inspection, template construction and removal, equipment installation and movement, ECT. Steam generator tube job is divided into preparatory job, inspection, template construction and removal, equipment installation and movement, plugging, sleeving, equipment decontamination and others. Steam generator lancing job is divided into preparatory job, H/H job, Lancing, Equipment removal and decontamination and others [8]. However, this thesis refers to radiation exposure possible happen operation in steam generator replacement operation as decommissioning preparation process.

In case of steam generator replacement operation, kinds of replacement operations are classified into total 113 operations, naturally, all replacement operations have different working time and number of workers per each operation [6]. Entire replacement operations are largely divided into 9 operation group. They are welding operation, mechanical measurement and inspection, lagging installation to OSG and concerned tube, eddy current inspection, radioactive waste storage wall construction and spent steam generator storage operation, various ancillary equipment installation and removal, radioactive waste treatment, decontamination operation, laundry operation [6]. In this thesis, part of spent steam generator replacement operations is assumed to decommissioning preparation operations, that’s why total 10 operations in 113 replacement operations are selected to describe actual decommissioning preparation process.

2.2.2 Decommissioning method

Expected decommissioning process and method is as in the following. Spent steam generator would put on left-right movement and normal-reverse rotation possible saddle. Spent steam generator falls into radiation pollution and non-pollution part, bounded part would be cut and separated by plasma cutting method as a shape of circle or piece.

According to evaluation article of dismantling technology for decommissioning, four main commercial cutting technologies are introduced. They are each waterjet cutting, shear cutting, plasma cutting, band saw cutting technologies. Waterjet cutting technology uses high pressure water for abrasive injection. Shear cutting uses two blades to cut object on same principle of a pair of scissors. Plasma cutting uses direct current arc to make metal oxidation reaction. Band saw cutting uses continuous band of metal with teeth as a blade. Among them, Shear cutting was evaluated as a best cutting technology for steam generator tube cutting in terms of site-specific impact, safety impact and cost impact [9].

Pre-post dismantling decontamination process would be enforced. In case of post-dismantling decontamination methods, largely three, electrochemical decontamination, jetting decontamination and ultrasonic decontamination methods was applied in abroad steam generator decommissioning process [10]. Decontamination factor of their methods was reported, for example, DF (decontamination factor) of high pressure water jetting decontamination technique was over 50, DF of abrasive medium (dry blasting) or water (wet blasting) jetting was distributed from 13 to 125, DF of ultrasonic wave method to detach liquid contamination substances was about 100 [10]. In other article, AP-CITROX decontamination technique was used to remove mixture of citric and oxalic acids on contaminated surface layer of steam generator in Paks NPP(Hungary) as a chemical decontamination method [11].

Also, melting technology would be widely used to treat metallic waste, it is considered as promising technology. Already, some European countries including France, Sweden, Germany has done melting technology for treatment of metallic waste [3].

III. Method

Information like radioactive nuclides and radioactivity to calculate exposure dose of worker was secured by 'surface radiation dose rate evaluation of steam generator in Kori-1 for replacement'. Working hours and distance of workers were secured by steam generator replacement plan and replacement operation licensing document and operation proceeding of V1 reactor in Slovakia. According to 'Surface dose rate evaluation of substituted steam generator in Kori-1', 13 nuclides are as in Table 1.

Table 1. Radionuclides and Surface contamination of steam generator [6]

Radionuclides	Surface Contamination level (Bq/m^2)
Ce-141	9.87×10^6
Co-57	4.41×10^5
Co-58	2.02×10^8
Co-60	8.58×10^7
Fe-59	5.50×10^6
Mn-54	4.99×10^6
Nb-95	3.01×10^7
Ru-103	4.38×10^7
Ru-106	2.62×10^7
Sn-113	9.06×10^5
Sr-85	2.77×10^7
Zn-65	2.86×10^6
Zr-95	1.18×10^7

In case of external exposure, VISIPLAN produced by SCK·CEN in Belgian Nuclear Research Centre was used, geometry of steam generator, radioactivity of 13 nuclides, working time and distance were input. Internal exposure dose was calculated by internal exposure dose calculation formula for case of inhalation and ingestion provided by IAEA safety guide report. Radioactivity level change in cutting or decontamination process was also reflected in exposure dose calculation.

External exposure dose calculation of worker by direct radiation is expressed in following formula (1) [12].

$$\mathbf{D_{dir} = 2\pi * r_{in} * h *} \sum_{op}\left(\boldsymbol{t_{op}} * \sum_{i,N}\left(\boldsymbol{DR_{N,i}} * \boldsymbol{A_i}\right)\right) \quad -\mathbf{(1)}$$

Here, variables indicate

r_{in}: Inner radius of a contaminated pipe (cm)

h: Length of the source (cm)

t_{op}: Time of operation (h)

$DR_{N,i}$: Dose rate factor in worker position N from i-th source with 1 Bq of total activity (mSv/(h*Bq))

A_i: Surface contamination of i-th source (Bq/cm^2)

Internal exposure dose calculation of worker in decommissioning process refers to formula from IAEA safety report [12].

Effective dose formula by inhalation [12]

$$\mathbf{D_{inh,x,v,r} = INH * t_{inh} * \frac{1}{APFr} * k * \sum_{i}^{n}(DCF_{inh,\,i} * \overline{C}_{i,x,v}) - (2)}$$

Effective dose formula by ingestion [12]

$$\mathbf{D_{ing,x,v,r} = INH * t_{inh} * \frac{1}{APFr} * (1 - k) * \sum_{i}^{n}(DCF_{ing,\,i} * \overline{C}_{i,x,v}) - (3)}$$

Here, variables in formula (2) and (3) indicate

INH: Breathing rate of worker ($1.2\ m^3/h$)

T_{inh}: Breathing time of worker (h)

APFr: Protection factor (10)

k: Ratio of breathing activity (Total activity ratio =1, here 0.9)

DCF_i: Effective dose coefficient of i-nuclide (Sv/Bq)

$\overline{C}_{i,x,v}$:Radioactivity concentration of i-nuclide (Bq/m^3)

Radioactive concentration and Surface activity conversion formula [12]

$$\mathbf{\overline{C}_{i,x,v} = z_x*l*A_i*f_x*t^{-1}*Q_v^{-1} - (4)}$$

Here, variables in formula (4) indicates

z_X: kerf width of type x cutting technology (0.35 cm) l: kerf length (1 cm, kerf length is assumed to 1)

A_i: Surface activity of the i-th radionuclide (Bq/cm^2)

f_x: Released respirable mass fraction of removed material (0.019)

t: Time to cut material ($\frac{1}{12}$ h)

Q_v: Air flow from the room to the outside (2500 m^3/h)

After calculation is done, below formula is gained.

$$\overline{C}_{i,x,v} = 3.192\times10^{-12} * A_i \quad -(5)$$

In thesis, average value of variables in 10,000 times-simulation was also used. Using normal distribution, convictive values are attained. Here, Protection factor APFr value means how much air-purifying respirators well remove contaminants from air, according to OSHA (Occupational safety Safety and and health admir Health Administration) report, APF value of dust/half mask was set by 10. Effective dose coefficient for 13 nuclides by inhalation or ingestion is arranged as in Table 2 [13].

Table 2. Effective dose coefficient by inhalation and ingestion [13]

Nuclide	Effective dose coefficient by inhalation (Sv/Bq)	Effective dose coefficient by ingestion (Sv/Bq)
Ce-141	3.60E-09	7.10E-10
Co-57	9.40E-10	2.10E-10
Co-58	2.00E-09	7.40E-10
Co-60	2.90E-08	3.40E-09
Fe-59	3.50E-09	1.80E-09
Mn-54	1.50E-09	7.10E-10
Nb-95	1.60E-09	5.80E-10
Ru-103	2.30E-09	7.30E-10
Ru-106	6.20E-08	7.00E-09
Sn-113	2.50E-09	7.30E-10
Sr-85	7.70E-10	5.60E-10
Zn-65	2.90E-09	3.90E-09
Zr-95	5.50E-09	8.80E-10
Total	1.18E-07	2.20E-08

In cutting operation, additional exposure by inner tube contamination was set with reference in steam generator decommissioning of Dampierre 1 reactor in 1992, France in the Table 6 [14]. Simple concept about inner tube surface radioactivity in exposure calculation on cutting process was shown. Additional consideration will appear on cutting process exposure calculation method explanation more detail.

Applying same ratio radioactivity contamination, assume tube inner contamination level, worker exposure dose calculation was conducted in cutting operation. In decontamination operation, using decontamination factor in each decontamination technologies and process, radionuclide partitioning factors. Expected decommissioning stage of steam generator is as in Table 3,4 and 5. Table 3 shows decommissioning preparation process of steam generator before any substantive decommissioning process proceeds such as cutting or decontamination.

Table 3. Decommissioning preparation process of steam generator

Work name	Working Time (min)	Working Distance (cm)
Welding Equipment Installation	1440	170
RCS Pipe In-Outside Welding	9360	70
Equipment Dismantling	720	170
Lagging Removal	6480	70
Containment Vessel Amputation/Restoration	5160	30
Transfer Canal Installation/Removal	720	170
Main Feed Water Piping Removal	1440	70
Lifting Device Installation/Removal	2400	170
Plumbing Part Operation	1440	70
Auxiliary Crane Installation/Removal	120	170

Above all operation name were from ‘Kori-1 steam generator substitution experience’ and ‘steam generator substitution plan’, working distance was input with reference to working distance in decommissioning of V1 reactor in Slovakia.

Table 4. Cutting process of steam generator

Work name	Working Time (min)	Working Distance (cm)
Cutting and taking out end part	720	30
Fragmentation preparation of steam generator	353	170
Fragmentation of end parts	1058	38
Cutting and taking out upper part	1850	30
Fragmentation of upper part	914	38
Cutting heat exchange tube	2326	30
Fragmentation of heat exchange tube	1332	38
Dismantling preparation of collector	73742	170
Cutting and taking out collector	6772	30
Fragmentation of collector	33098	38

Table 4 shows expected actual cutting process of steam generator referred to abroad article concerning actual steam generator cutting decommissioning process, generally above 10 procedure proceeds as actual cutting process of steam generator in German NPP greifsward decommissioning project [15].

Table 5. Dose rate ratio and working time set of cutting processes

Work name	Dose rate (mSv/h)	Time Fraction	Working time (min)
Cutting and taking out end part	2.48E-13	0.182	1.85E+03
Fragmentation preparation of steam generator	1.22E-13	0.369	3.77E+03
Fragmentation of end parts	3.66E-13	0.123	1.26E+03
Cutting and taking out upper part	6.38E-13	0.071	7.20E+02
Fragmentation of upper part	3.14E-13	0.144	1.46E+03
Cutting heat exchange tube	8.01E-12	0.006	5.73E+01
Fragmentation of heat exchange tube	4.59E-13	0.098	1.00E+03
Dismantling preparation of collector	2.54E-11	0.002	1.81E+01
Cutting and taking out collector	2.30E-11	0.002	2.00E+01
Fragmentation of collector	1.14E-11	0.004	4.03E+01

Working time of cutting process was calculated by average dose rate of steam generator collector cutting process, suppose that dose value is directly proportional to working time of steam generator cutting process [6]. Ratio was round off the numbers to the nearest hundredths. If working time of cutting and taking out end part process fixes to 720 min based on cutting scenario time in RESRAD-RECYCLE for steel, working time of other processes was also fixed according to ratio of dose value. They are described in Table 5. Surface radioactivity of steam generator tube was applied depending on location of tube differently using different ratio of tube surface activity from lower part to upper part.

Table 6. Tube surface radioactivity ratio on location

Location	Inside tube surface activity (Bq/cm^2)	Outside tube surface activity (Bq/cm^2)	Cut tube surface activity (Bq/cm^2)	Surface activity ratio between outside tube and cut tube
Lower	2.02	3.7	5.72	1.55
Part	1.02	4.7	5.72	1.22
Upper	3.13	19.7	22.83	1.17

Table 7. Nuclides radioactivity on tube location

Radionuclides	Surface activity on outside tube (Bq/m^2)	Surface activity on cut lower tube (Bq/m^2)	Surface activity on cut part location tube (Bq/m^2)	Surface activity on cut upper tube (Bq/m^2)
Ce-141	9.87E+06	1.53E+07	1.20E+07	1.14E+07
Co-57	4.41E+05	6.84E+05	5.38E+05	5.12E+05
Co-58	2.02E+08	3.13E+08	2.46E+08	2.34E+08
Co-60	8.58E+07	1.33E+08	1.05E+08	9.95E+07
Fe-59	5.50E+06	8.53E+06	6.71E+06	6.38E+06
Mn-54	4.99E+06	7.73E+06	6.09E+06	5.79E+06
Nb-95	3.01E+07	4.67E+07	3.67E+07	3.49E+07
Ru-103	4.38E+07	6.79E+07	5.34E+07	5.08E+07
Ru-106	2.62E+07	4.06E+07	3.20E+07	3.04E+07
Sn-113	9.06E+05	1.40E+06	1.11E+06	1.05E+06
Sr-85	2.77E+07	4.29E+07	3.38E+07	3.21E+07
Zn-65	2.86E+06	4.43E+06	3.49E+06	3.32E+06
Zr-95	1.18E+07	1.83E+07	1.44E+07	1.37E+07

Available data of detailed cutting scenario was only dose rate value that's why it is assumed dose rate ratio is inverse proportional to working time of each cutting operation considering higher dose rate would cost less working time in terms of work radiation hazard and protective equipment utilization. Working time calculation is done as working time of Cutting and taking out upper part operation is set by 720 minutes. Different tube surface radio activity depending on location of tube from lower part to upper part is arranged in Table 7 [8]. Surface activity ratio between outside tube and cut tube was round off the numbers to the nearest hundredths. In addition, nuclides radioactivity on tube location is arranged in Table 7. These dose rate value was also from steam generator of abroad nuclear power plant, it is assumed similar dose rate ratio maintains in cutting process of steam generator in Kori-1. Based on dose rate value, virtual working time was calculated in inverse proportion relationship assumption.

Table 8. Smelting decontamination and recycling process of steam generator

Work name	Working Time (min)	Working Distance (cm)
Cutting Component Loading	240	400
Cutting Component Transfer	240	200
Cutting Component Treatment	720	200
Smelting Operation Preparation	4800	1000
Smelter Loading	240	400
Furnace Operation	300	300
Baghouse Processing	60	200
Refining Operation	300	300
Ingot Gathering	150	150
Slag Treatment	1500	150
Ingot Loading	120	400
Ingot Transfer	300	200
Storage Operation	2400	1000
Product Loading	1200	400
Product Transfer	480	200

Table 8 shows smelting decontamination and recycling process of steam generator referred to RESRAD-RECYCLE report offered from Argonne National Laboratory(ANL) [16]. This table shows overall smelting decontamination and recycling process including cutting component loading and processing, smelting processing and working, by-product such as slag, ingot, product delivery, fabrication, distribution. All external exposure dose rate and dose and nuclide dose contribution was calculated by VISIPLAN made from SCK-CEN in Belgium. First, external diameter and height of steam generator in Kori-1 reactor was set as in the following Figure 1. All of operation name in cutting and smelting stage refers to recycle operation for steel in RESRAD-RECYCLE report [16].

Steam generator cutting scenario indicates preparation of cutting component to deliver to smelter, it includes shredding, cutting, smashing, chopping, bailing, banding of cutting component.

Cutting component Loading scenario indicates loading of radioactively contaminated cutting component to transfer to smelter, mechanical loading equipment would be used in this operation.

Cutting component Transfer scenario indicates transportation of contaminated cutting component to processing place. (Ingestion or Inhalation activity would be excluded because driver would bet be directly in contact with contaminant)

Cutting component Processing scenario indicates preparation of cutting component for processing at smelter.

Smelting Processing scenario indicates potential dose exposure at smelting facility.

Smelter Loading scenario indicates crane operator exposure in the way of loading cutting component into furnace.

Furnace Operating scenario indicates potential dose exposure when workers operate furnace.

Baghouse Processing scenario indicates exposure of workers who handle and load baghouse content into special dust bag. Water would be sprayed to reduce dust inhalation, loaded dust bags are transported to storage or processing place.

Refinery Operation scenario indicates process of quality enhancement of metal melt from smelting process. Metal loss would not be happened.

Ingot Casting scenario indicates worker exposure to cast metal ingot for gathering.

Slag Treatment scenario indicates process of loading and unloading equipment to move slag product at smelting facility.

Ingot Loading scenario indicates loading ingot to fabrication plant.

Ingot Transfer scenario indicates transfer ingot to fabrication plant.

Storage Operation scenario indicates worker exposure at processing cast ingot at storage place of fabrication plant.

Product Loading scenario indicates loading and unloading of final product at trucks.

Product Transfer scenario indicates transfer of final product for distribution.

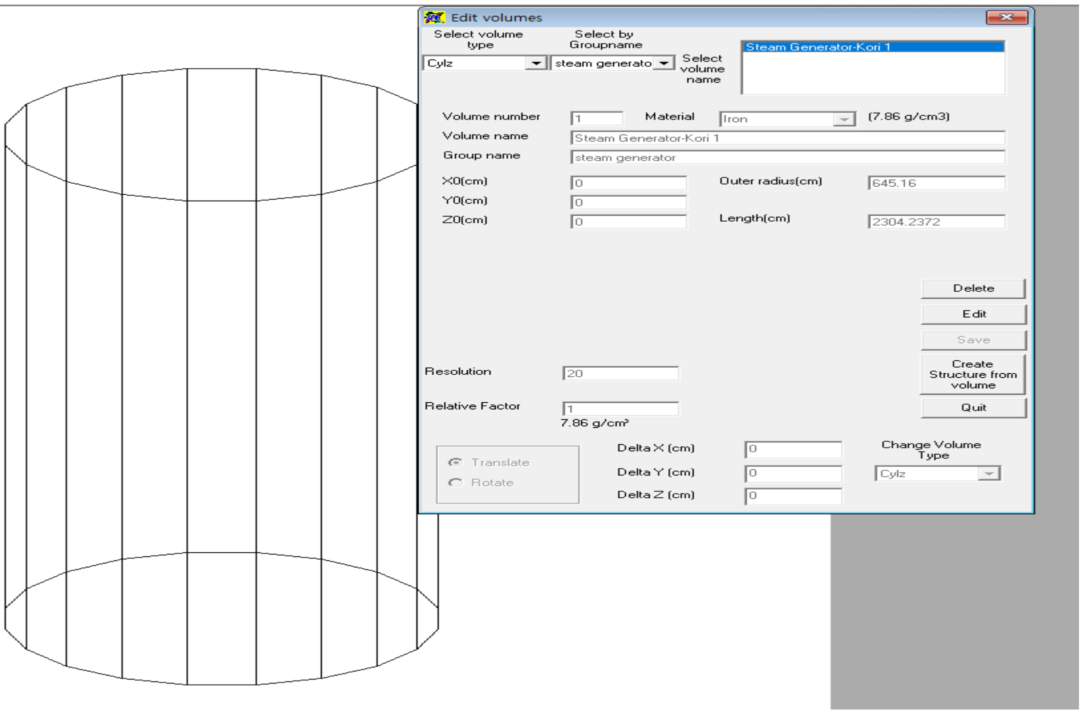

Figure 4. Designing factor data input in VISIPLAN

Geometry and data of new substituted steam generator comes from designing factor of APR 1400 model is in Figure 4 and Table 8. Figure 4 shows actual geometry input data of steam generator in Kori-1 such as material and outer radius and length for calculating external exposure dose by VISIPLAN. Table 5 shows various values regarding height, inside radius of primary and secondary head, body external and internal diameter of top/bottom, weight, heat transfer tube material [4].

Table 9. APR-1400 steam generator designing factor [4]

Article	APR1400
Number of steam generator	2
Height (in)	907.18
Inside radius of primary head (in)	93.02
Inside radius of secondary head (in)	116.02
Body external diameter of top/bottom (in)	232/196
Body internal diameter of top/bottom (in)	254/210.5
Weight (ton)	768
Heat transfer tube material	Alloy690 TT

In succession, activity data of 13 radionuclides from surveyed data when spent steam generator is substituted was input as in the following Figure 5 and 6. 13 radionuclides are Ce-141, Co-57, Co-58, Co-60, Fe-59, Mn-54, Nb-95, Ru-103, Ru-106, Sn-113, Sr-85, Zn-65, Zr-95. Figure 5 and 6 shows actual radionuclide activity input in VISIPLAN, in figure, activity of Ce-141 and Zr-96 nuclides are input. Among 13 nuclides, only 2 nuclides are input as an example.

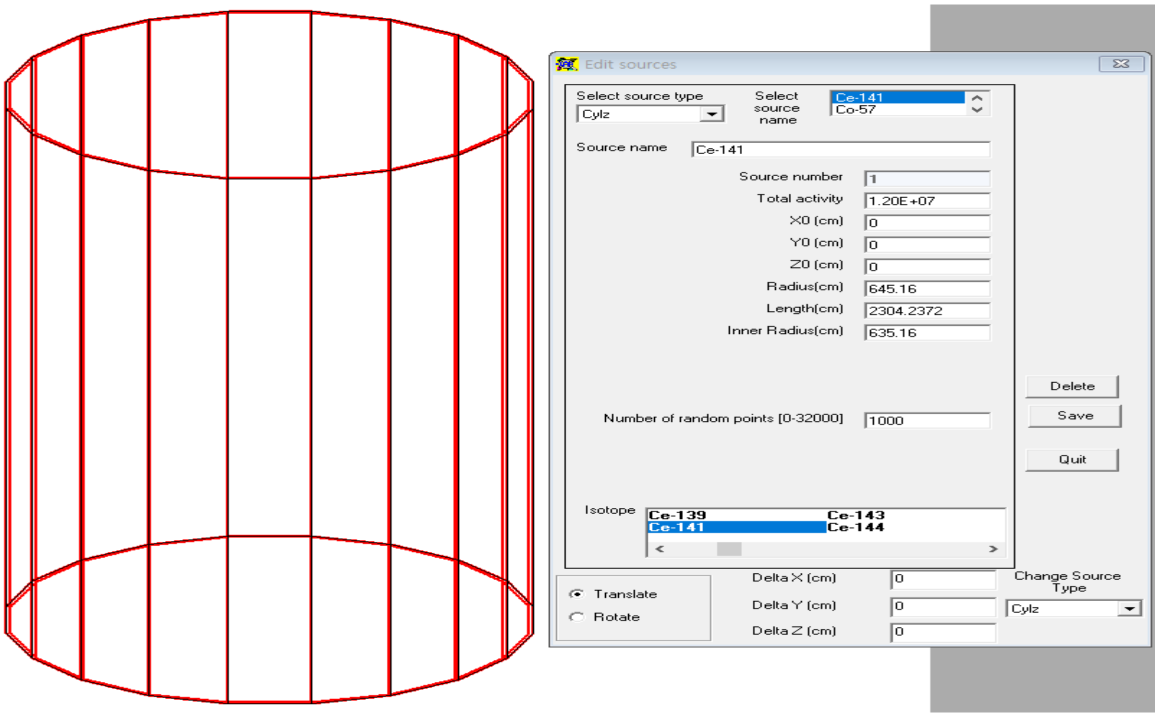

Figure 5. Radionuclide activity input in VISIPLAN (Ce-141)

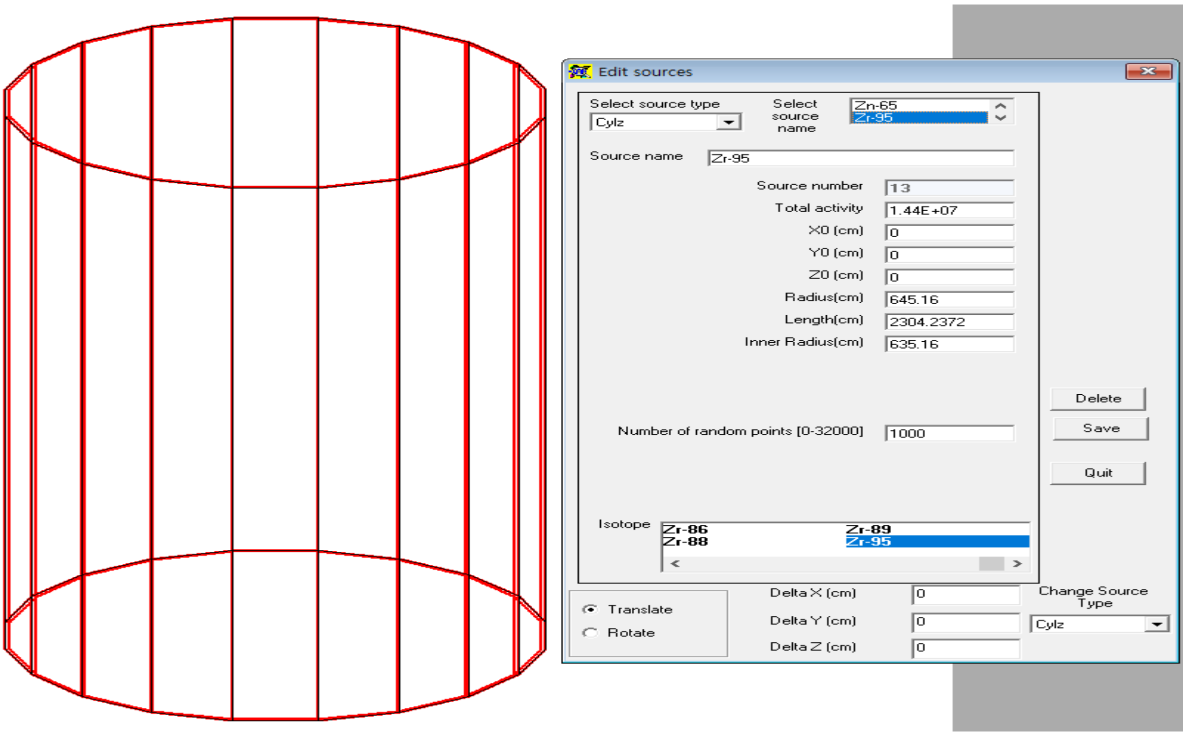

Figure 6. Radionuclide activity input in VISIPLAN (Zr-95)

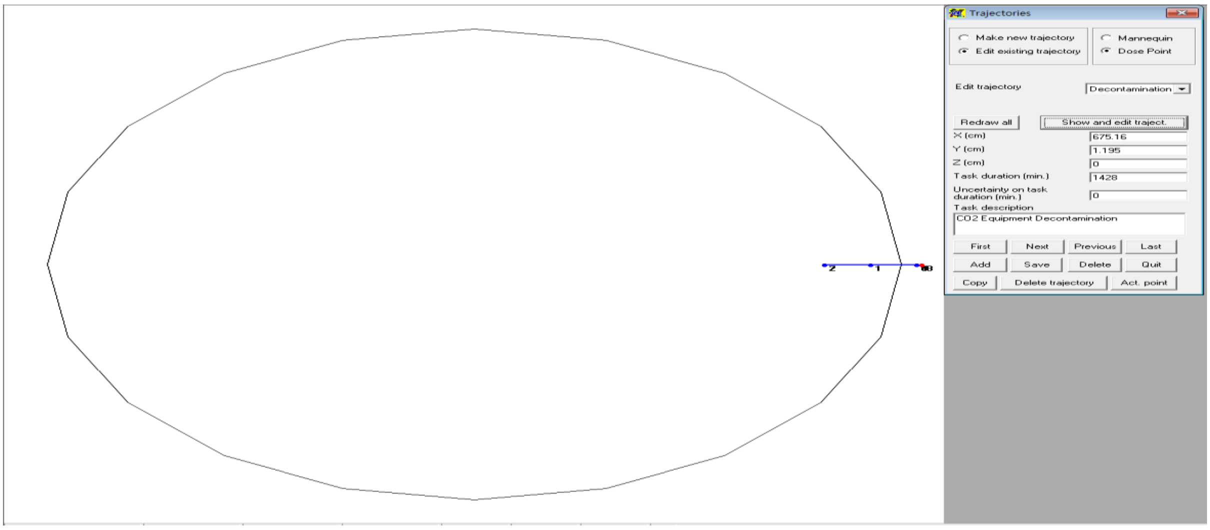

Figure 7. Working distance and time input for each operation using trajectory function

Each operation process was set using trajectory function in VISIPLAN by inserting working distance and working time for each decommissioning operation as Figure 7. For each decommissioning operation, working time when workers do the operation and working distance between radionuclide and worker were input. External exposure dose calculation was carried out for each operation trajectory set-up as Figure 8. As a build-up factor, air was set, using 13 radionuclides source and point set, external exposure dose was calculated for each decommissioning process.

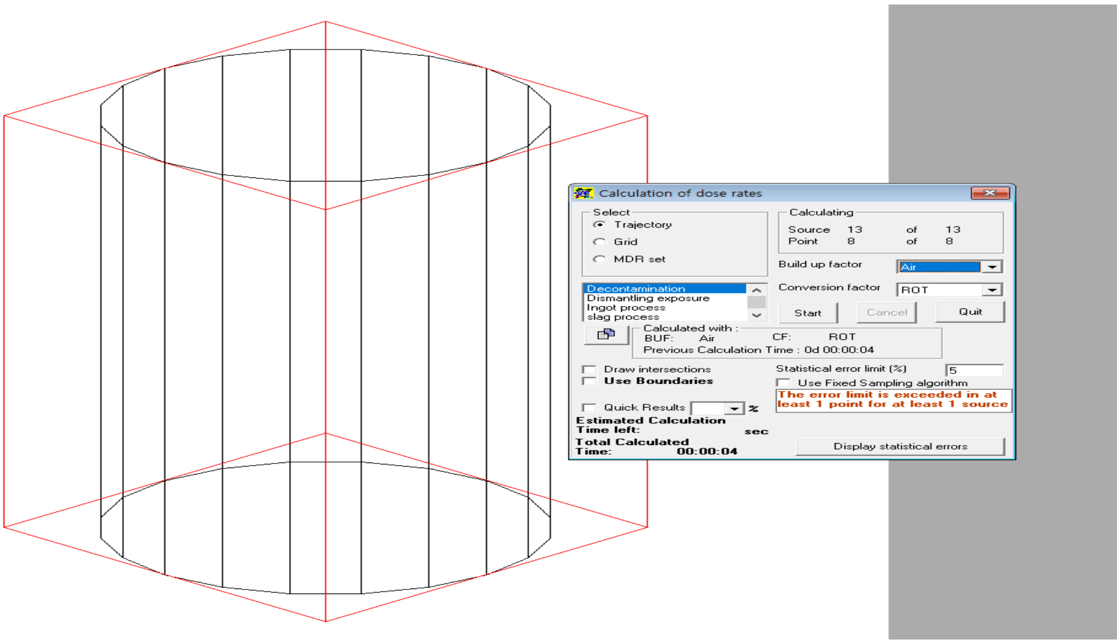

Figure 8. Trajectory input for set-up decommissioning operation

As a result, information about external exposure dose rate and total working dose and nuclide dose contribution for each nuclide was gained as Figure 9. Actual dose calculation result for each decommissioning operation was presented in Figure 9. In each decommissioning task, various dose rate, working dose and nuclide contribution to exposure dose were gained depending on various working time and distance.

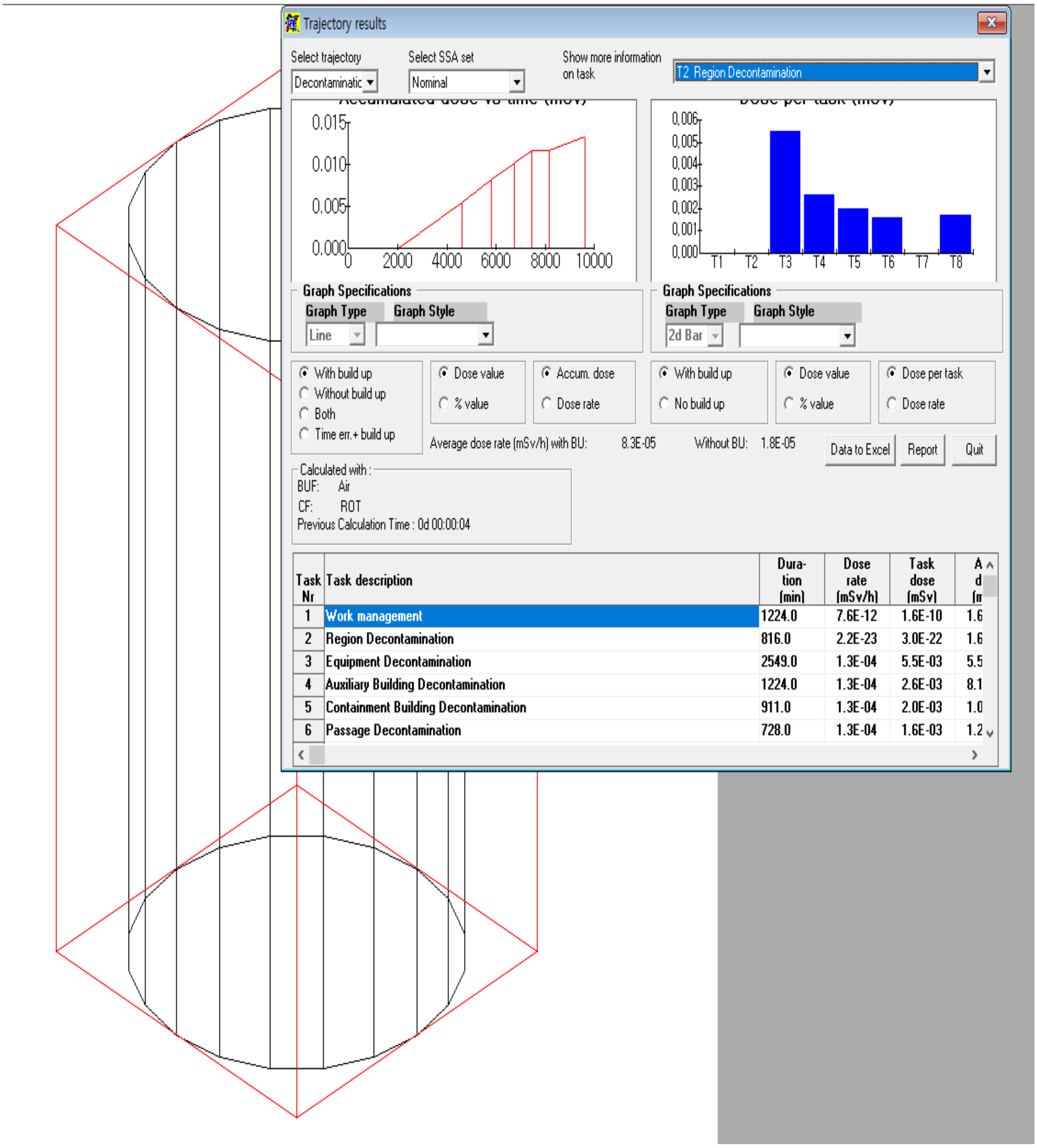

Figure 9. External dose calculation data for each set-up operation

IV. Results and Discussions

Exposure dose calculation results for decommissioning process worker in decommissioning preparation, cutting and smelting decontamination process are as in the following Figures 10-60. Figure 10-19 indicates steam generator decommissioning preparation processes and exposure dose calculation results for each process. Figure 20-29 indicates steam generator decommissioning cutting processes and exposure dose calculation results for each process. Figure 30-60 indicates steam generator smelting decontamination and recycling processes and exposure dose calculation results for each process. In Fig. 48 and 23, smelting operation preparation (56.6 mSv) and fragmentation preparation of steam generator (51.6 mSv) operations only show over 50 mSv (worker dose limit – not over 50 mSv per year and below 100 mSv for 5 years) internal exposure dose. However, internal exposure dose calculation applied effective dose concept, it means adult worker receive that dose for 50 years (adult worker standard), on average, virtual worker receives little over 1 mSv per year. If it is considered internal exposure dose is exponentially decrease as time goes, worker receives a lot more over 1 mSv per year, however, effective dose concept indicates worker receives total internal exposure dose for 50 years.

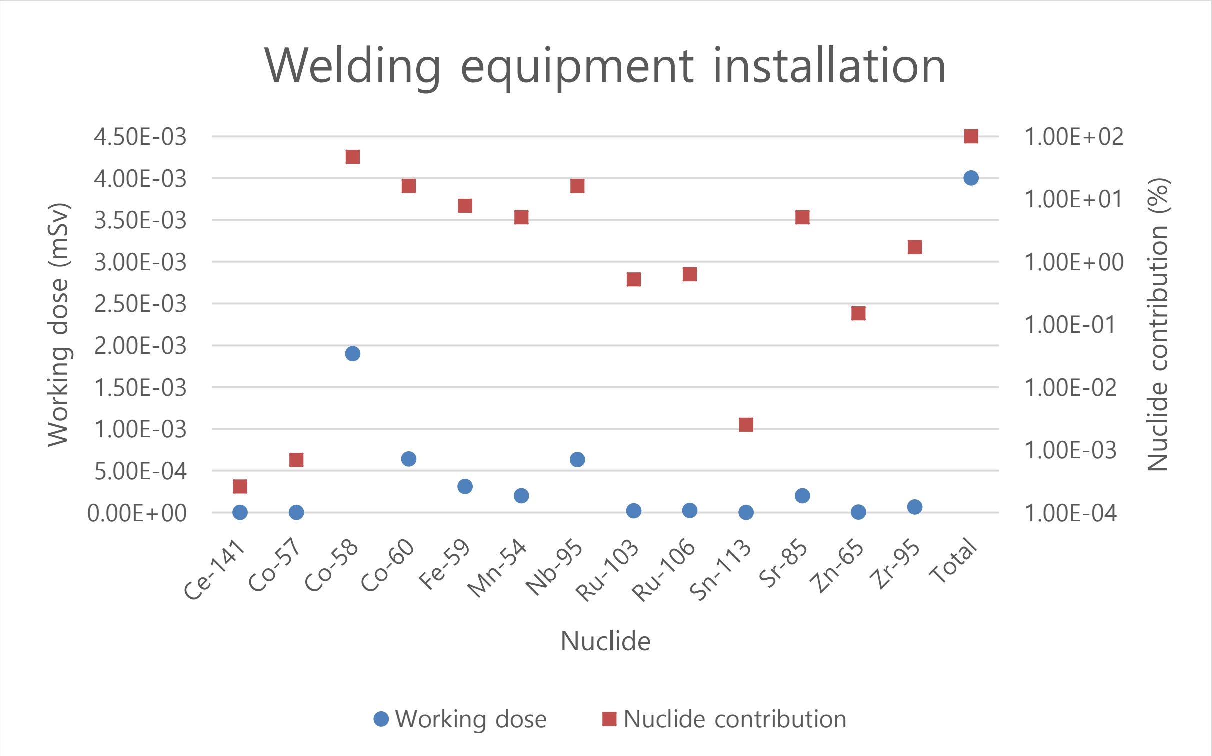

Figure 10. Dose calculation result for welding equipment installation process

Figure 10 shows worker would be exposed to total 0.004 mSv external exposure working dose in welding equipment installation process. Nuclide Co-58 (47%), Co-60 (16%), Nb-95 (16%) was dominant, they took a share 79 % of total working dose.

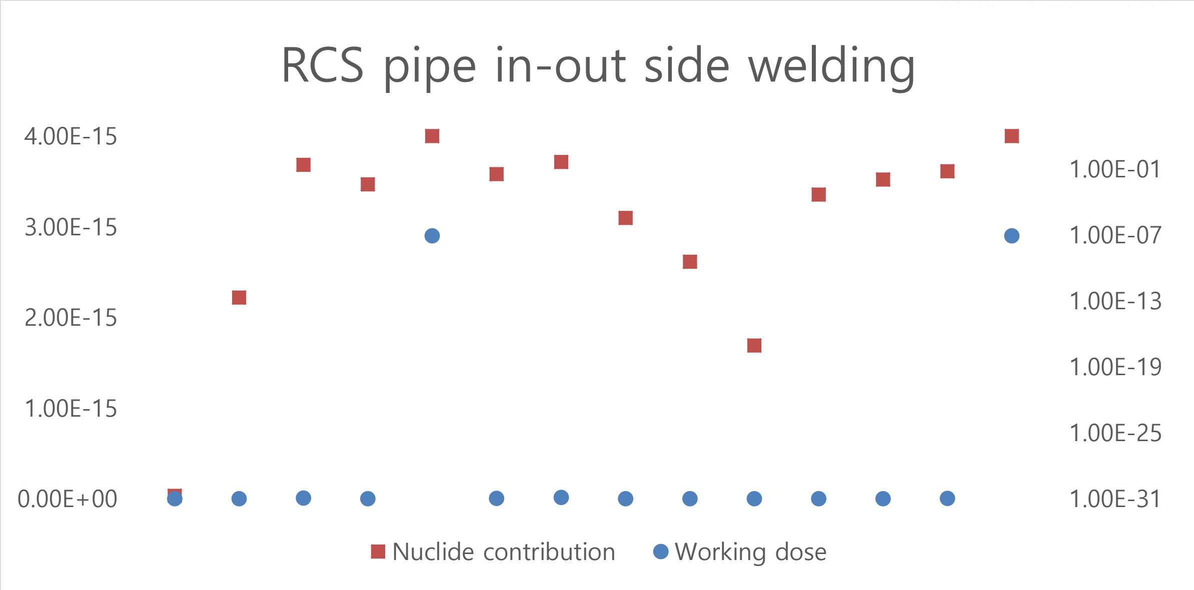

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Figure 11. Dose calculation result for RCS pipe in-out side welding

Figure 11 shows worker would be exposed to total 2.90E-15 mSv external exposure working dose in RCS pipe in-outside welding process. Nuclide Fe-59 was outstandingly dominant, it took a share 99 % of total working dose.

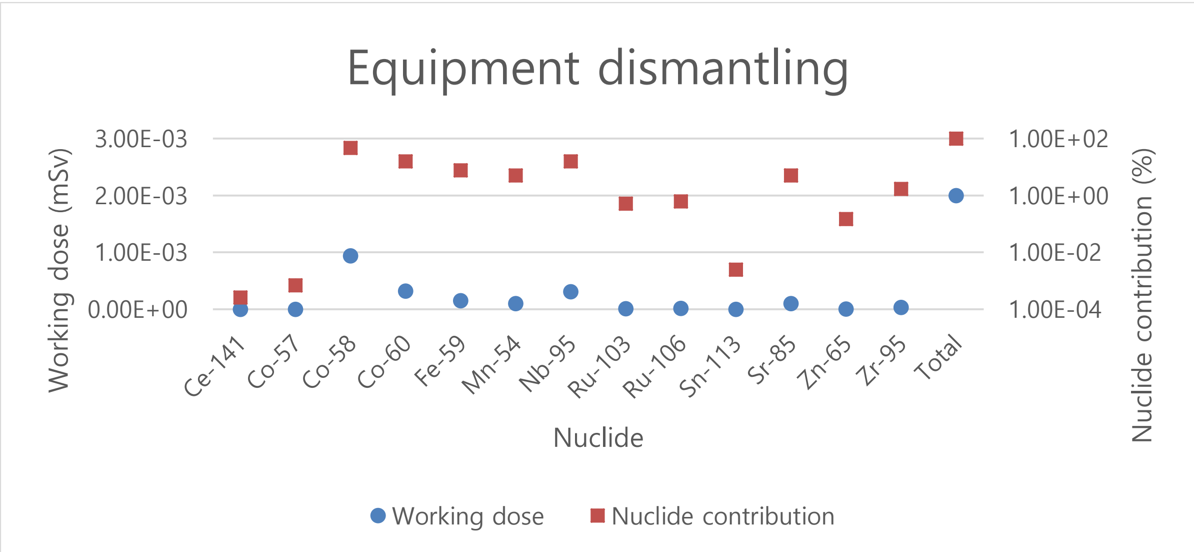

Figure 12. Dose calculation result for equipment dismantling

Figure 12 shows worker would be exposed to total 0.002 mSv external exposure working dose in Equipment dismantling process. Nuclide Co-58, Co-60, Nb-95 were dominant, they took a share 99 % of total working dose.

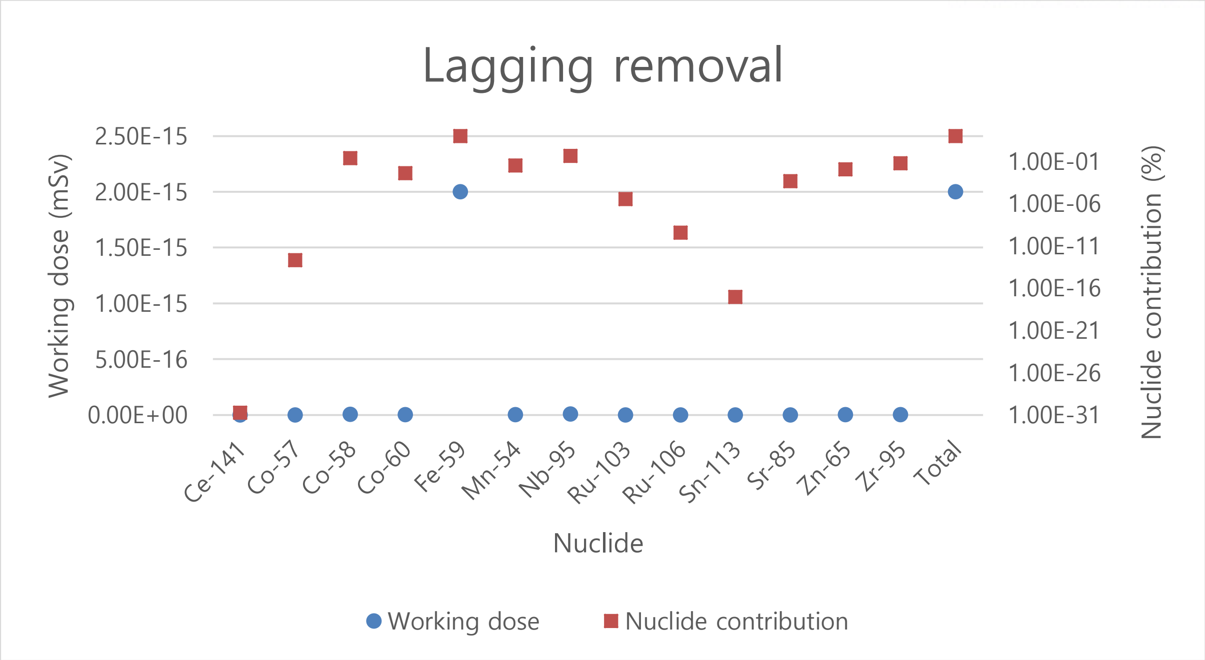

Figure 13. Dose calculation result for lagging removal

Figure 13 shows worker would be exposed to total 2.00E-15 mSv external exposure working dose in Lagging removal process. Nuclide Fe-59 was dominant, it took a share 99 % of total working dose.

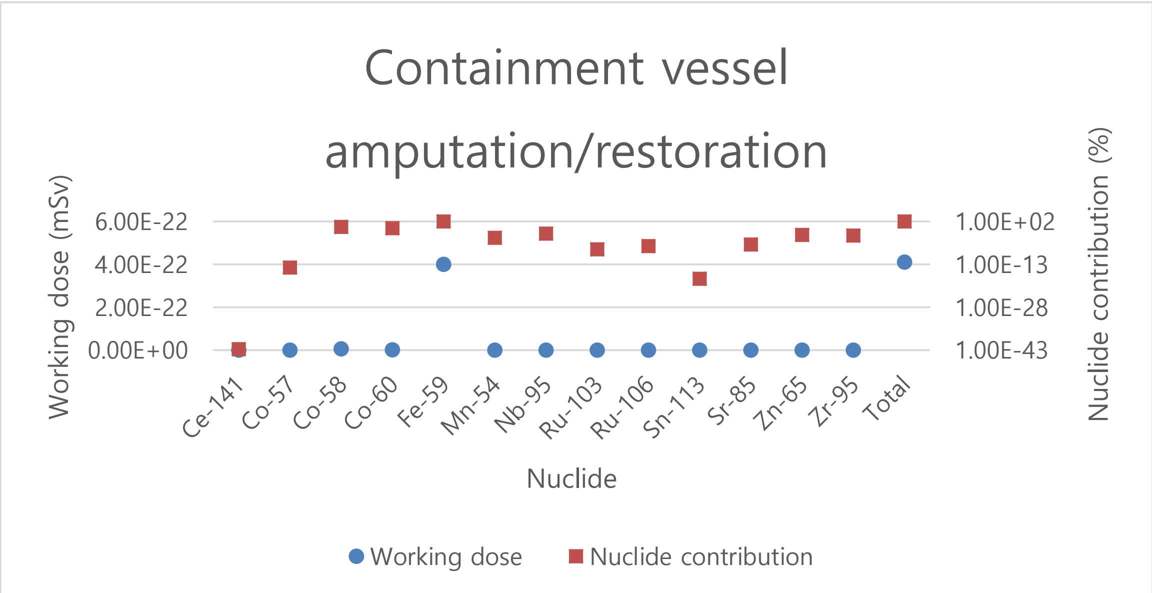

Figure 14. Dose calculation result for containment vessel amputation/restoration

Figure 14 shows worker would be exposed to total 4.10E-22 mSv external exposure working dose in Containment vessel amputation/restoration process. External exposure dose was very low. Nuclide Fe-59 was dominant, it took a share 98 % of total working dose. This process would be very safe to worker.

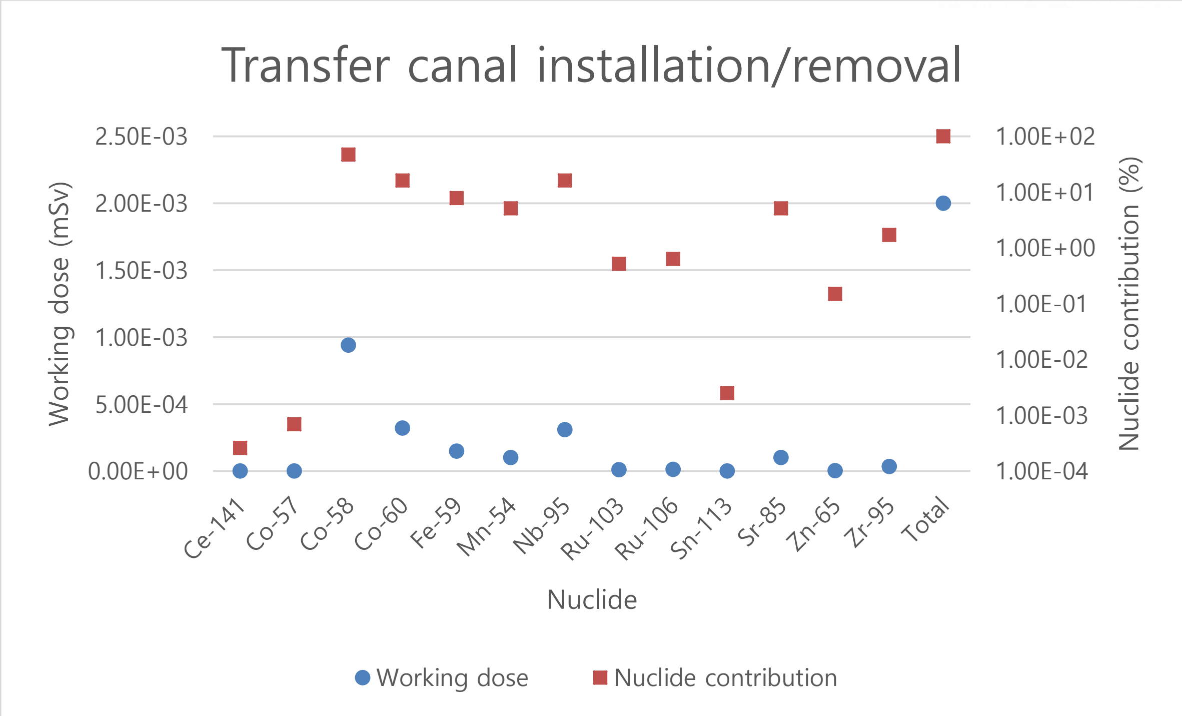

Figure 15. Dose calculation result for transfer canal installation/removal

Figure 15 shows worker would be exposed to total 0.002 mSv external exposure working dose in Transfer canal installation/removal process. Nuclide Co-58 was the most dominant and Co-60, Nb-95 are following. They took a share 79 % of total working dose.

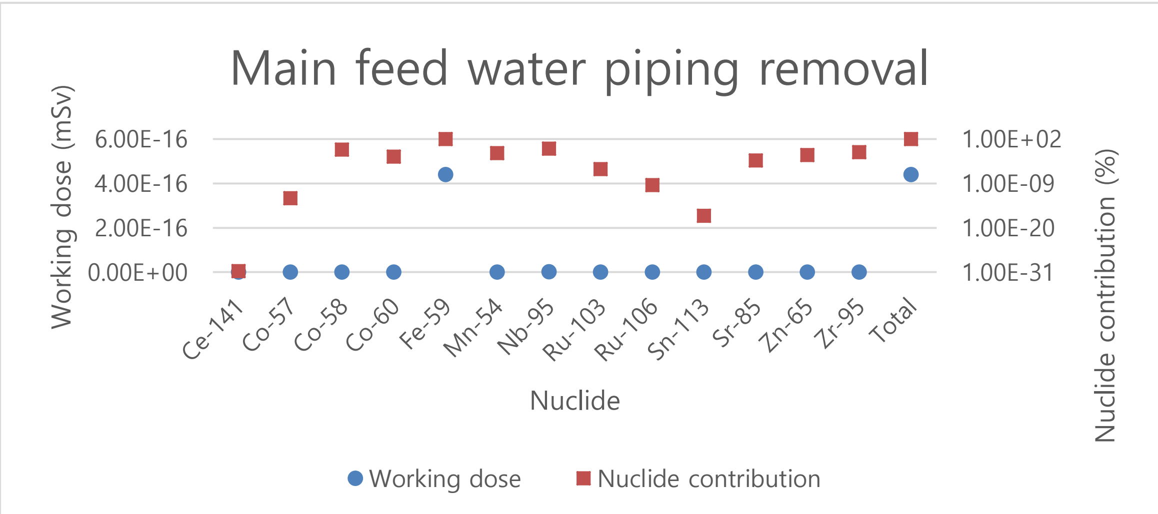

Figure 16. Dose calculation result for main feed water piping removal

Figure 16 shows worker would be exposed to total 4.40E-16 mSv external exposure working dose in Main feed water piping removal process. Nuclide Fe-59 was the most dominant. It took a share 99 % of total working dose.

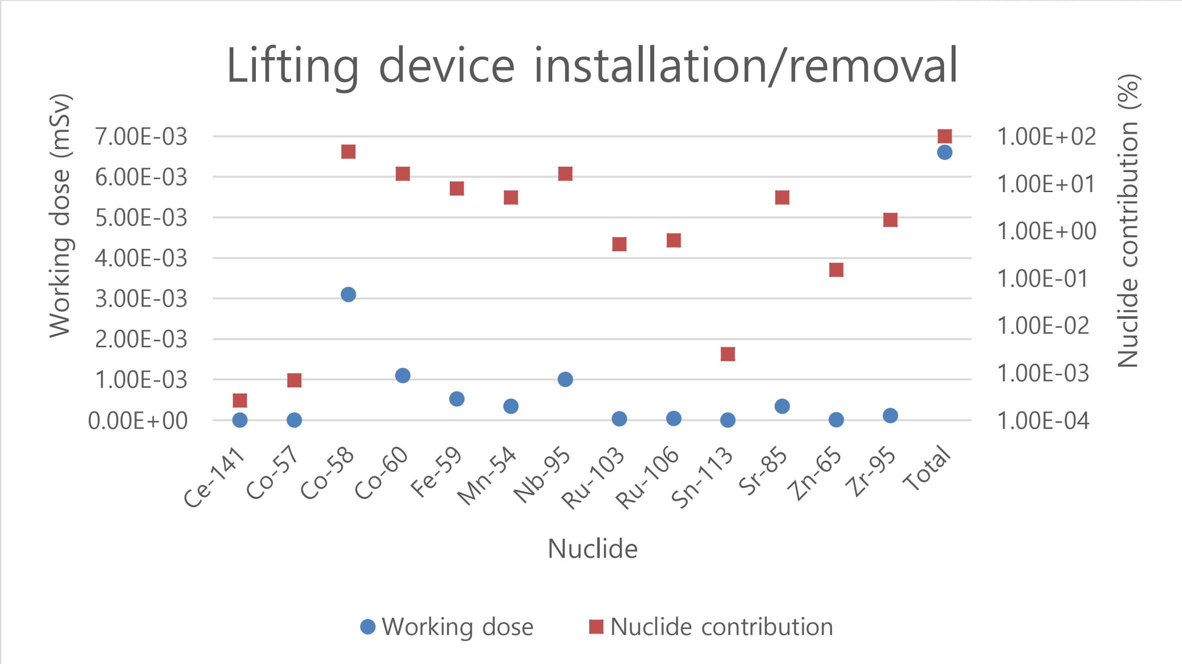

Figure 17. Dose calculation result for lifting device installation/removal

Figure 17 shows worker would be exposed to total 4.90E-20 mSv external exposure working dose in Lifting device installation/removal process. Nuclide Fe-59 was the most dominant, however, total working dose was very low. It took a share 99 % of total working dose, this process would not be dangerous to worker.

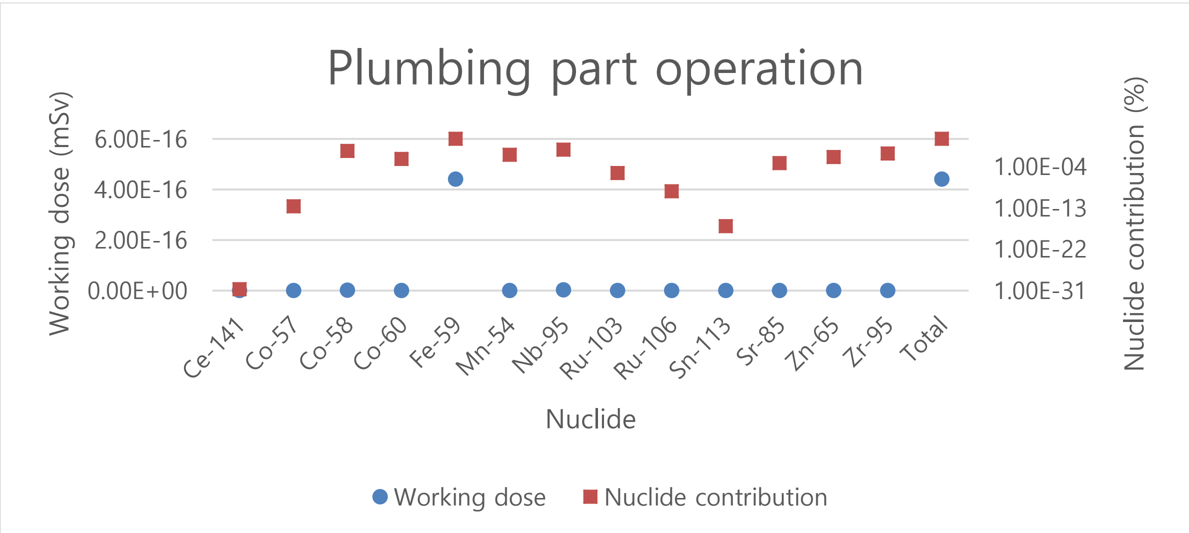

Figure 18. Dose calculation result for plumbing part operation

Figure 18 shows worker would be exposed to total 0.0066 mSv external exposure working dose in Plumbing part operation process. Nuclide Co-58 was the most dominant and Co-60, Nb-95 are following. They took a share 79 % of total working dose.

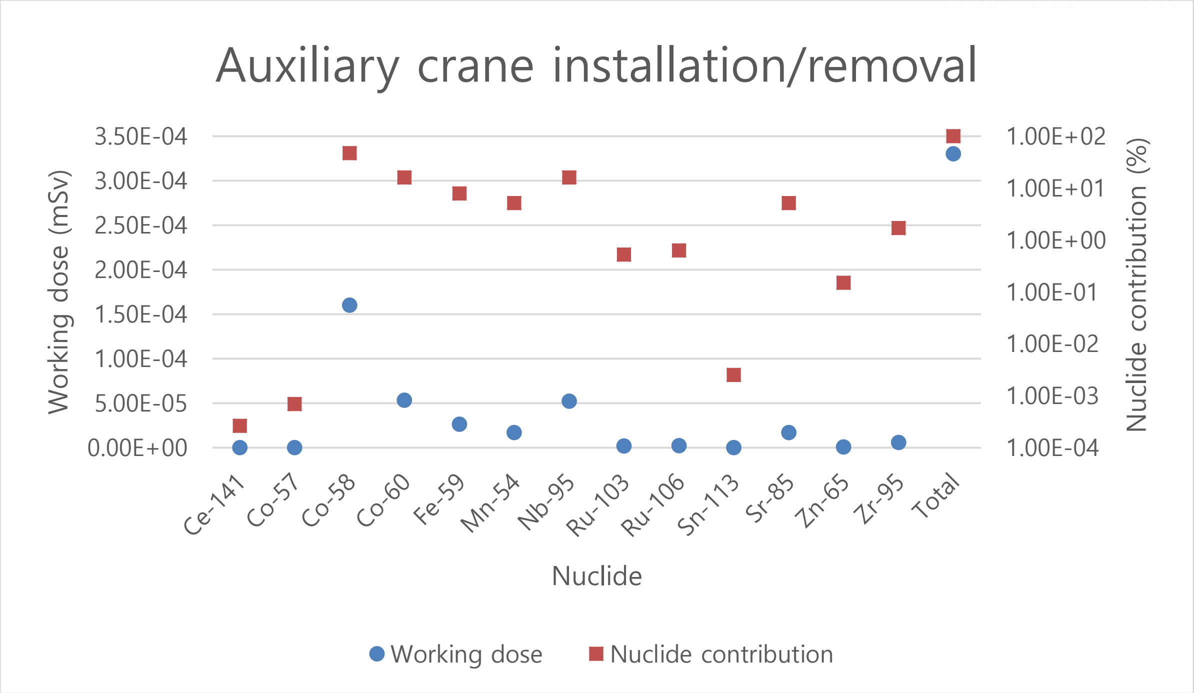

Figure 19. Dose calculation result for auxiliary crane installation/removal

Figure 19 shows worker would be exposed to total 4.40E-16 mSv external exposure working dose in Auxiliary crane installation/removal process. Nuclide Fe-59 was outstandingly dominant. It took a share 99 % of total working dose. Total working dose was very low. However, in most processes, external dose contribution by Co-60 was dominant because Co-60 releases powerful energy, 13.6 J per second, that’s why Co-60 nuclide is also used in non-destructive examination material.

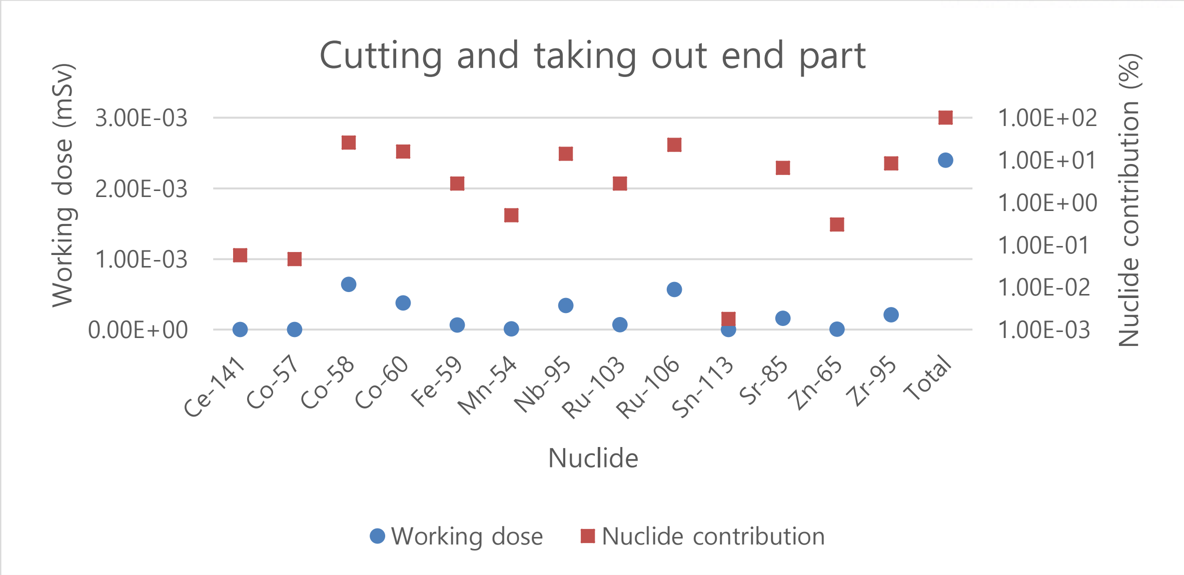

Figure 20. External dose calculation result for Cutting and taking out end part

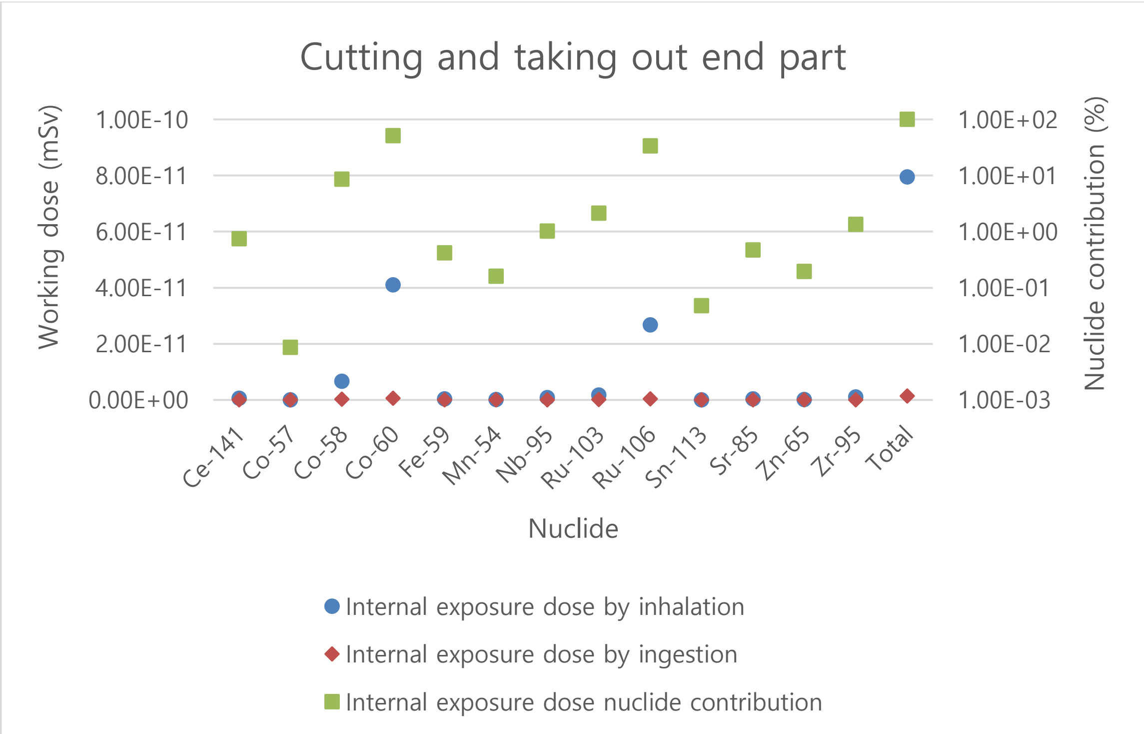

Figure 21. Internal dose calculation result for Cutting and taking out end part

Figure 20 shows worker would be exposed to total 0.0024 mSv external exposure working dose in Cutting and taking out end part process. Nuclide Co-58 and Ru-106 were the most dominant. They took a share 49 % of total working dose. Dose by Co-60, Nb-95 was following their value.

Figure 21 shows worker would be exposed to total 8.07E-11 mSv internal exposure working dose in Cutting and taking out upper part process. Nuclide Co-60 (4.15E-11 mSv) and Ru-106(2.71E-11mSv) were dominant. It took a share 84.9 % of total working dose

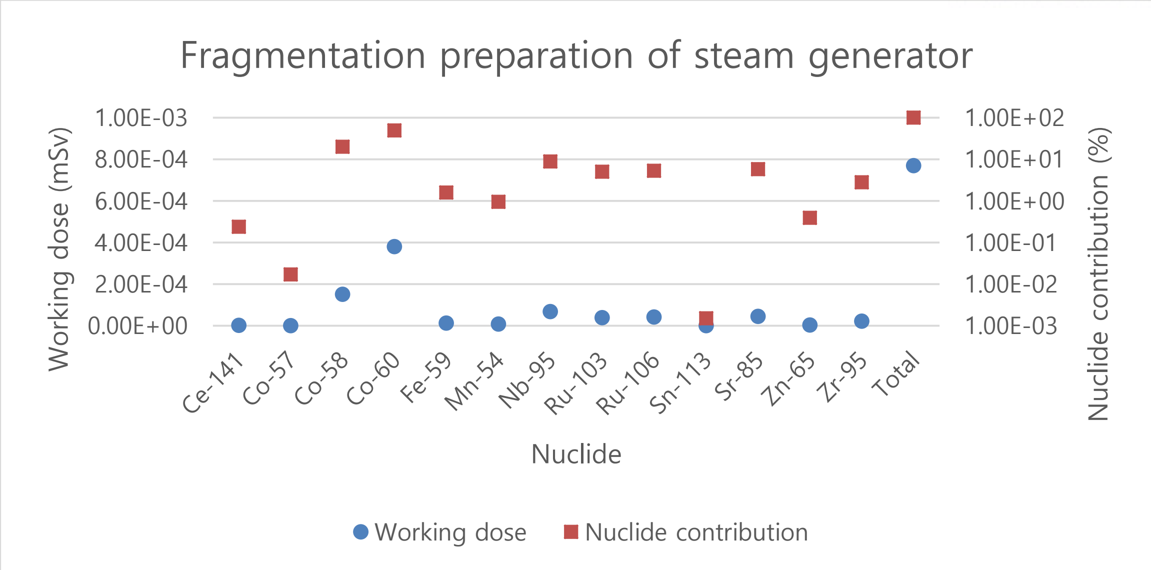

Figure 22. External dose calculation result for Fragmentation preparation of steam generator

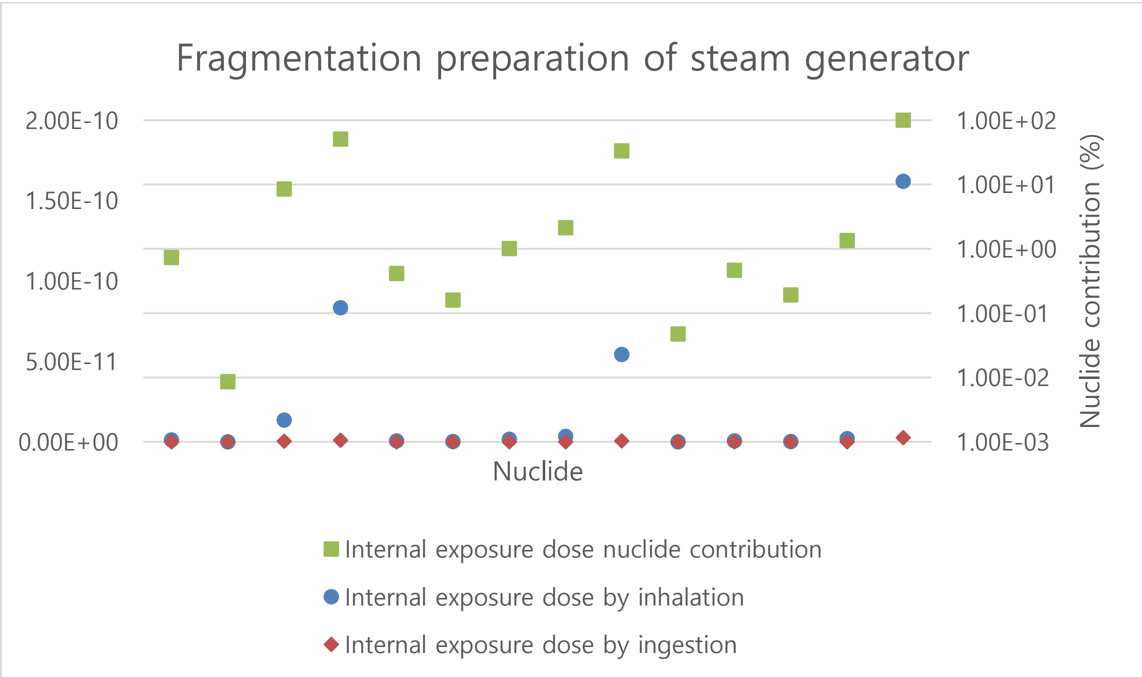

Figure 23. Internal dose calculation result for Fragmentation preparation of steam generator

Figure 22 shows worker would be exposed to total 7.70E-04 mSv external exposure working dose in Fragmentation preparation of steam generator process. Nuclide Co-60 was the most dominant. They took a share 69 % of total working dose with Co-58.

Figure 23 shows worker would be exposed to total 1.65E-10 mSv internal exposure working dose in Cutting and taking out upper part process. Nuclide Co-60 (8.46E-11 mSv) and Ru-106(5.52E-11 mSv) were dominant. It took a share 84.9 % of total working dose.

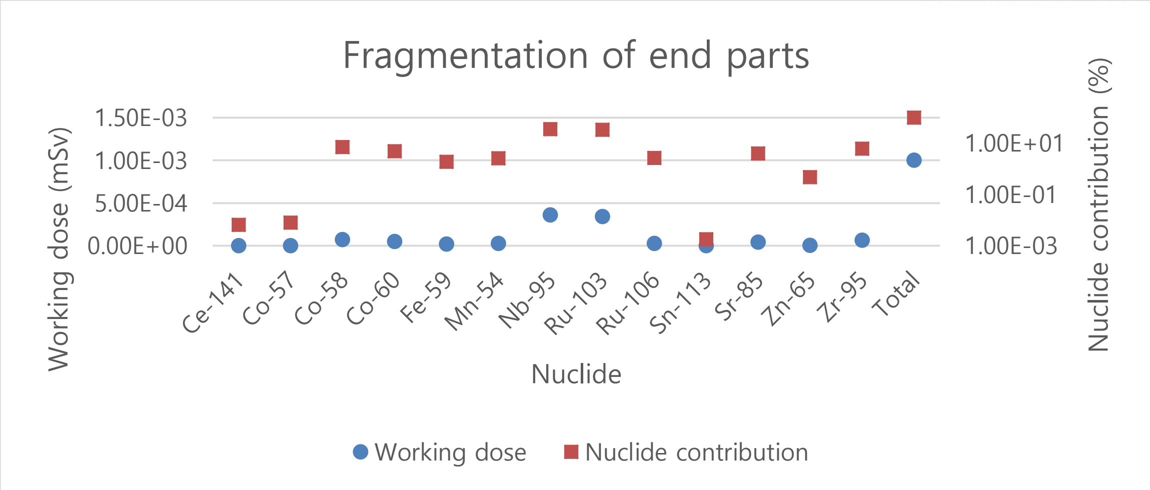

Figure 24. External dose calculation result for Fragmentation of end parts

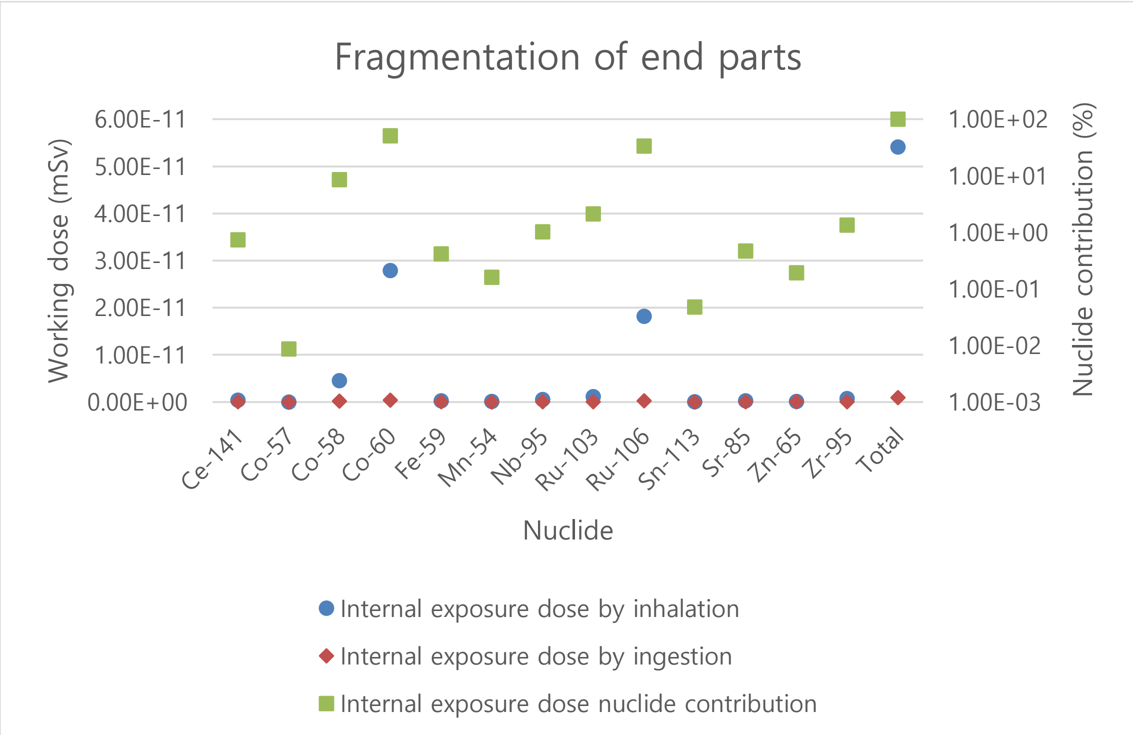

Figure 25. Internal dose calculation result for Fragmentation of end parts

Figure 24 shows worker would be exposed to total 0.001 mSv external exposure working dose in Fragmentation of end parts process. Nuclide Nb-95 and Rb-103 were the most dominant. They took a share 70 % of total working dose.

Figure 25 shows worker would be exposed to total 5.51E-11mSv internal exposure working dose in Cutting and taking out upper part process. Nuclide Co-60 (2.83E-11 mSv) and Ru-106(1.85E-11mSv) were dominant. It took a share 84.9 % of total working dose

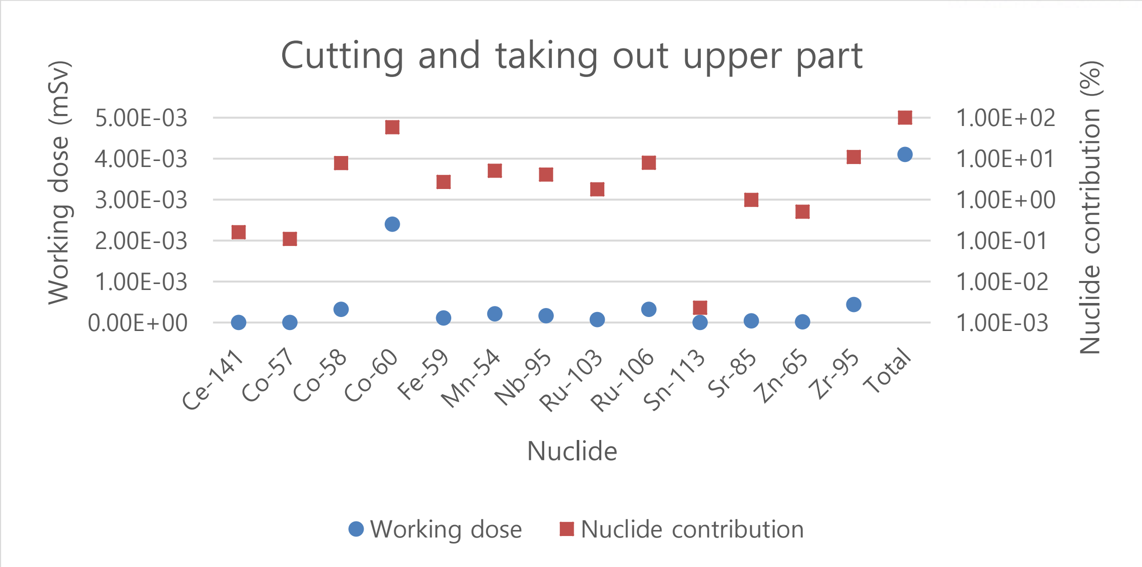

Figure 26. External dose calculation result for Cutting and taking out upper part

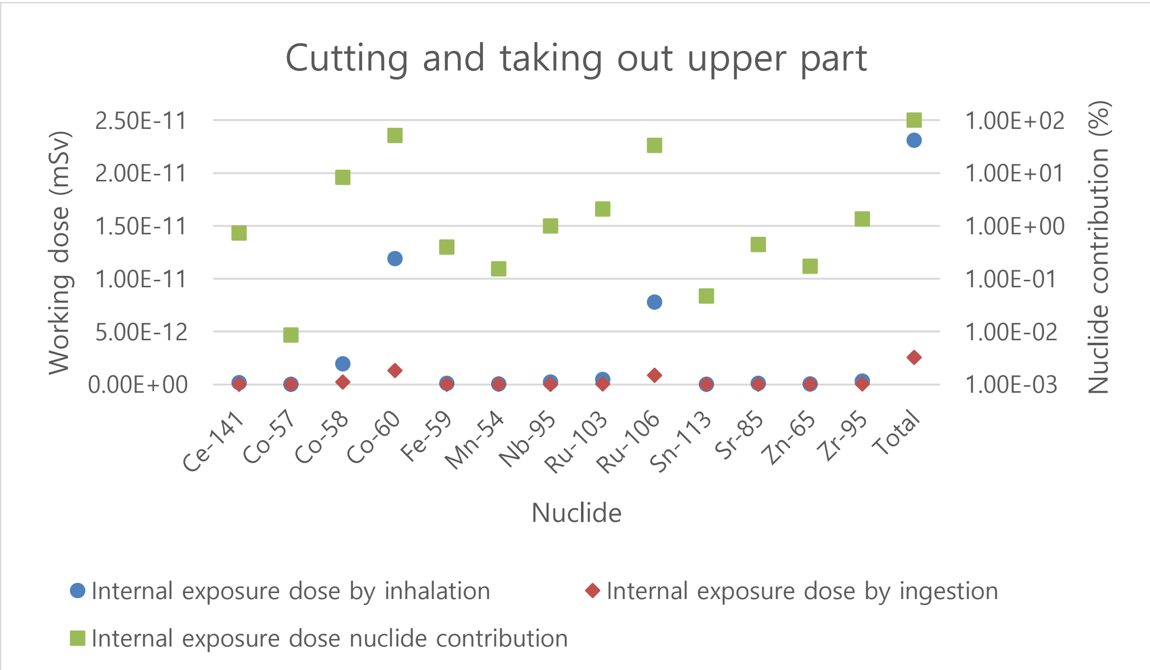

Figure 27. Internal dose calculation result for Cutting and taking out upper part

Figure 26 shows worker would be exposed to total 0.0041 mSv external exposure working dose in Cutting and taking out upper part process. Nuclide Co-60 was the most dominant. It took a share 58 % of total working dose.

Figure 27 shows worker would be exposed to total 2.57E-11 mSv internal exposure working dose in Cutting and taking out upper part process. Nuclide Co-60 (1.33E-11 mSv) and Ru-106(8.66E-12 mSv) were dominant. It took a share 84.9 % of total working dose

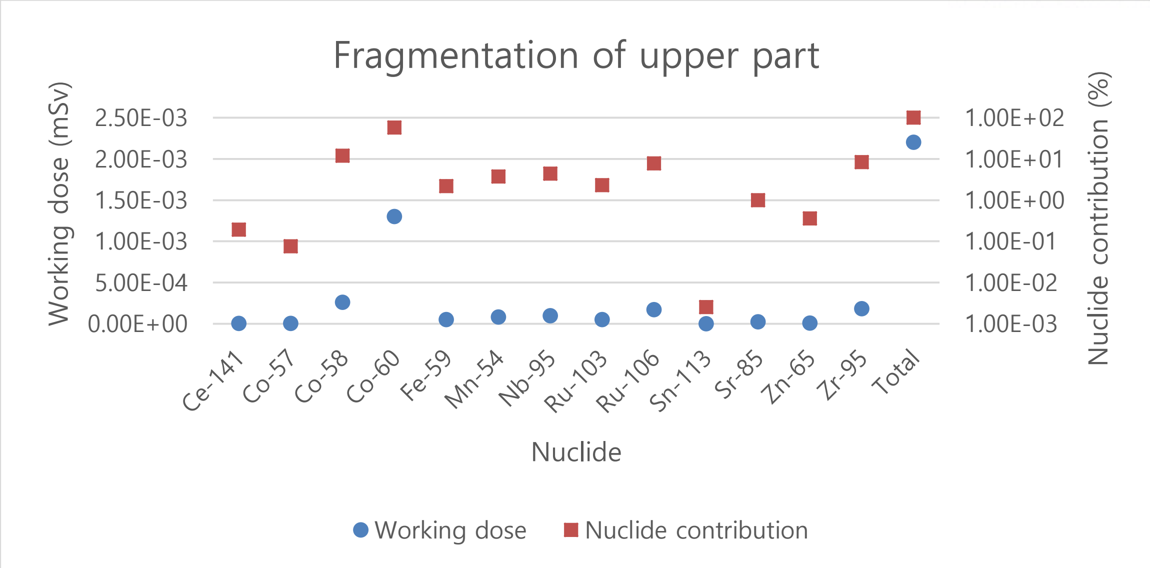

Figure 28. External dose calculation result for Fragmentation of upper part

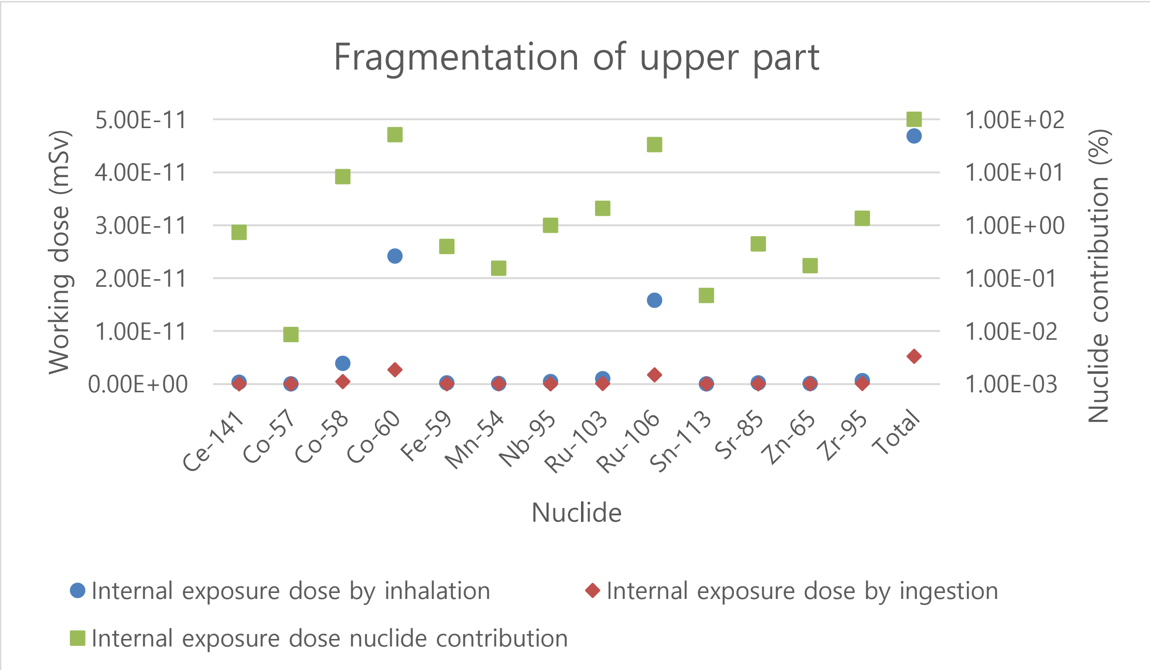

Figure 29. Internal dose calculation result for Fragmentation of upper part

Figure 28 shows worker would be exposed to total 0.0041 mSv external exposure working dose in Cutting and taking out upper part process. Nuclide Co-60 was the most dominant. It took a share 58 % of total working dose.

Figure 29 shows worker would be exposed to total 5.21E-11 mSv internal exposure working dose in Cutting and taking out upper part process. Nuclide Co-60 (2.69E-11 mSv) and Ru-106(1.75E-11 mSv) were dominant. It took a share 84.9 % of total working dose.

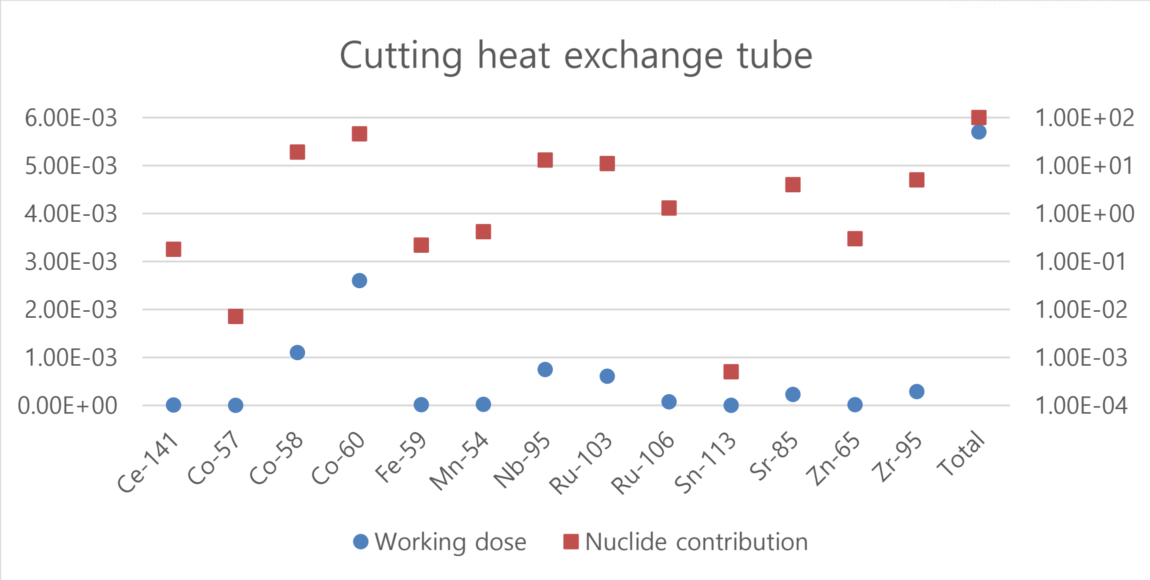

Figure 30. External dose calculation result for Cutting heat exchange tube

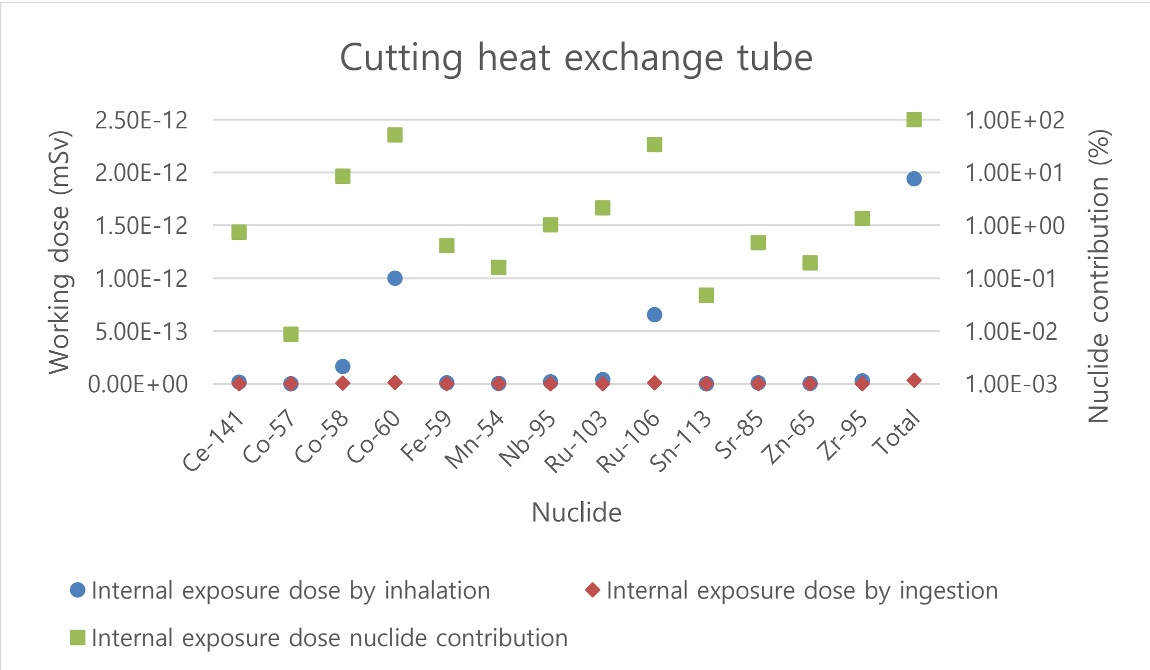

Figure 31. Internal dose calculation result for Cutting heat exchange tube

Figure 30 shows worker would be exposed to total 0.0057 mSv external exposure working dose in Cutting and taking out upper part process. Nuclide Co-60 was the most dominant. It took a share 46 % of total working dose.

Figure 31 shows worker would be exposed to total 1.97E-12 mSv internal exposure working dose in Cutting and taking out upper part process. Nuclide Co-60 (1.02E-12 mSv) and Ru-106(6.61E-13 mSv) were dominant. It took a share 84.9 % of total working dose.

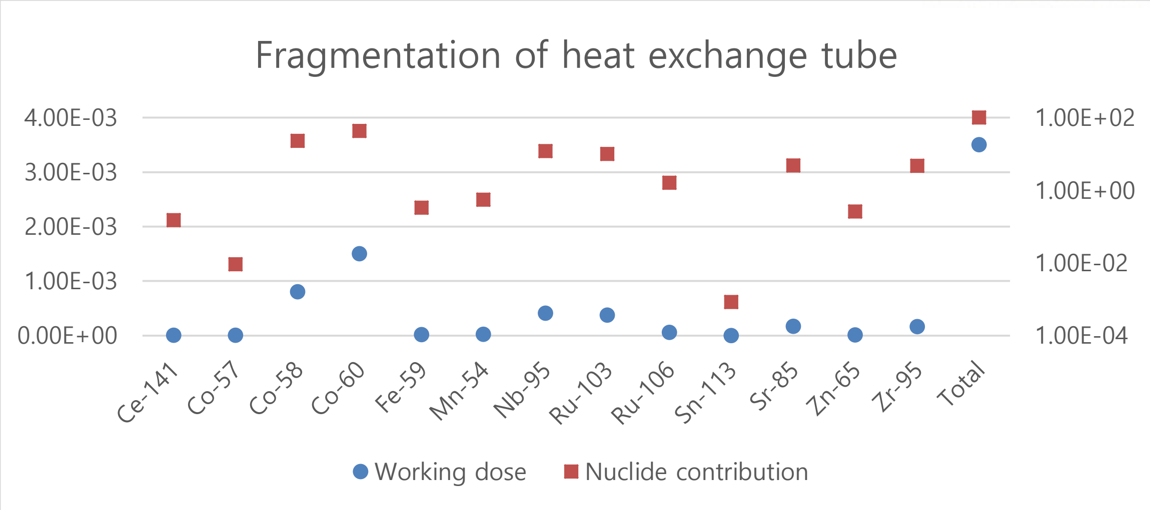

Figure 32. External dose calculation result for Fragmentation of heat exchange tube

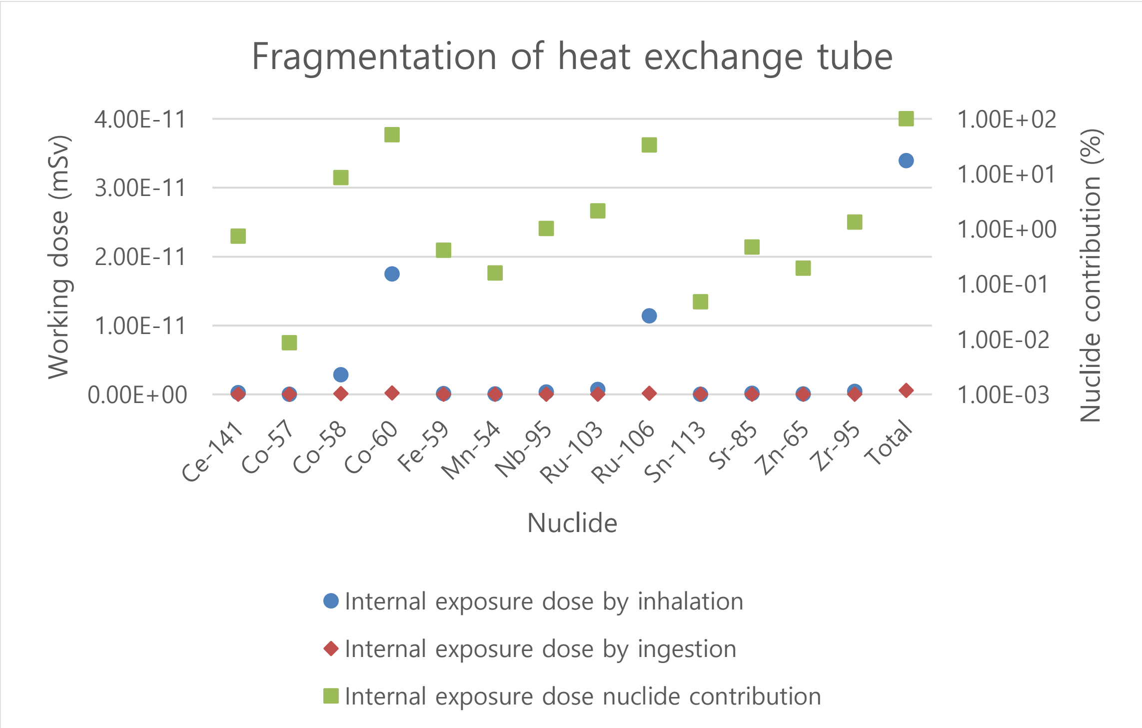

Figure 33. Internal dose calculation result for Fragmentation of heat exchange tube

Figure 32 shows worker would be exposed to total 0.0035 mSv external exposure working dose in Fragmentation of heat exchange tube process. Nuclide Co-60 and Co-58 were the most dominant. They took a share 66 % of total working dose.

Figure 33 shows worker would be exposed to total 3.45E-11 mSv internal exposure working dose in Fragmentation of heat exchange tube process. Nuclide Co-60(1.78E-11 mSv) and Ru-106(1.16E-11 mSv) were dominant. They took a share 84.9 % of total working dose.

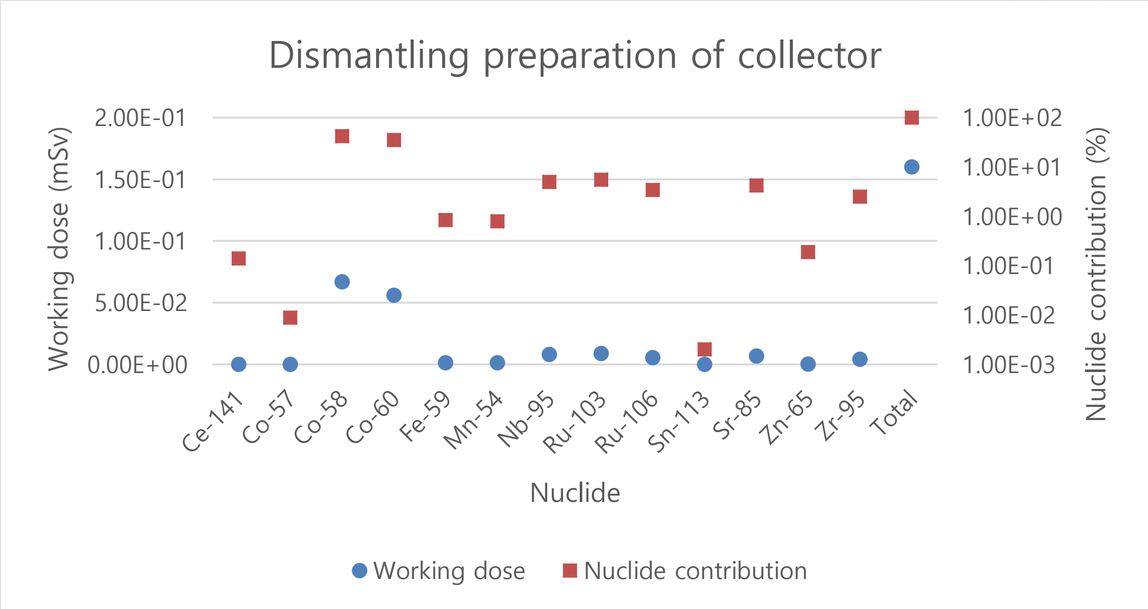

Figure 34. External dose calculation result for Dismantling preparation of collector

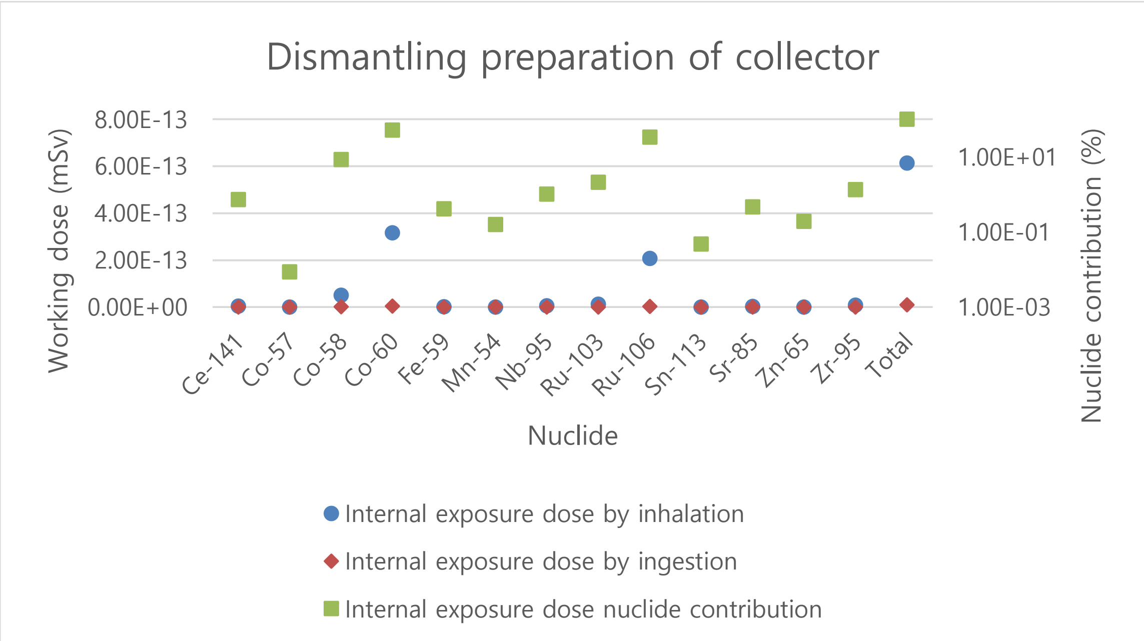

Figure 35. Internal dose calculation result for Dismantling preparation of collector

Figure 34 shows worker would be exposed to total 0.16 mSv external exposure working dose in Dismantling preparation of collector process. Nuclide Co-58 and Co-60 were the most dominant. It took a share 77 % of total working dose.

Figure 35 shows worker would be exposed to total 6.24E-13 mSv internal exposure working dose in Dismantling preparation of collector process. Nuclide Co-60 (3.21E-13 mSv) and Ru-106 (2.09E-13 mSv) were dominant. It took a share 84.9 % of total working dose.

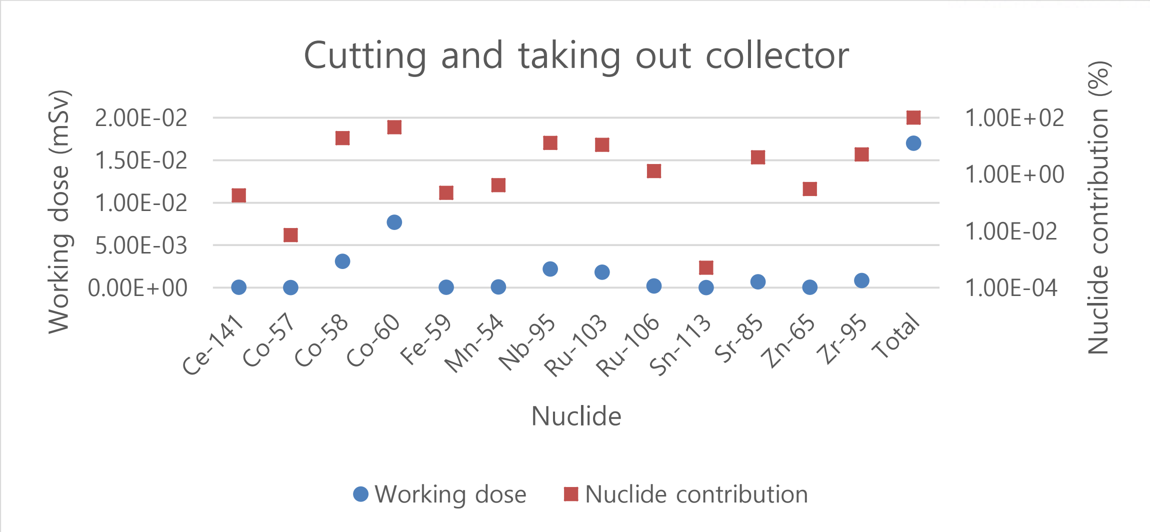

Figure 36. External dose calculation result for Cutting and taking out collector

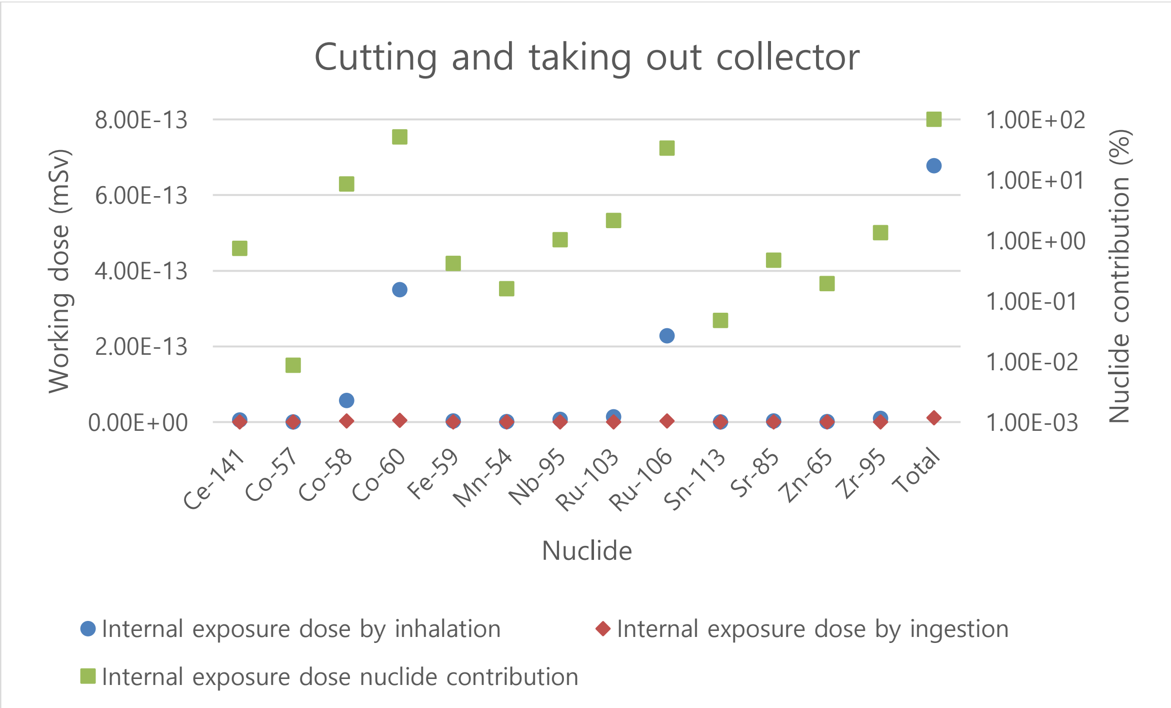

Figure 37. Internal dose calculation result for Cutting and taking out collector

Figure 36 shows worker would be exposed to total 0.017 mSv external exposure working dose in Cutting and taking out collector process. Nuclide Co-60 was the most dominant. It took a share 46 % of total working dose.

Figure 37 shows worker would be exposed to total 6.88E-13 mSv internal exposure working dose in Cutting and taking out collector process. Nuclide Co-60 (3.54E-13 mSv) was the most dominant. It took a share 51.4 % of total working dose.

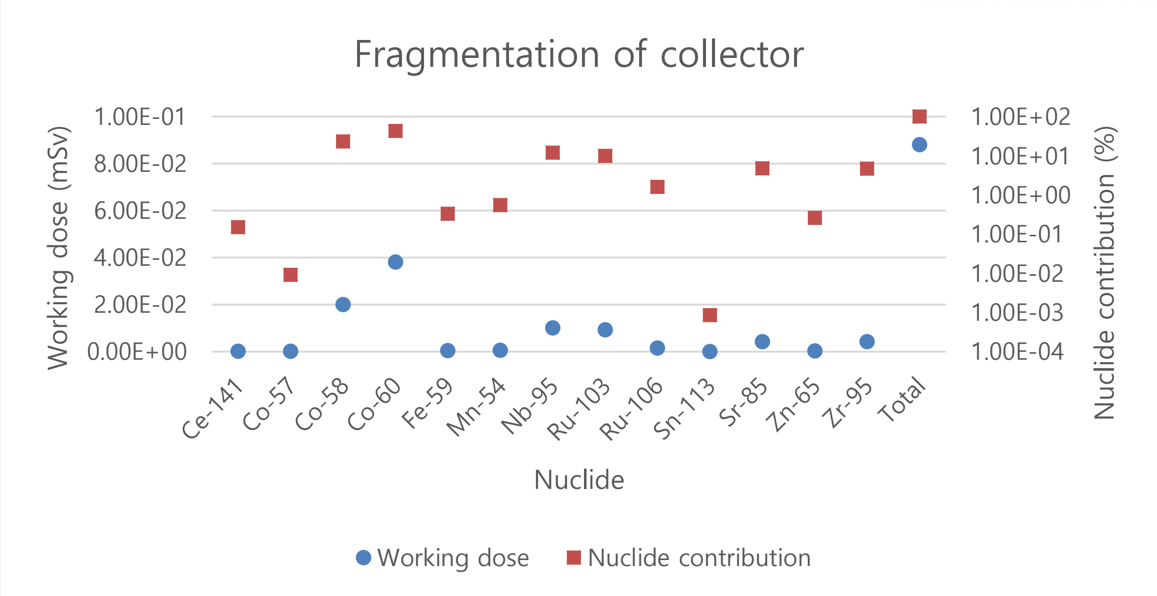

Figure 38. External dose calculation result for Fragmentation of collector

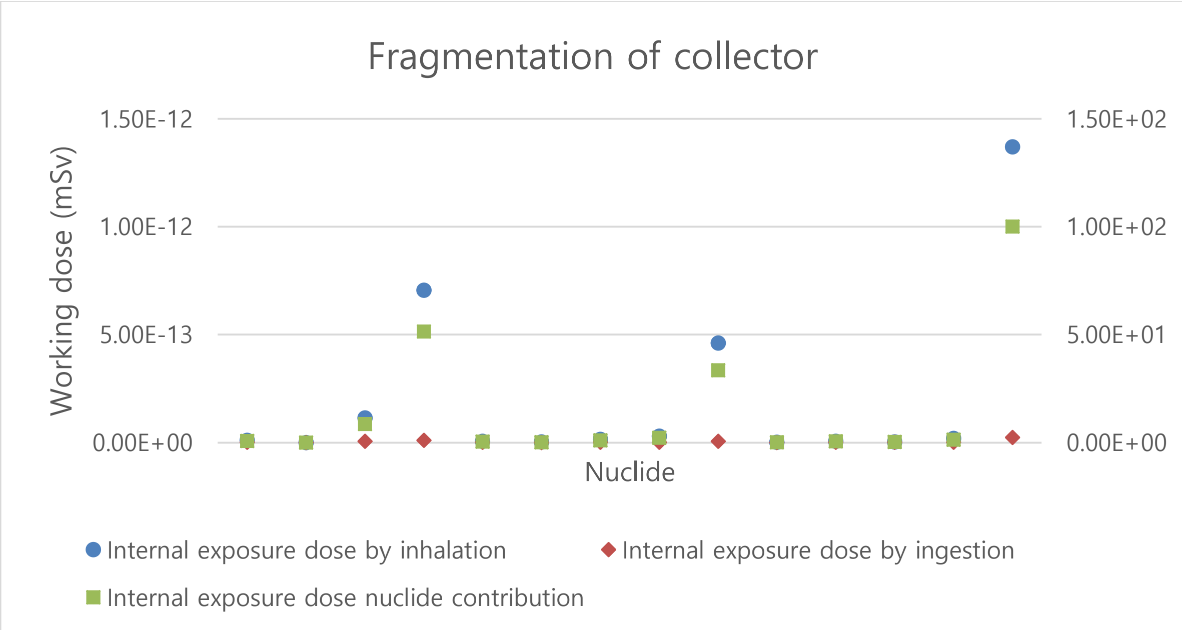

Figure 39. Internal dose calculation result for Fragmentation of collector

Figure 38 shows worker would be exposed to total 0.088 mSv external exposure working dose in Fragmentation of collector process. Nuclide Co-60 was the most dominant. It took a share 43 % of total working dose.

Figure 39 shows worker would be exposed to total 1.39E-12 mSv internal exposure dose in Fragmentation of collector process. Most internal exposure dose was from inhalation of radioactive particles, nuclide Co-60 (7.15E-13 mSv) and Ru-106 (4.65E-13 mSv) were dominant. They took a share 84.9 % of total internal exposure dose.

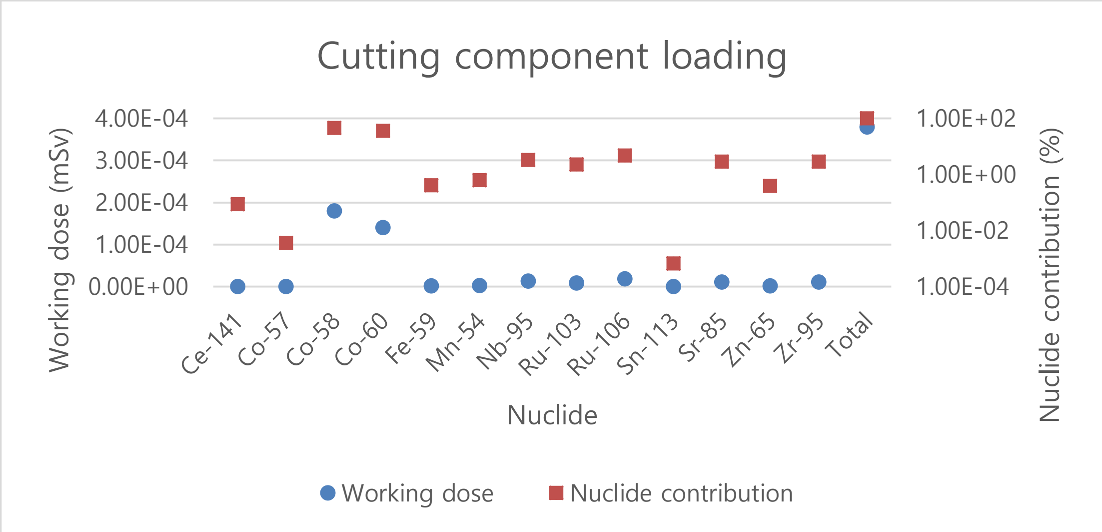

Figure 40. External dose calculation result for cutting component loading

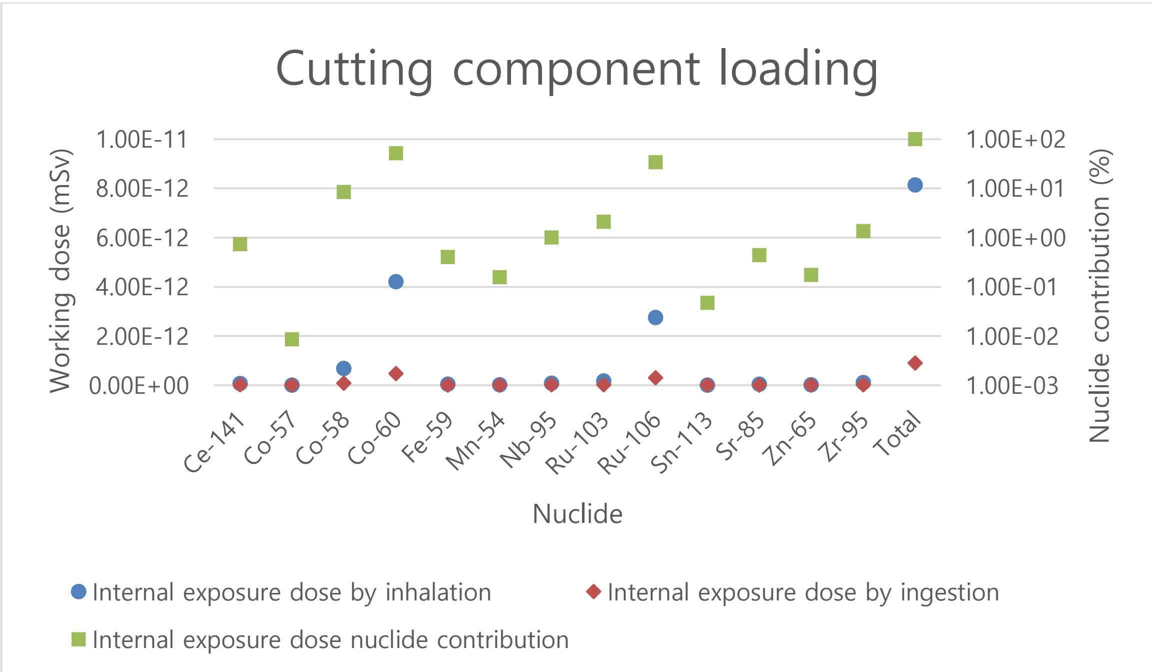

Figure 41. Internal dose calculation result for cutting component loading

Figure 40 shows worker would be exposed to total 0.00038 mSv external exposure working dose in Cutting component loading process. Nuclide Co-58 and Co-60 were dominant. It took a share 82 % of total working dose.

Figure 41 shows worker would be exposed to total 9.04E-12 mSv internal exposure dose in Cutting component loading process. Most internal exposure dose was from inhalation of radioactive particles, nuclide Co-60 (4.67E-12 mSv) and Ru-106 (3.04E-12 mSv) were dominant. They took a share 85.2 % of total internal exposure dose.

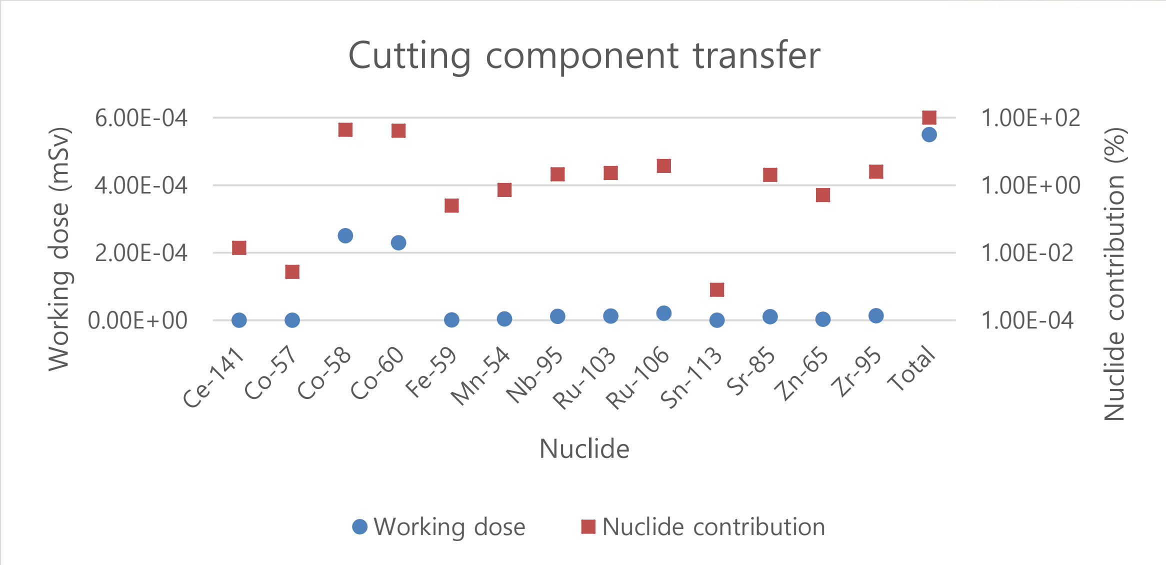

Figure 42. External dose calculation result for cutting component transfer

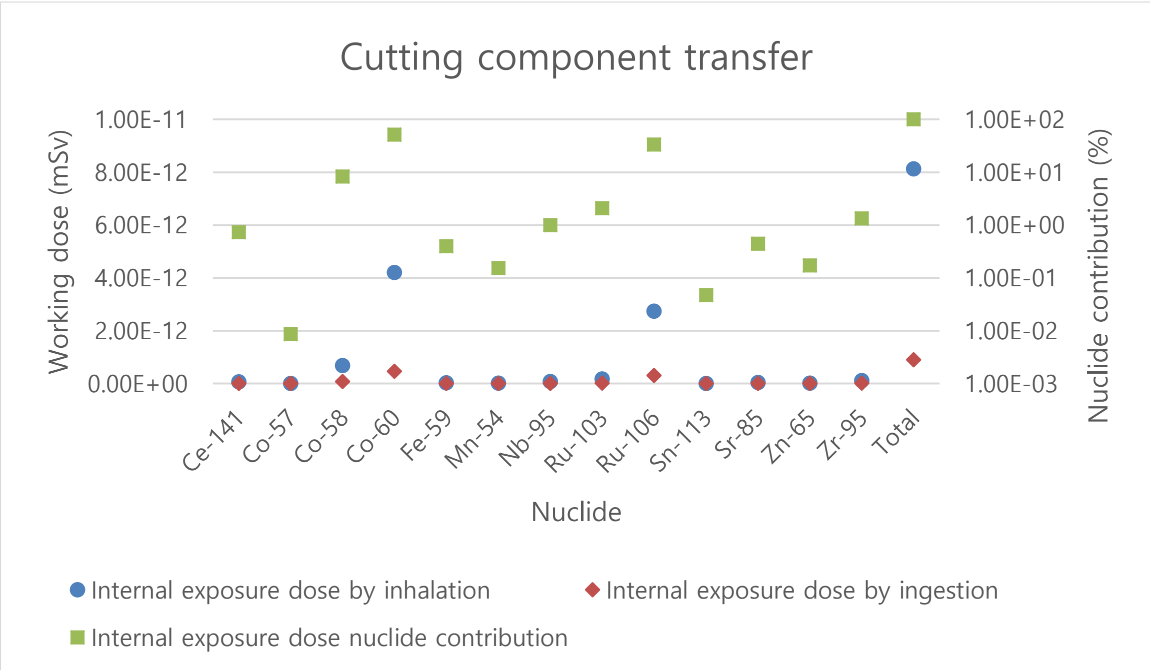

Figure 43. Internal dose calculation result for cutting component transfer

Figure 42 shows worker would be exposed to total 0.00055 mSv external exposure working dose in Cutting component transfer process. Nuclide Co-58 and Co-60 were dominant. It took a share 85 % of total working dose.

Figure 43 shows worker would be exposed to total 9.04E-12 mSv internal exposure dose in Cutting component transfer process. Most internal exposure dose was from inhalation of radioactive particles, nuclide Co-60 (4.67E-12 mSv) and Ru-106 (3.04E-12 mSv) were dominant. They took a share 85.2 % of total internal exposure dose.

Figure 44. Steam generator transfer

Actual Steam generator transfer by truck was described in this figure 34 [17]. Using truck, steam generator was loaded and unloaded after cutting and decontamination processing and packaging. Actually, cutting component loading, transfer and treatment would take each 240 minutes, 240 minutes, 720 minutes. Through transfer operation, worker receive 9.04E-12 mSv internal exposure dose and 0.00055 mSv external exposure dose. Similarly, cutting component treatment. Loading operation causes worker radiation external/internal exposure.

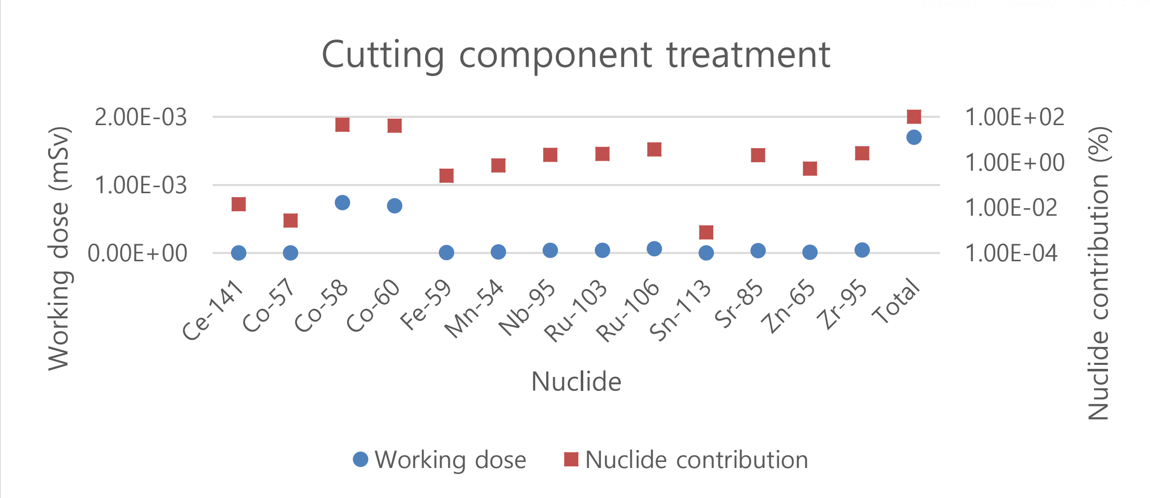

Figure 45. External dose calculation result for cutting component treatment

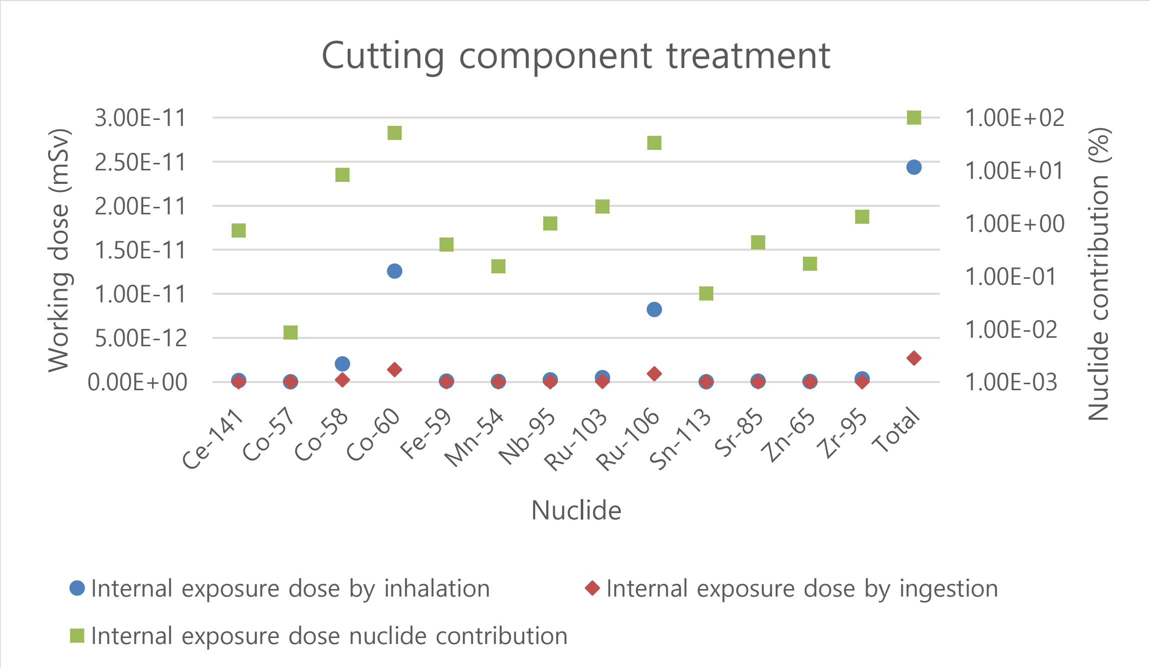

Figure 46. Internal dose calculation result for cutting component treatment

Figure 45 shows worker would be exposed to total 0.0017 mSv external exposure working dose in Cutting component treatment process. Nuclide Co-58 and Co-60 were dominant. It took a share 85 % of total working dose.

Figure 46 shows worker would be exposed to total 2.71E-11 mSv internal exposure dose in Cutting component treatment process. Most internal exposure dose was from inhalation of radioactive particles, nuclide Co-60 (1.40E-11 mSv) and Ru-106 (9.12E-12 mSv) were dominant. They took a share 85.2 % of total internal exposure dose.

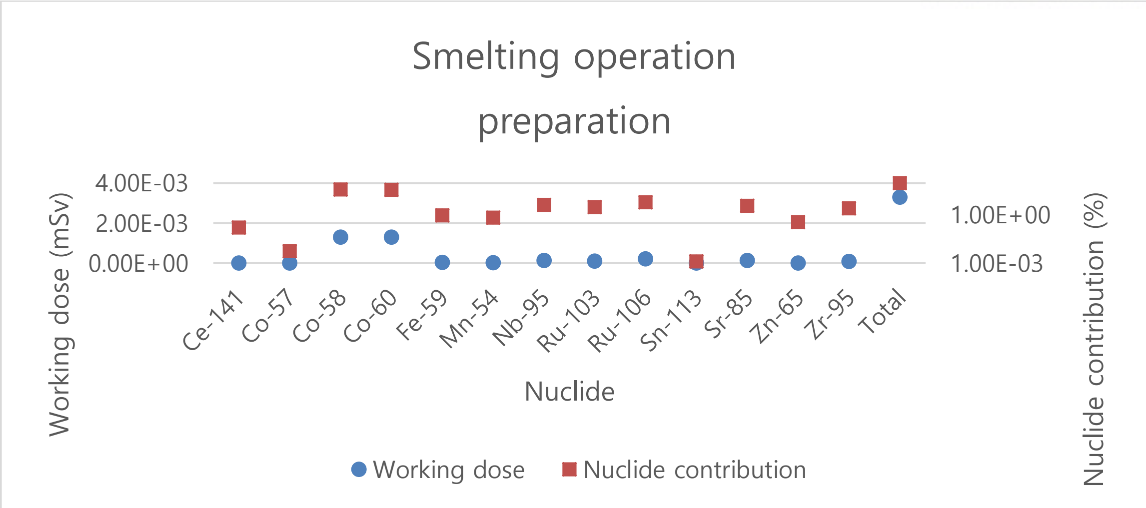

Figure 47. External dose calculation result for smelting operation preparation

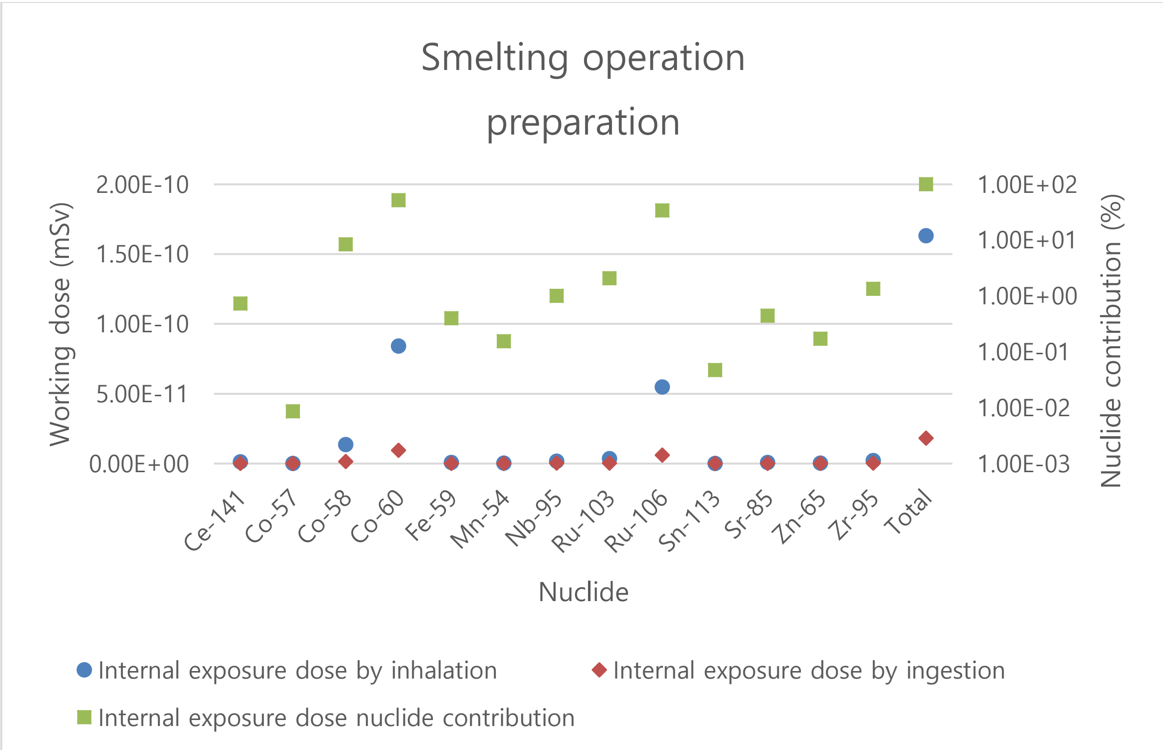

Figure 48. Internal dose calculation result for smelting operation preparation

Figure 47 shows worker would be exposed to total 0.0033 mSv external exposure working dose in Smelting operation preparation process. Nuclide Co-58 and Co-60 were dominant. It took a share 77 % of total working dose.

Figure 48 shows worker would be exposed to total 1.81E-10 mSv internal exposure dose in Smelting operation preparation process. Most internal exposure dose was from inhalation of radioactive particles, nuclide Co-60 (9.33E-11 mSv) and Ru-106 (6.08E-11 mSv) were dominant. They took a share 85.2 % of total internal exposure dose.

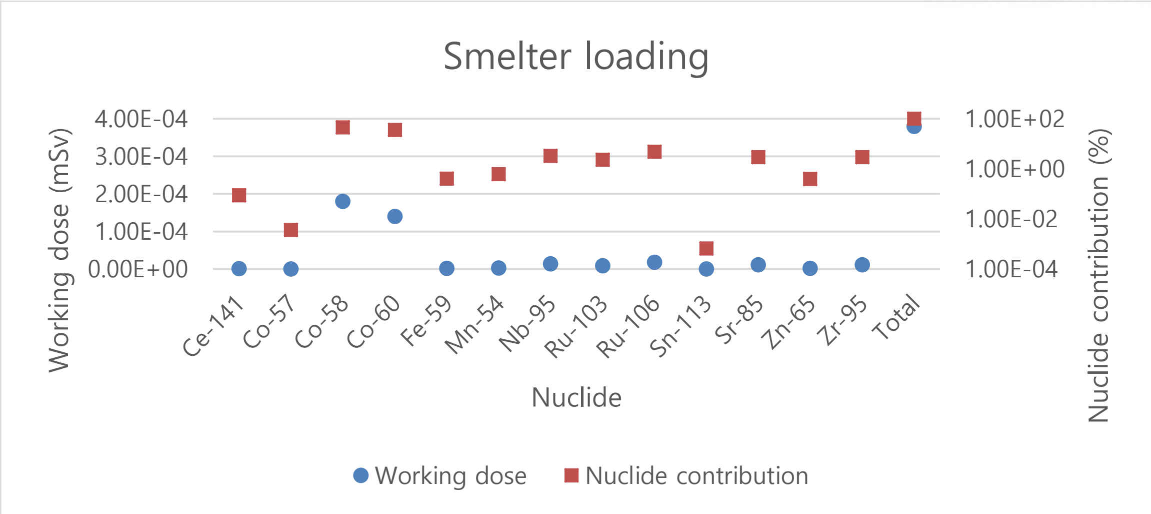

Figure 49. External dose calculation result for smelter loading

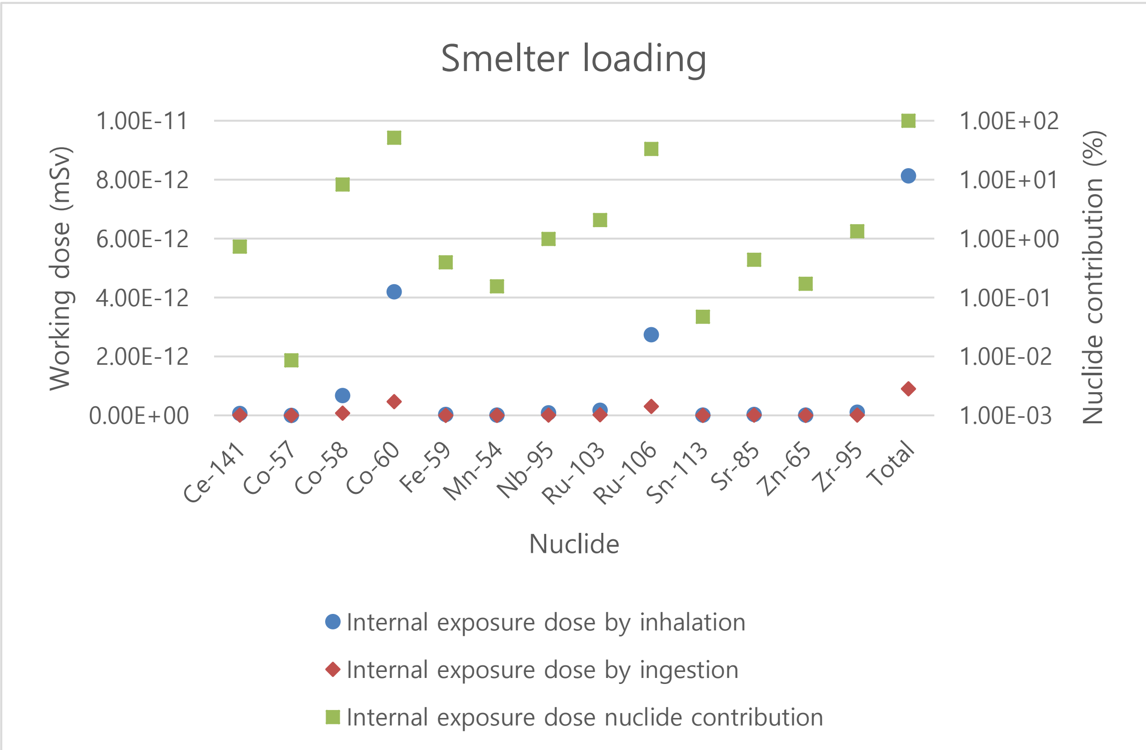

Figure 50. Internal dose calculation result for smelter loading

Figure 49 shows worker would be exposed to total 0.00038 mSv external exposure working dose in Smelter loading process. Nuclide Co-58 and Co-60 were dominant. It took a share 82 % of total working dose.

Figure 50 shows worker would be exposed to total 9.04E-12 mSv internal exposure dose in Smelter loading process. Most internal exposure dose was from inhalation of radioactive particles, nuclide Co-60 (4.67E-12 mSv) and Ru-106 (3.04E-12 mSv) were dominant. They took a share 85.2 % of total internal exposure dose.

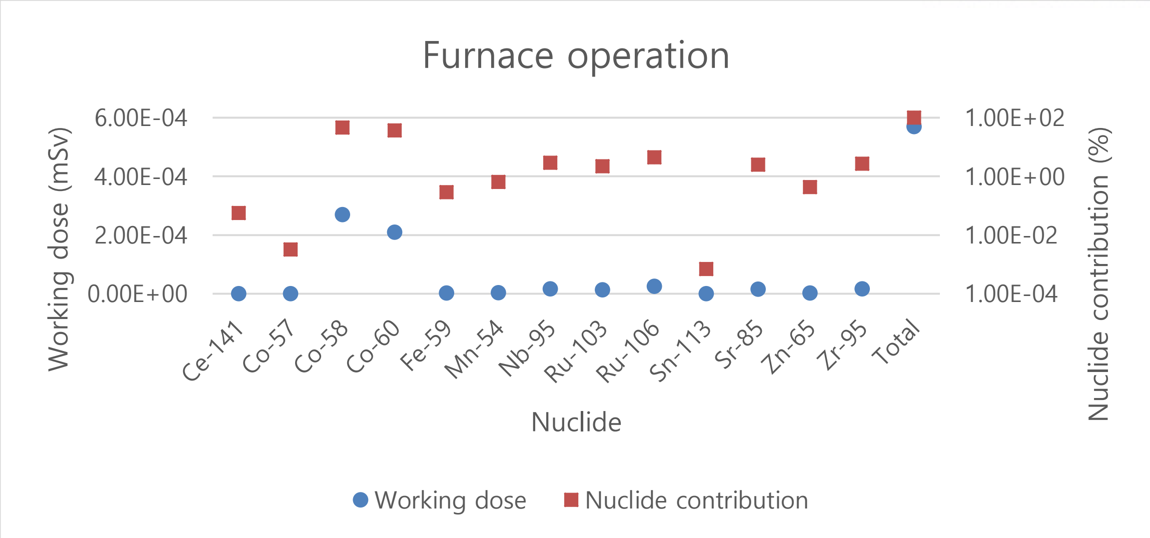

Figure 51. External dose calculation result for furnace operation

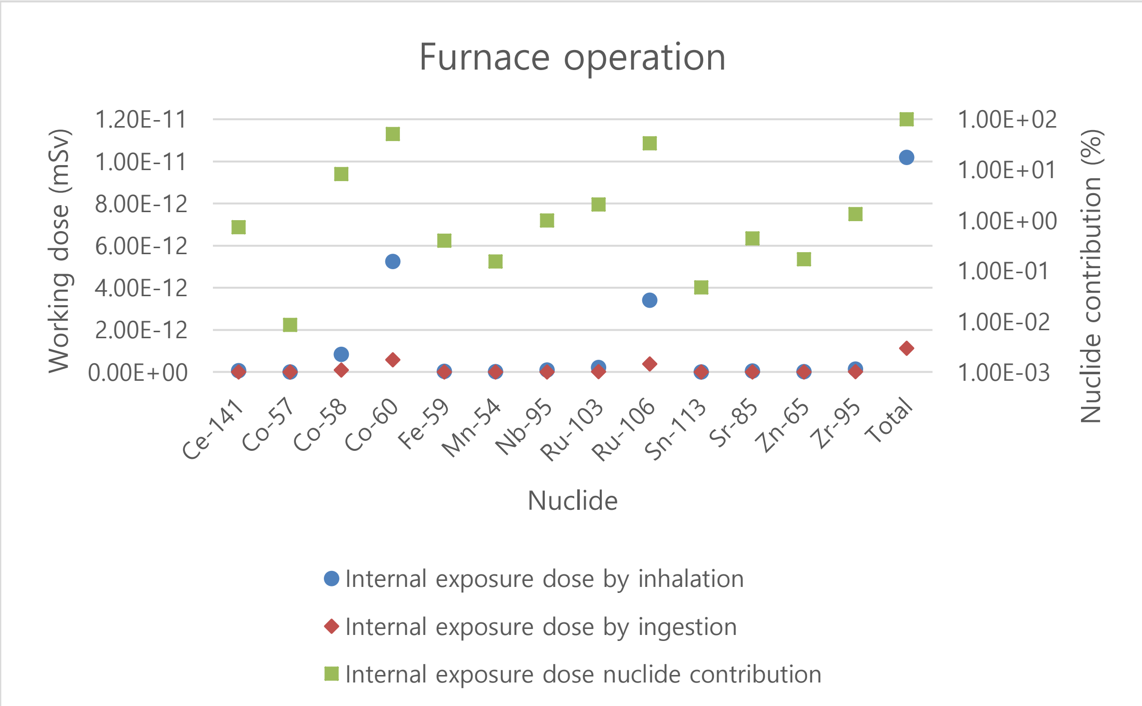

Figure 52. Internal dose calculation result for furnace operation

Figure 51 shows worker would be exposed to total 0.00057 mSv external exposure working dose in Furnace operation process. Nuclide Co-58 and Co-60 were dominant. It took a share 83 % of total working dose.

Figure 52 shows worker would be exposed to total 1.13E-11 mSv internal exposure dose in Furnace operation process. Most internal exposure dose was from inhalation of radioactive particles, nuclide Co-60 (5.83E-12 mSv) and Ru-106 (3.80E-12 mSv) were dominant. They took a share 85.2 % of total internal exposure dose.

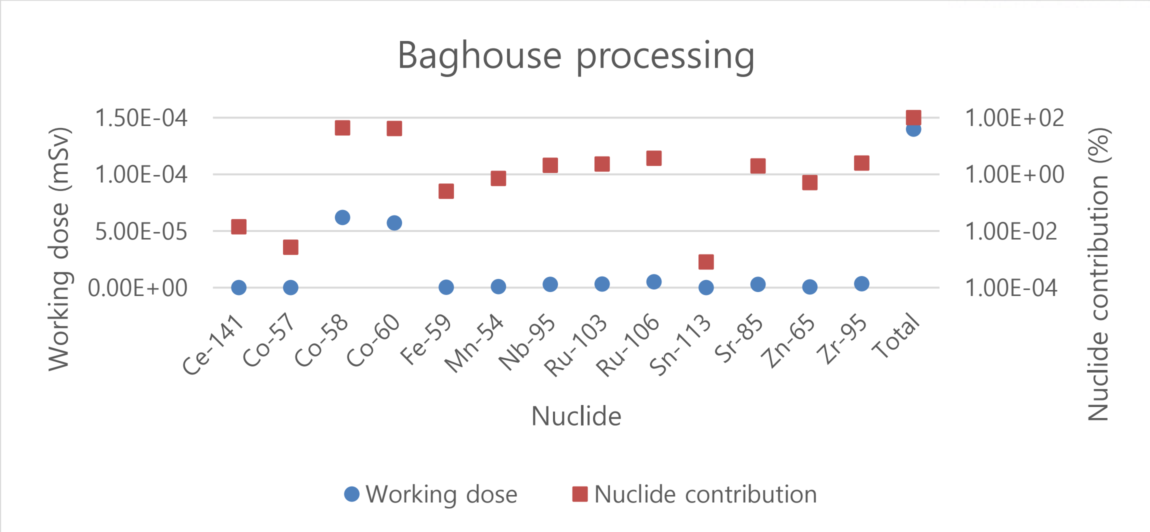

Figure 53. External dose calculation result for baghouse processing

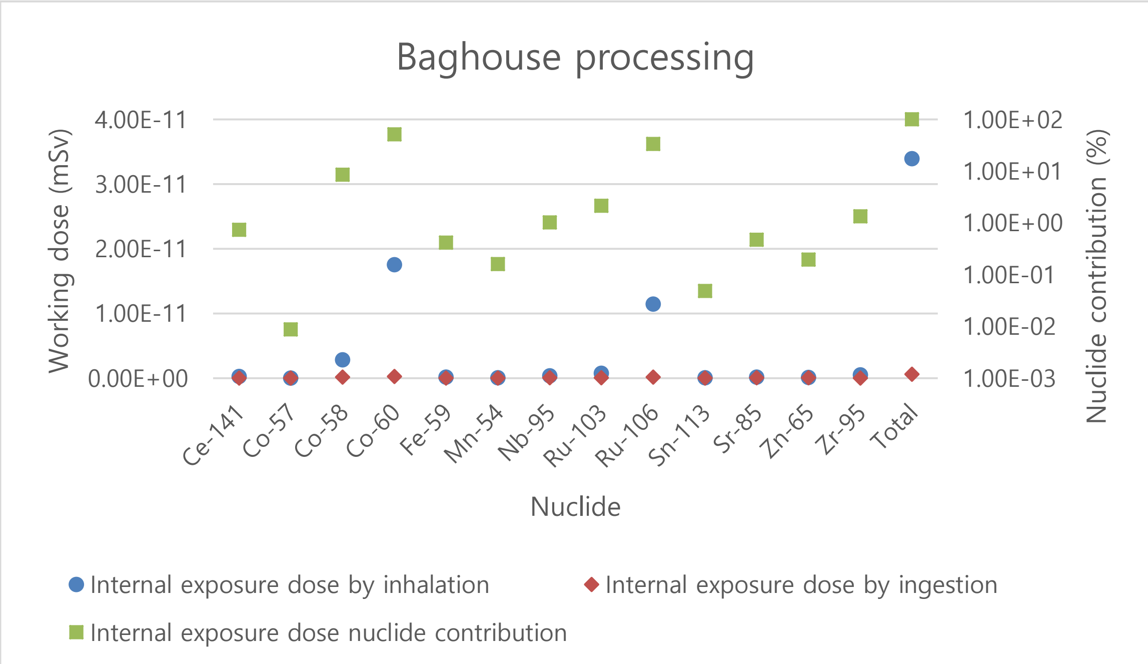

Figure 54. External dose calculation result for baghouse processing

Figure 53 shows worker would be exposed to total 0.00014 mSv external exposure working dose in Baghouse processing process. Nuclide Co-58 and Co-60 were dominant. It took a share 85 % of total working dose.

Figure 54 shows worker would be exposed to total 3.45E-11 mSv internal exposure dose in Baghouse processing process. Most internal exposure dose was from inhalation of radioactive particles, nuclide Co-60 (1.78E-11 mSv) and Ru-106 (1.16E-11 mSv) were dominant. They took a share 84 % of total internal exposure dose.

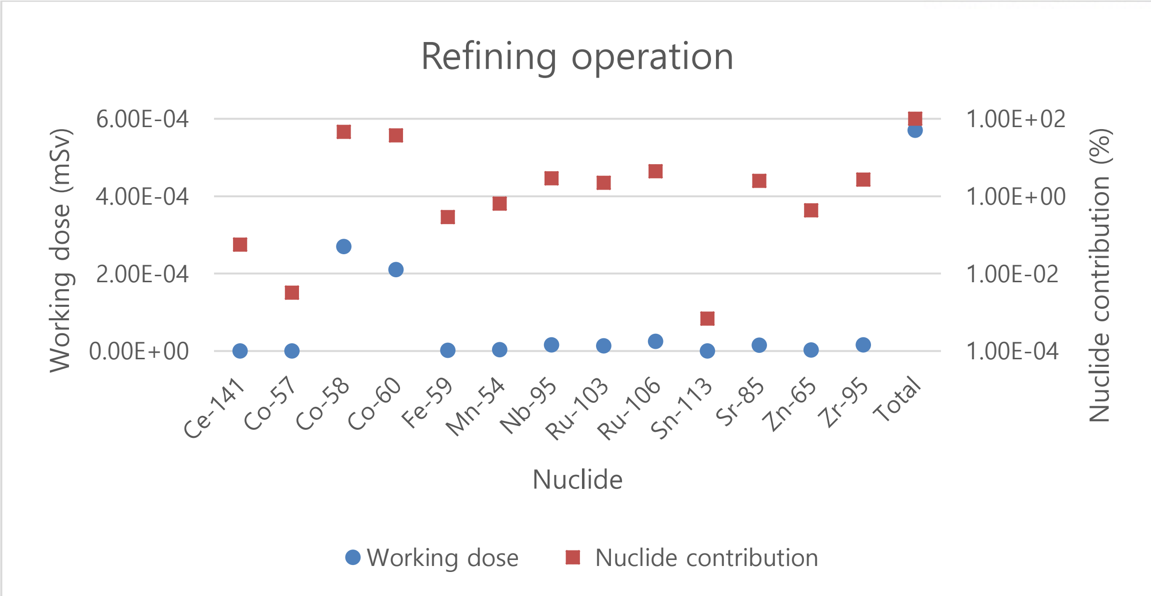

Figure 55. External dose calculation result for refining operation

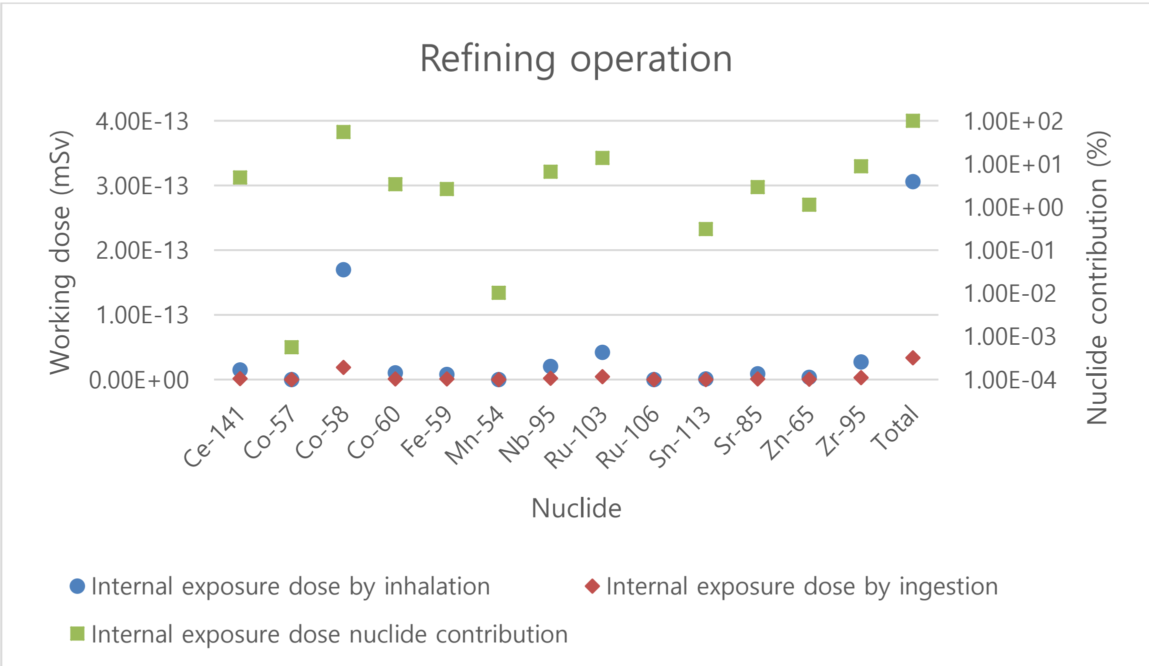

Figure 56. External dose calculation result for refining operation

Figure 55 shows worker would be exposed to total 0.00057 mSv external exposure working dose in Refining operation process. Nuclide Co-58 and Co-60 were dominant. It took a share 83 % of total working dose.

Figure 56 shows worker would be exposed to total 3.40E-13 mSv internal exposure dose in Refining operation process. Most internal exposure dose was from inhalation of radioactive particles, nuclide Co-58 (1.88E-13 mSv) was dominant. They took a share 55.3 % of total internal exposure dose.

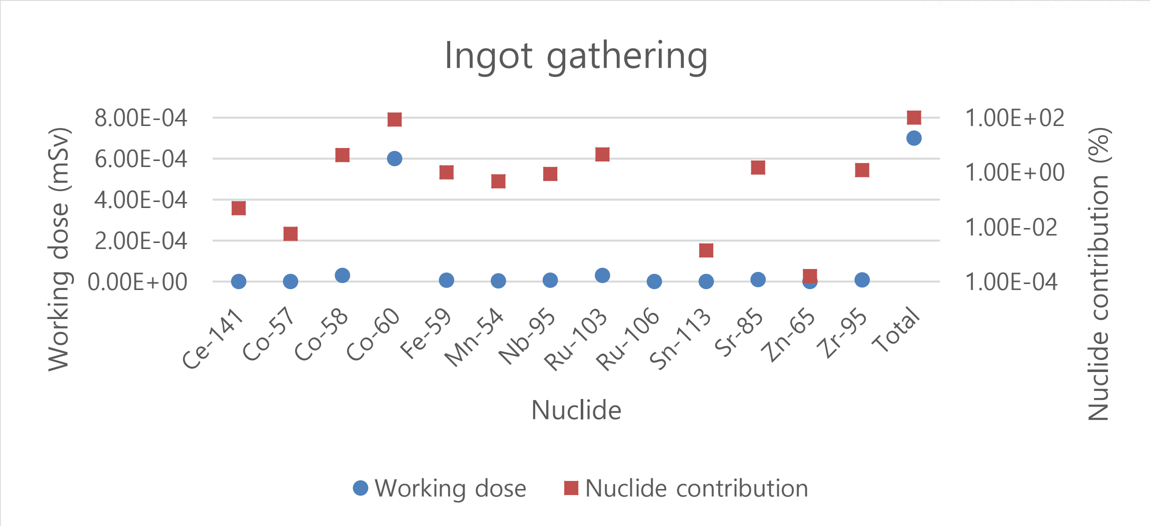

Figure 57. External dose calculation result for ingot gathering

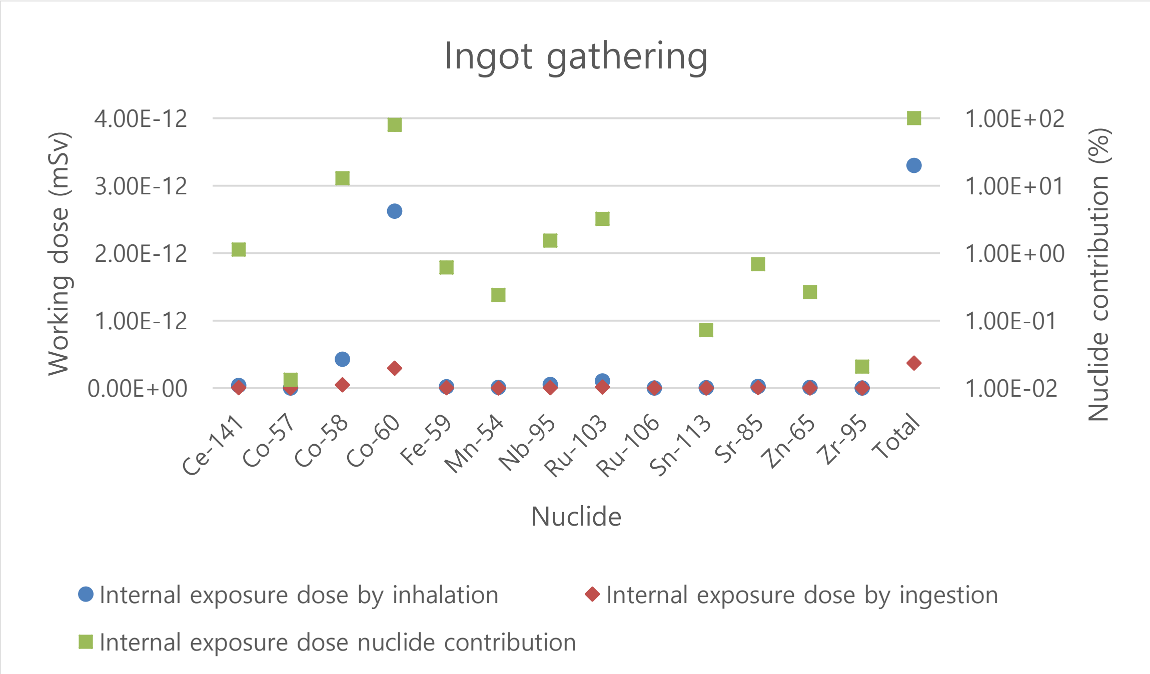

Figure 58. Internal dose calculation result for ingot gathering

Figure 57 shows worker would be exposed to total 0.0007 mSv external exposure working dose in Ingot gathering process. Nuclide Co-60 was the most dominant. It took a share 86 % of total working dose.

Figure 58 shows worker would be exposed to total 3.67E-12 mSv internal exposure dose in Ingot gathering process. Most internal exposure dose was from inhalation of radioactive particles, nuclide Co-60 (2.92E-12 mSv) was the most dominant. It took a share 79.4 % of total internal exposure dose. Internal exposure dose by Ru-106 was not happen considering nuclide partitioning factor of ingot form.

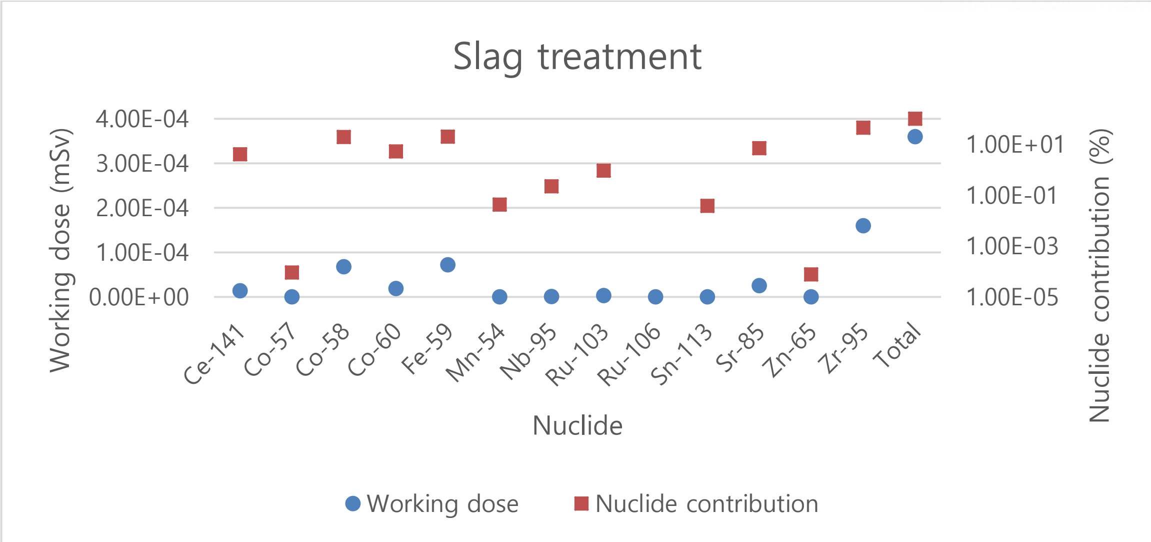

Figure 59. External dose calculation result for slag treatment

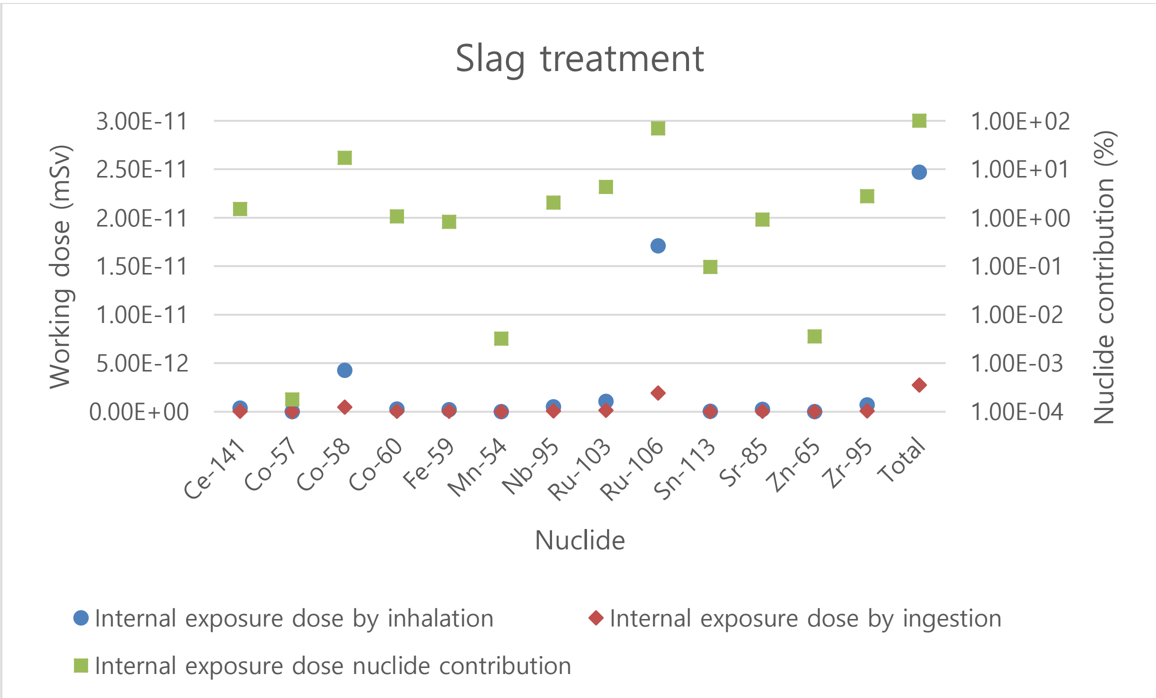

Figure 60. Internal dose calculation result for slag treatment

Figure 59 shows worker would be exposed to total 0.00036 mSv external exposure working dose in Slag treatment process. Nuclide Zr-95(44 %) was the most dominant and Co-58(19 %), Fe-59(20 %) are following. Zr-59 took a share 44 % of total working dose.

Figure 60 shows worker would be exposed to total 2.74E-11 mSv internal exposure dose in Slag treatment process. Most internal exposure dose was from inhalation of radioactive particles, nuclide Ru-105 (1.90E-11mSv) was the most dominant. It took a share 69.3 % of total internal exposure dose.

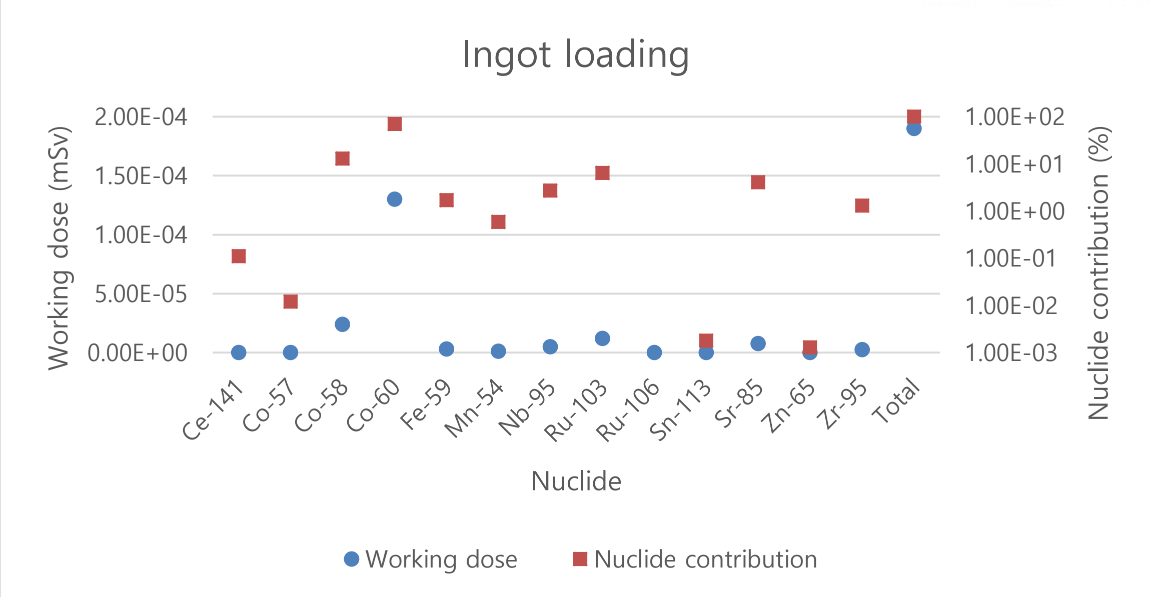

Figure 61. External dose calculation result for ingot loading

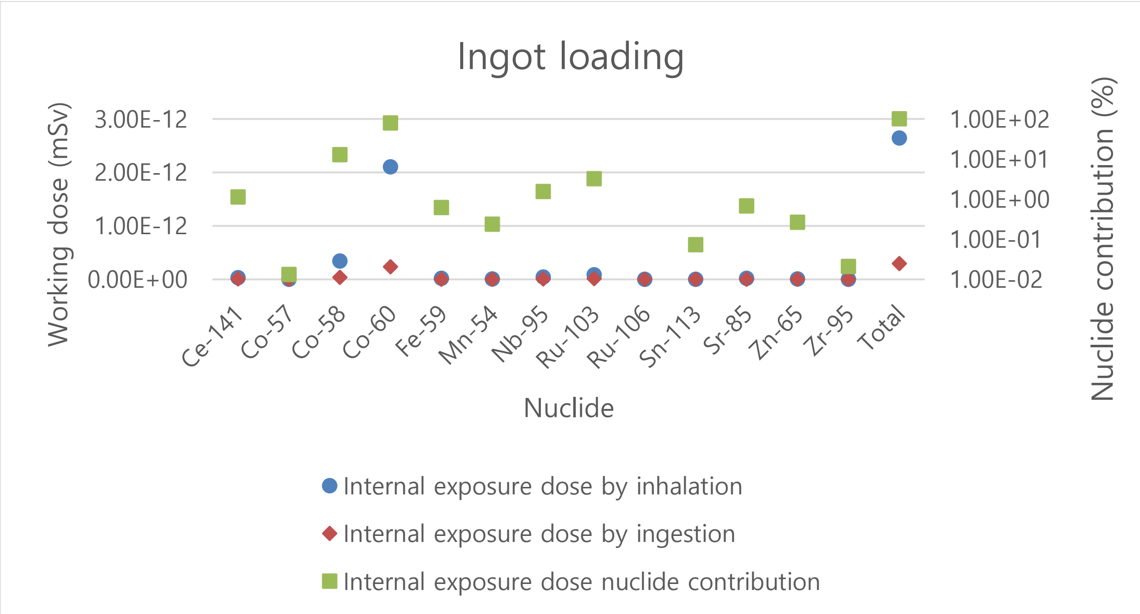

Figure 62. Internal dose calculation result for ingot loading

Figure 61 shows worker would be exposed to total 0.00019 mSv external exposure working dose in Ingot loading process. Nuclide Co-60 was the most dominant. It took a share 70 % of total working dose.

Figure 62 shows worker would be exposed to total 2.94E-12 mSv internal exposure dose in Ingot loading process. Most internal exposure dose was from inhalation of radioactive particles, nuclide Co-60 (2.33E-12 mSv) was the most dominant. It took a share 79.4 % of total internal exposure dose. Internal exposure dose by Ru-106 was not happen considering nuclide partitioning factor of ingot form.

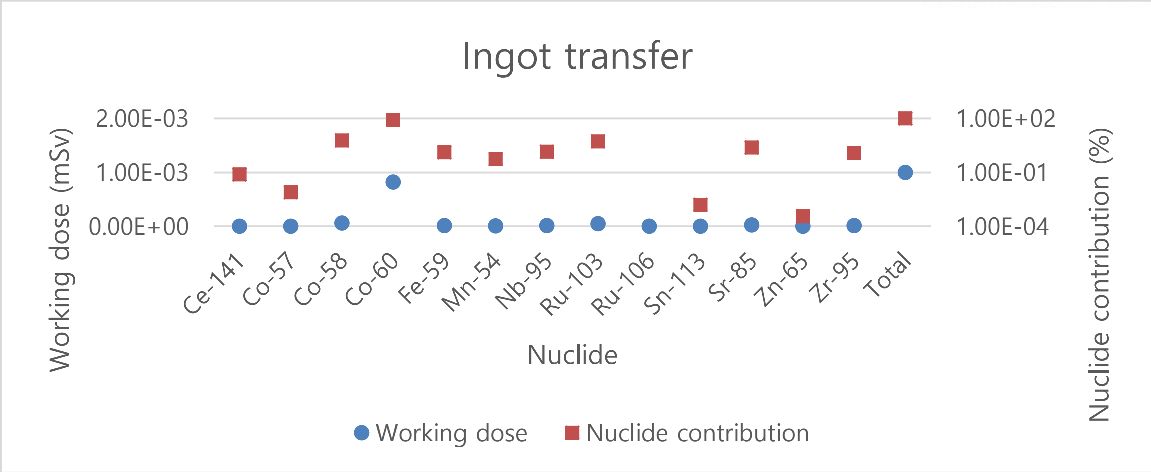

Figure 63. External dose calculation result for ingot transfer

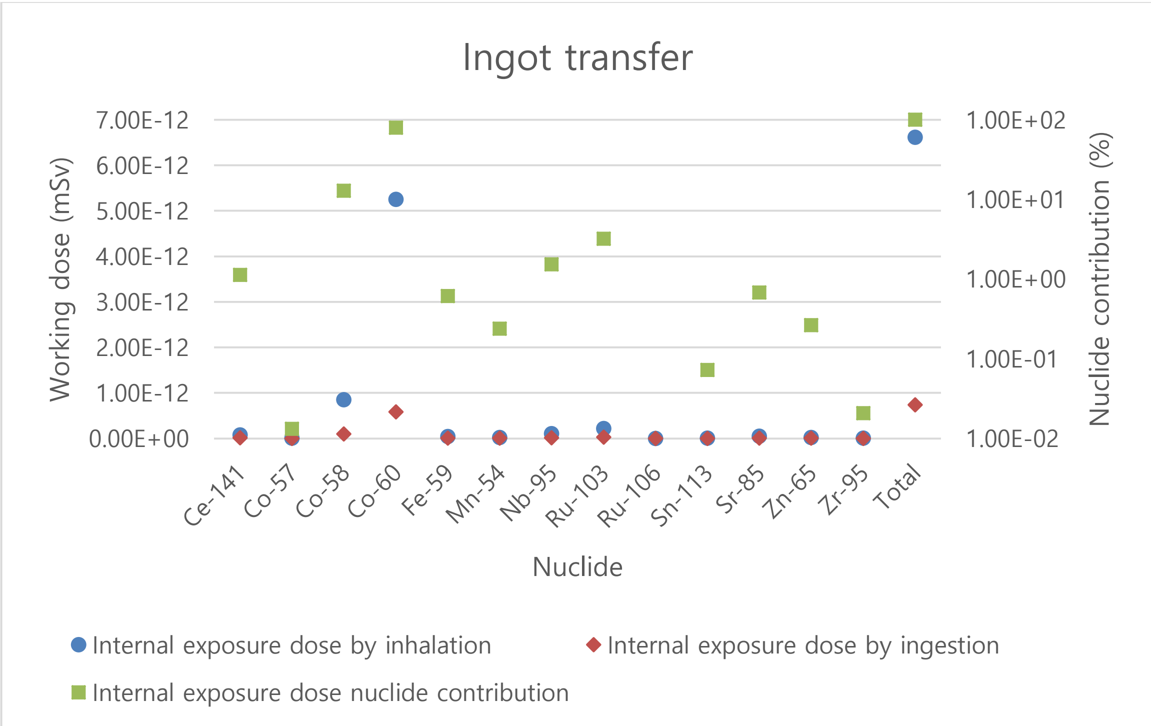

Figure 64. Internal dose calculation result for ingot transfer

Figure 63 shows worker would be exposed to total 0.001 mSv external exposure working dose in Ingot transfer process. Nuclide Co-60 was the most dominant. It took a share 82 % of total working dose.

Figure 64 shows worker would be exposed to total 7.34E-12 mSv internal exposure dose in Ingot transfer process. Most internal exposure dose was from inhalation of radioactive particles, nuclide Co-60 (5.83E-12 mSv) was the most dominant. It took a share 79.4 % of total internal exposure dose. Internal exposure dose by Ru-106 was not happen considering nuclide partitioning factor of ingot form.

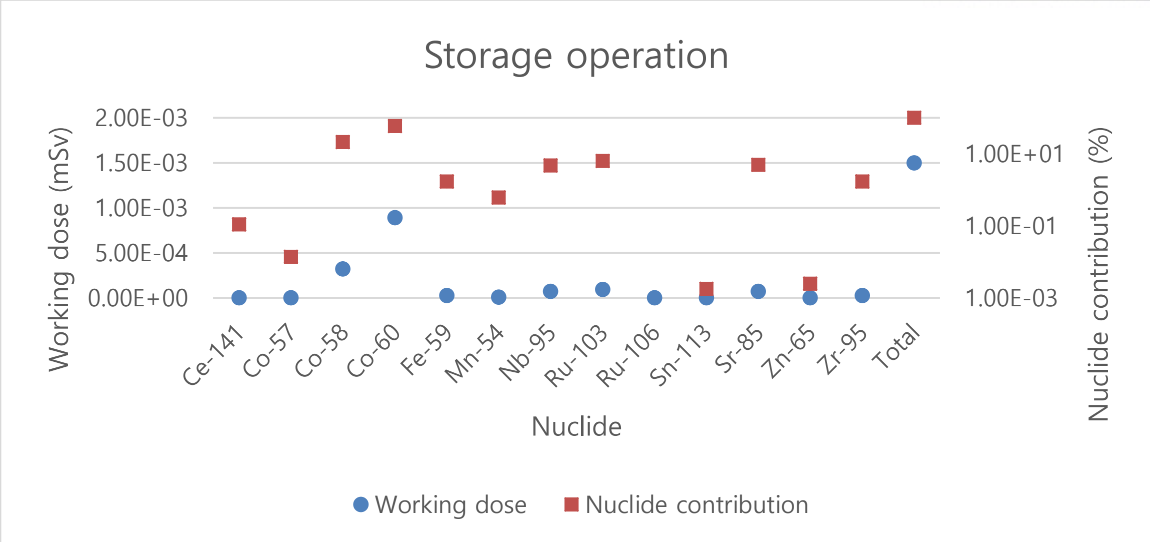

Figure 65. External dose calculation result for storage operation

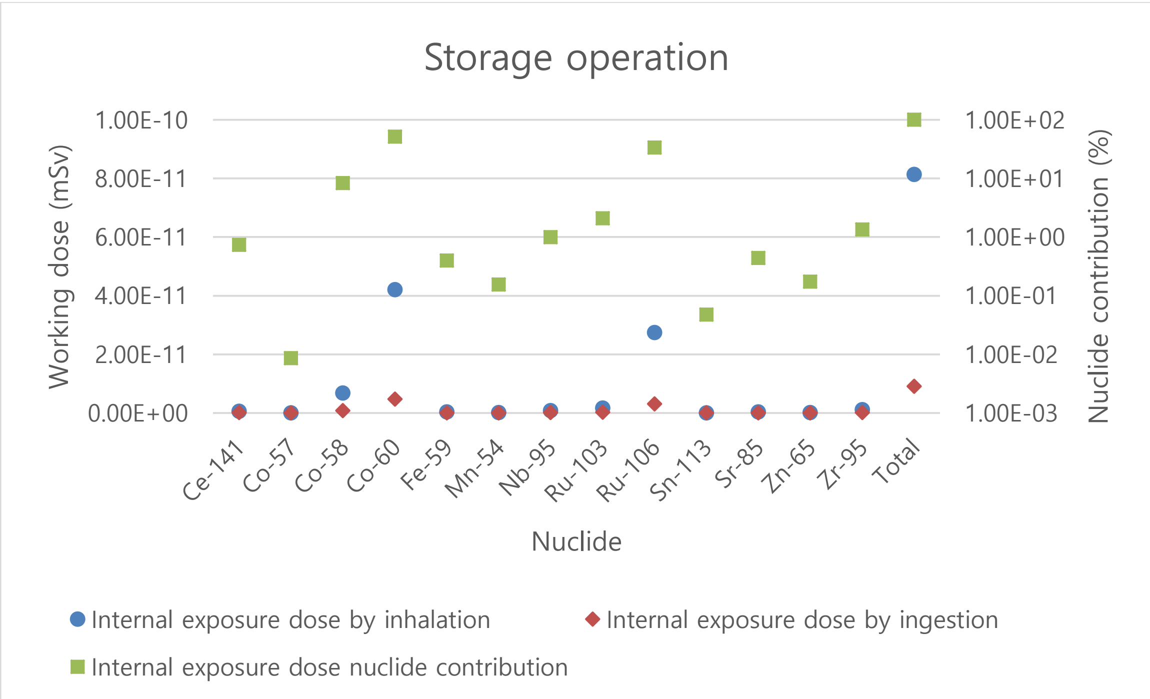

Figure 66. Internal dose calculation result for storage operation

Figure 65 shows worker would be exposed to total 0.0015 mSv external exposure working dose in Storage operation process. Nuclide Co-60 was the most dominant. It took a share 59 % of total working dose.

Figure 66 shows worker would be exposed to total 9.04E-11 mSv internal exposure dose in Storage operation process. Most internal exposure dose was from inhalation of radioactive particles, nuclide Co-60 (4.67E-11 mSv) was the most dominant. It took a share 51.6 % of total internal exposure dose.

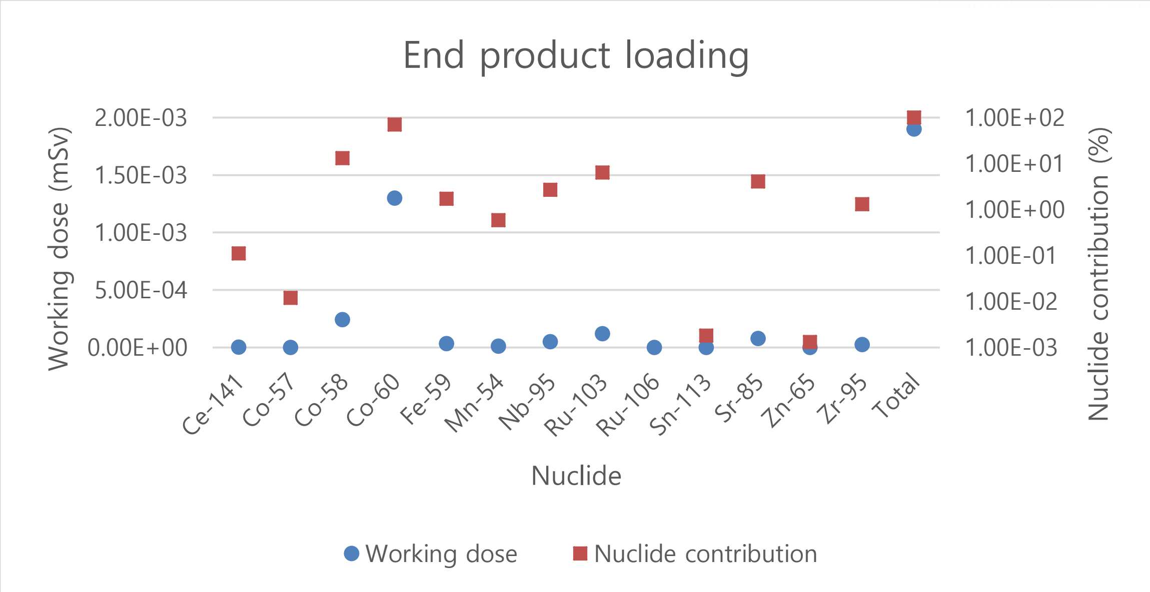

Figure 67. External dose calculation result for End product loading

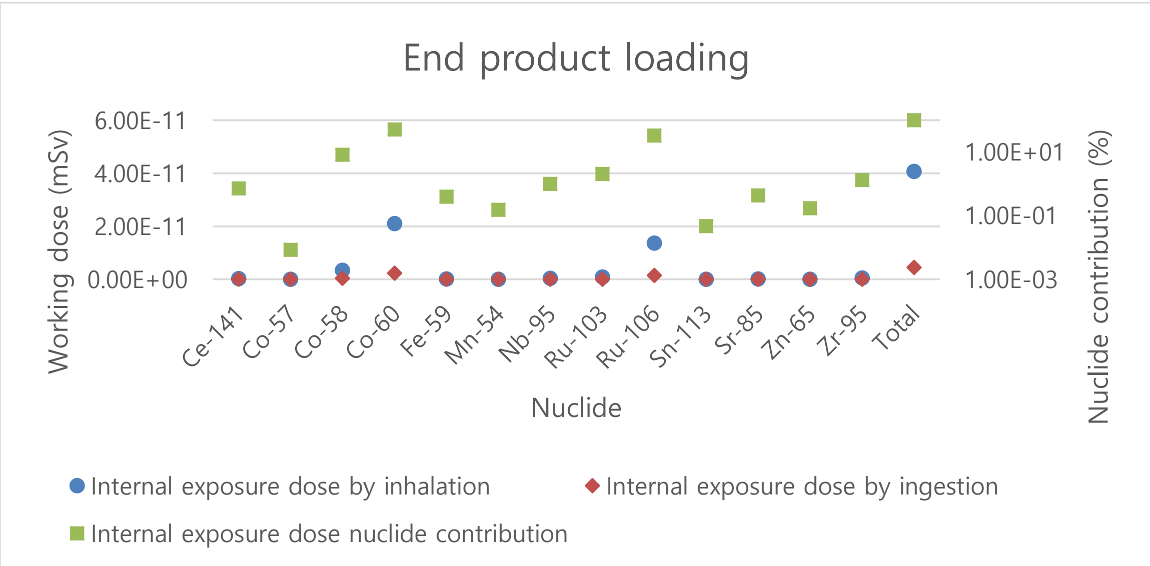

Figure 68. Internal dose calculation result for End product loading

Figure 67 shows worker would be exposed to total 0.0019 mSv external exposure working dose in End product loading process. Nuclide Co-60 was the most dominant. It took a share 70 % of total working dose.

Figure 68 shows worker would be exposed to total 4.52E-11 mSv internal exposure dose in End product loading process. Most internal exposure dose was from inhalation of radioactive particles, nuclide Co-60 (2.33E-11 mSv) was the most dominant. It took a share 51.6 % of total internal exposure dose.

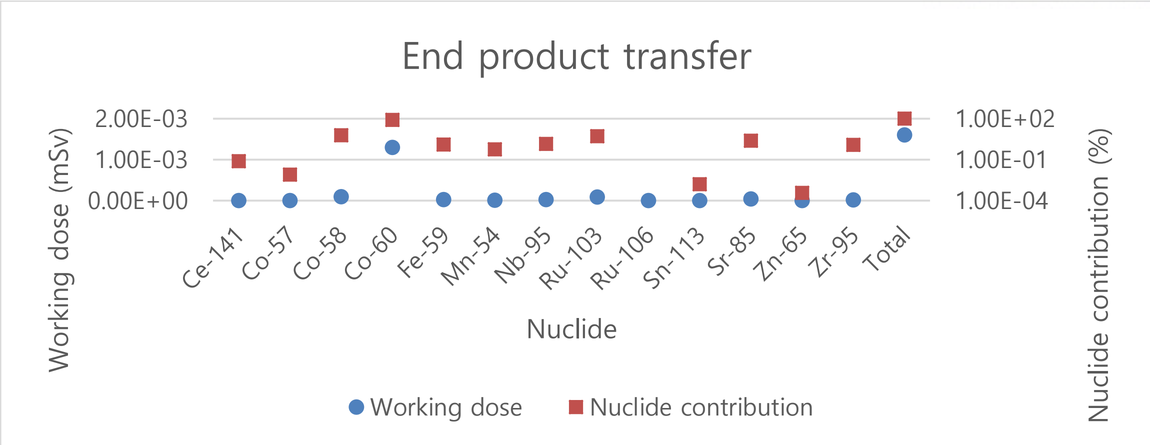

Figure 69. External dose calculation result for end product transfer

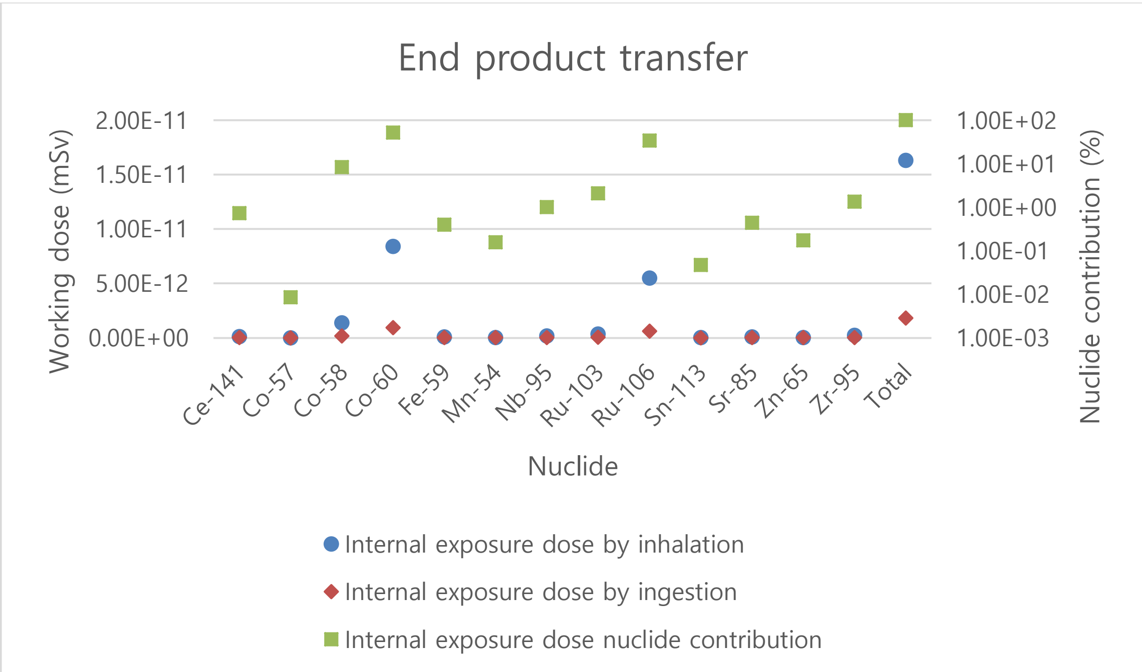

Figure 70. Internal dose calculation result for end product transfer

Figure 69 shows worker would be exposed to total 0.0016 mSv external exposure working dose in End product transfer process. Nuclide Co-60 was the most dominant. It took a share 82 % of total working dose.

Figure 70 shows worker would be exposed to total 1.81E-11 mSv internal exposure dose in End product transfer process. Most internal exposure dose was from inhalation of radioactive particles, nuclide Co-60 (9.33E-12mSv) was the most dominant. It took a share 51.6 % of total internal exposure dose.

V. Conclusions

Expected decommissioning operations of steam generator in Kori-1 was set largely by 3 parts. Each part is decommissioning preparation process, cutting process and smelting decontamination and recycling process. Each part also is composed of several operations, decommissioning preparation is composed by 10 operations, cutting process is composed by 10 operations and smelting decontamination and recycling process is composed by 15 operations each.

As a radiation exposure calculation and analysis result, external exposure value was distributed from minimum 4.1×10^{-22} mSv by Fe-59 (98% of nuclide dose contribution) in Containment vessel amputation and restoration operation to maximum 0.16 mSv by Co-58 and Co-60 (79% of nuclide dose contribution) in Dismantling preparation of collector operation. Also, internal exposure value was distributed from minimum 3.4×10^{-13} mSv in Refining operation by Co-60 and Ru-106 to maximum 1.8×10^{-10} mSv in Smelting operation preparation by Co60 (51.6%) and Ru-106 (33.6%). Both internal exposure value was made by Co-60 and Ru-106 radionuclides (84% of nuclide dose contribution).

Internal exposure dose value was very higher than external exposure dose value that's because complete inhalation or ingestion situation was assumed for every decommissioning processes and committed effective dose concept was applied. Exposure dose was very different on each operation depending on working distance and working time of worker. However, additional consideration about decontamination effect by developing technologies or methods would make lower exposure value than current results. By doing these, understanding of upcoming steam generator decommissioning operation process was possible. Utilization of worker exposure evaluation could be helpful to uncertain decommissioning operation plan establishment and operation risk evaluation. Possible operation classification and worker participation rate control are also possible. Using this data in thesis, hope undecided decommissioning process would be set reasonably, safe decommissioning operation design and additional radiation protection equipment and method development guarantees safe Kori-1 decommissioning operation with no accident.

VI. Reference

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VII. Appendix

A. Decommissioning preparation operation

B. Cutting operation

C. Smelting decontamination and recycling operation

A. Decommissioning preparation operation

Table A-1 to A-10 indicates steam generator decommissioning preparation processes and exposure dose calculation results for each operation. This process is composed of welding, equipment dismantling, lagging removal, canal removal, piping removal, lifting device removal operations. These operations are based on work experience on replacement of steam generator in Kori-1 in 1998 [6]. External exposure dose calculation for worker was done for each operation using set working time and working distance. Among total 113 operations, important and necessary operations are selected. In actual future decommissioning process of steam generator in Kori-1 would continue part of operation in replacement of steam generator process. Removal welding of fixed steam generator, dismantling equipment installation and movement, operation preparation, lagging removal and movement, inspection execution, duct break-up, transfer canal installation and removal, lifting device installation and removal operations are expected to proceed future decommissioning process. Working time of each operations are based on actual specific replacement operation experience, working distance between worker and object are assigned based on abroad steam generator decommissioning operation data. Average working distance were arranged on each specific operation for movement or inspection. On trojan nuclear power plant decommissioning process on January in 1999, steam generator, steam generator blowdown system (tank and pump), blow down building, RCS support steel, containment roll-up door was removed [18]. Besides, by 2017. 12. 31, license terminated for two nuclear power plants in each 1998, 2010 in Germany, for one nuclear power plant in 2015, in Spain and 2004, Switzerland, for 16 nuclear power plants in United states [19]. Also, Decommissioning scenario evaluation are proceeded by 3D computer simulation. For optimization of decommissioning process, modelling of dismantling equipment or facility and structure design run parallel. CAD or animation technology are used in maintenance and repair of nuclear facility and exposure dose evaluation of worker [20]. In this thesis, Also, VISIPLAN simulation program is used for exposure dose calculation in decommissioning process or worker.

A-1. Dose calculation result for Welding equipment installation process

Table A-1. Dose calculation result for Welding equipment installation process

Welding equipment installation (Working time: 1440 min, Working distance: 170 cm)			
Nuclide	External exposure doserate (mSv/h)	Nuclide dose rate contribution (%)	External exposure working dose (mSv)
Ce-141	4.40E-10	2.60E-04	1.10E-08
Co-57	1.10E-09	6.90E-04	2.80E-08
Co-58	7.80E-05	4.70E+01	1.90E-03
Co-60	2.70E-05	1.60E+01	6.40E-04
Fe-59	1.30E-05	7.80E+00	3.10E-04
Mn-54	8.40E-06	5.10E+00	2.00E-04
Nb-95	2.60E-05	1.60E+01	6.30E-04
Ru-103	8.70E-07	5.20E-01	2.10E-05
Ru-106	1.10E-06	6.30E-01	2.50E-05
Sn-113	4.10E-09	2.50E-03	9.90E-08
Sr-85	8.50E-06	5.10E+00	2.00E-04
Zn-65	2.50E-07	1.50E-01	6.00E-06
Zr-95	2.80E-06	1.70E+00	6.60E-05

Total	1.70E-04	1.00E+02	4.00E-03

A-2. Dose calculation result for RCS pipe in-out side welding

Table A-2. Dose calculation result for RCS pipe in-out side welding

RCS pipe in-outside welding (Working time: 9360 min, Working distance: 70 cm)			
Nuclide	External exposure dose rate (mSv/h)	Nuclide dose rate contribution (%)	External exposure working dose (mSv)
Ce-141	3.30E-50	1.80E-31	5.20E-48
Co-57	3.70E-32	2.00E-13	5.80E-30
Co-58	4.30E-20	2.30E-01	6.80E-18
Co-60	7.60E-22	4.10E-03	1.20E-19
Fe-59	1.80E-17	9.90E+01	2.90E-15
Mn-54	6.10E-21	3.30E-02	9.40E-19
Nb-95	7.90E-20	4.30E-01	1.20E-17
Ru-103	6.50E-25	3.50E-06	1.00E-22
Ru-106	6.70E-29	3.60E-10	1.00E-26
Sn-113	1.60E-36	8.80E-18	2.50E-34
Sr-85	8.40E-23	4.50E-04	1.30E-20
Zn-65	2.00E-21	1.10E-02	3.20E-19
Zr-95	1.10E-20	6.10E-02	1.80E-18

Total	1.90E-17	1.00E+02	2.90E-15

A-3. Dose calculation result for Equipment dismantling

Table A-3. Dose calculation result for Equipment dismantling

Equipment dismantling (Working time: 720 min, Working distance: 170 cm)			
Nuclide	External exposure dose rate (mSv/h)	Nuclide dose rate contribution (%)	External exposure working dose (mSv)
Ce-141	4.40E-10	2.60E-04	5.30E-09
Co-57	1.10E-09	6.90E-04	1.40E-08
Co-58	7.80E-05	4.70E+01	9.40E-04
Co-60	2.70E-05	1.60E+01	3.20E-04
Fe-59	1.30E-05	7.80E+00	1.50E-04
Mn-54	8.40E-06	5.10E+00	1.00E-04
Nb-95	2.60E-05	1.60E+01	3.10E-04
Ru-103	8.70E-07	5.20E-01	1.00E-05
Ru-106	1.10E-06	6.30E-01	1.30E-05
Sn-113	4.10E-09	2.50E-03	4.90E-08
Sr-85	8.50E-06	5.10E+00	1.00E-04
Zn-65	2.50E-07	1.50E-01	3.00E-06
Zr-95	2.80E-06	1.70E+00	3.30E-05

Total	1.70E-04	1.00E+02	2.00E-03

A-4. Dose calculation result for Lagging removal

Table A-4. Dose calculation result for Lagging removal

Lagging removal (Working time: 6480 min, Working distance: 70 cm)			
Nuclide	External exposure dose rate (mSv/h)	Nuclide dose rate contribution (%)	External exposure working dose (mSv)
Ce-141	3.30E-50	1.80E-31	3.60E-48
Co-57	3.70E-32	2.00E-13	4.00E-30
Co-58	4.30E-20	2.30E-01	4.70E-18
Co-60	7.60E-22	4.10E-03	8.20E-20
Fe-59	1.80E-17	9.90E+01	2.00E-15
Mn-54	6.10E-21	3.30E-02	6.50E-19
Nb-95	7.90E-20	4.30E-01	8.50E-18
Ru-103	6.50E-25	3.50E-06	7.00E-23
Ru-106	6.70E-29	3.60E-10	7.30E-27
Sn-113	1.60E-36	8.80E-18	1.80E-34
Sr-85	8.40E-23	4.50E-04	9.10E-21
Zn-65	2.00E-21	1.10E-02	2.20E-19
Zr-95	1.10E-20	6.10E-02	1.20E-18

Total	1.90E-17	1.00E+02	2.00E-15

A-5. Dose calculation result for Containment vessel amputation/restoration

Table A-5. Dose calculation result for Containment vessel amputation/restoration

Containment vessel amputation/restoration (Working time: 5160 min, Working distance: 30 cm)			
Nuclide	External exposure dose rate (mSv/h)	Nuclide dose rate contribution (%)	External exposure working dose (mSv)
Ce-141	9.80E-69	2.00E-43	8.40E-67
Co-57	3.40E-40	7.10E-15	2.90E-38
Co-58	7.40E-26	1.50E+00	6.40E-24
Co-60	2.40E-26	4.90E-01	2.00E-24
Fe-59	4.70E-24	9.80E+01	4.00E-22
Mn-54	9.00E-30	1.90E-04	7.70E-28
Nb-95	2.60E-28	5.50E-03	2.30E-26
Ru-103	8.20E-34	1.70E-08	7.10E-32
Ru-106	1.30E-32	2.80E-07	1.10E-30
Sn-113	4.30E-44	9.00E-19	3.70E-42
Sr-85	3.90E-32	8.20E-07	3.40E-30
Zn-65	1.10E-28	2.20E-03	9.10E-27
Zr-95	6.70E-29	1.40E-03	5.80E-27

Total	4.80E-24	1.00E+02	4.10E-22

A-6. Dose calculation result for Transfer canal installation/removal

Table A-6. Dose calculation result for Transfer canal installation/removal

Transfer canal installation/removal (Working time: 720 min, Working distance: 170 cm)			
Nuclide	External exposure dose rate (mSv/h)	Nuclide dose rate contribution (%)	External exposure working dose (mSv)
Ce-141	4.40E-10	2.60E-04	5.30E-09
Co-57	1.10E-09	6.90E-04	1.40E-08
Co-58	7.80E-05	4.70E+01	9.40E-04
Co-60	2.70E-05	1.60E+01	3.20E-04
Fe-59	1.30E-05	7.80E+00	1.50E-04
Mn-54	8.40E-06	5.10E+00	1.00E-04
Nb-95	2.60E-05	1.60E+01	3.10E-04
Ru-103	8.70E-07	5.20E-01	1.00E-05
Ru-106	1.10E-06	6.30E-01	1.30E-05
Sn-113	4.10E-09	2.50E-03	4.90E-08
Sr-85	8.50E-06	5.10E+00	1.00E-04
Zn-65	2.50E-07	1.50E-01	3.00E-06
Zr-95	2.80E-06	1.70E+00	3.30E-05

Total	1.70E-04	1.00E+02	2.00E-03

A-7. Dose calculation result for Main feed water piping removal

Table A-7. Dose calculation result for Main feed water piping removal

Main feed water piping removal (Working time: 1440 min, Working distance: 70 cm)			
Nuclide	External exposure dose rate (mSv/h)	Nuclide dose rate contribution (%)	External exposure working dose (mSv)
Ce-141	3.30E-50	1.80E-31	8.00E-49
Co-57	3.70E-32	2.00E-13	8.90E-31
Co-58	4.30E-20	2.30E-01	1.00E-18
Co-60	7.60E-22	4.10E-03	1.80E-20
Fe-59	1.80E-17	9.90E+01	4.40E-16
Mn-54	6.10E-21	3.30E-02	1.50E-19
Nb-95	7.90E-20	4.30E-01	1.90E-18
Ru-103	6.50E-25	3.50E-06	1.60E-23
Ru-106	6.70E-29	3.60E-10	1.60E-27
Sn-113	1.60E-36	8.80E-18	3.90E-35
Sr-85	8.40E-23	4.50E-04	2.00E-21
Zn-65	2.00E-21	1.10E-02	4.90E-20
Zr-95	1.10E-20	6.10E-02	2.70E-19

Total	1.90E-17	1.00E+02	4.40E-16

A-8. Dose calculation result for Lifting device installation/removal

Table A-8. Dose calculation result for Lifting device installation/removal

Lifting device installation/removal (Working time: 2400 min, Working distance: 170 cm)			
Nuclide	External exposure dose rate (mSv/h)	Nuclide dose rate contribution (%)	External exposure working dose (mSv)
Ce-141	4.40E-10	2.60E-04	1.80E-08
Co-57	1.10E-09	6.90E-04	4.60E-08
Co-58	7.80E-05	4.70E+01	3.10E-03
Co-60	2.70E-05	1.60E+01	1.10E-03
Fe-59	1.30E-05	7.80E+00	5.20E-04
Mn-54	8.40E-06	5.10E+00	3.40E-04
Nb-95	2.60E-05	1.60E+01	1.00E-03
Ru-103	8.70E-07	5.20E-01	3.50E-05
Ru-106	1.10E-06	6.30E-01	4.20E-05
Sn-113	4.10E-09	2.50E-03	1.60E-07
Sr-85	8.50E-06	5.10E+00	3.40E-04
Zn-65	2.50E-07	1.50E-01	1.00E-05
Zr-95	2.80E-06	1.70E+00	1.10E-04

Total	1.70E-04	1.00E+02	6.60E-03

A-9. Dose calculation result for Plumbing part operation

Table A-9. Dose calculation result for Plumbing part operation

Plumbing part operation (Working time:1440 min, Working distance: 70 cm)			
Nuclide	External exposure dose rate (mSv/h)	Nuclide dose rate contribution (%)	External exposure working dose (mSv)
Ce-141	3.30E-50	1.80E-31	8.00E-49
Co-57	3.70E-32	2.00E-13	8.90E-31
Co-58	4.30E-20	2.30E-01	1.00E-18
Co-60	7.60E-22	4.10E-03	1.80E-20
Fe-59	1.80E-17	9.90E+01	4.40E-16
Mn-54	6.10E-21	3.30E-02	1.50E-19
Nb-95	7.90E-20	4.30E-01	1.90E-18
Ru-103	6.50E-25	3.50E-06	1.60E-23
Ru-106	6.70E-29	3.60E-10	1.60E-27
Sn-113	1.60E-36	8.80E-18	3.90E-35
Sr-85	8.40E-23	4.50E-04	2.00E-21
Zn-65	2.00E-21	1.10E-02	4.90E-20
Zr-95	1.10E-20	6.10E-02	2.70E-19

Total	1.90E-17	1.00E+02	4.40E-16

A-10. Dose calculation result for Auxiliary crane installation/removal

Table A-10. Dose calculation result for Auxiliary crane installation/removal

Auxiliary crane installation/removal (Working time: 120 min, Working distance: 170 cm)			
Nuclide	External exposure dose rate (mSv/h)	Nuclide dose rate contribution (%)	External exposure working dose (mSv)
Ce-141	4.40E-10	2.60E-04	8.80E-10
Co-57	1.10E-09	6.90E-04	2.30E-09
Co-58	7.80E-05	4.70E+01	1.60E-04
Co-60	2.70E-05	1.60E+01	5.30E-05
Fe-59	1.30E-05	7.80E+00	2.60E-05
Mn-54	8.40E-06	5.10E+00	1.70E-05
Nb-95	2.60E-05	1.60E+01	5.20E-05
Ru-103	8.70E-07	5.20E-01	1.70E-06
Ru-106	1.10E-06	6.30E-01	2.10E-06
Sn-113	4.10E-09	2.50E-03	8.20E-09
Sr-85	8.50E-06	5.10E+00	1.70E-05
Zn-65	2.50E-07	1.50E-01	5.00E-07
Zr-95	2.80E-06	1.70E+00	5.50E-06

Total	1.70E-04	1.00E+02	3.30E-04

B. Cutting operation

Table B-1 to B-10 indicates steam generator decommissioning cutting processes and exposure dose calculation results for each operation. This process is composed of cutting and fragmentation of end part, upper part, heat exchange tube and collector. Depending on location and part of steam generator (upper, lower, part-heat exchange tube and collector), different radionuclides radioactivity was considered as an input value. For considering radioactivity on different part, inner tube surface contamination radioactivity was calculated. Based on Dampierr 1 reactor data in France, inner and outer tube contamination level ratio was applied depending on location of part in steam generator. Different radioactivity contamination level was input for calculation exposure dose of worker in cutting operations. Total 10 cutting operations describe cutting, fragmentation and preparation operations of end part and upper part, heat exchange tube and collector. Each working time was calculated on dose rate of V1 Slovakia Nuclear Power plant, it is assumed high dose rate is inverse proportional to working time on operation. External and Internal exposure dose of worker in cutting operations are calculated for 13 radionuclides. Actual cutting operations would be proceeded by remote cutting equipment for reducing worker exposure dose, however, in this thesis, it is assumed that situation worker did cutting operation using cutting equipment directly. For reference, steam generator in Trino Nuclear power plant shows inner surface contamination from minimum below 10.4 Bq/cm^2 in hot leg SG A and B, Cold leg SG and B to maximum 2,460 Bq/cm^2 in Cold leg SG C in cutting scenario [21]. In short, Dismantling scenario describes process from installing transporting and lifting equipment, cutting connected pipes and connected points and lifting and transporting cut components to working place [22].

B-1. Dose calculation result for Cutting and taking out end part

Table B-1. Dose calculation result for Cutting and taking out end part

Cutting and taking out end part (Working time: 1850 min, Working distance: 30 cm)							
Nuclide	External dose rate (mSv/h)	External dose nuclide contribution (%)	External working dose (mSv)	Internal exposure dose by inhalation (mSv)	Internal exposure dose by ingestion (mSv)	Total internal exposure dose (mSv)	Internal dose nuclide contribution (%)
Ce-141	1.20E-07	5.70E-02	1.40E-06	5.85E-13	1.28E-14	5.98E-13	7.40E-01
Co-57	9.50E-08	4.60E-02	1.10E-06	6.83E-15	1.69E-16	7.00E-15	8.66E-03
Co-58	5.30E-05	2.60E+01	6.40E-04	6.65E-12	2.73E-13	6.92E-12	8.57E+00
Co-60	3.20E-05	1.60E+01	3.80E-04	4.10E-11	5.33E-13	4.15E-11	5.14E+01
Fe-59	5.60E-06	2.80E+00	6.70E-05	3.17E-13	1.81E-14	3.35E-13	4.15E-01
Mn-54	1.00E-06	5.00E-01	1.20E-05	1.23E-13	6.47E-15	1.30E-13	1.60E-01
Nb-95	2.80E-05	1.40E+01	3.40E-04	7.93E-13	3.20E-14	8.25E-13	1.02E+00
Ru-103	5.70E-06	2.80E+00	6.80E-05	1.66E-12	5.85E-14	1.72E-12	2.13E+00
Ru-106	4.80E-05	2.30E+01	5.70E-04	2.67E-11	3.35E-13	2.71E-11	3.35E+01
Sn-113	3.70E-09	1.80E-03	4.40E-08	3.72E-14	1.21E-15	3.84E-14	4.75E-02
Sr-85	1.30E-05	6.50E+00	1.60E-04	3.51E-13	2.83E-14	3.79E-13	4.69E-01
Zn-65	6.20E-07	3.00E-01	7.40E-06	1.36E-13	2.04E-14	1.57E-13	1.94E-01

Zr-95	1.70E-05	8.40E+00	2.10E-04	1.07E-12	1.90E-14	1.09E-12	1.35E+00
Total	2.00E-04	1.00E+02	2.40E-03	7.94E-11	1.34E-12	8.07E-11	1.00E+02

B-2. Dose calculation result for Fragmentation preparation of steam generator

Table B-2. Dose calculation result for Fragmentation preparation of steam generator

Fragmentation preparation of steam generator (Working time: 3770 min, Working distance: 170 cm)							
Nuclide	External dose rate (mSv/h)	External dose nuclide contribution (%)	External working dose (mSv)	Internal exposure dose by inhalation (mSv)	Internal exposure dose by ingestion (mSv)	Total internal exposure dose (mSv)	Internal dose nuclide contribution (%)
Ce-141	3.10E-07	2.40E-01	1.80E-06	1.19E-12	2.61E-14	1.22E-12	7.40E-01
Co-57	2.30E-08	1.70E-02	1.30E-07	1.39E-14	3.46E-16	1.43E-14	8.66E-03
Co-58	2.60E-05	2.00E+01	1.50E-04	1.36E-11	5.57E-13	1.41E-11	8.57E+00
Co-60	6.50E-05	4.90E+01	3.80E-04	8.35E-11	1.09E-12	8.46E-11	5.14E+01
Fe-59	2.10E-06	1.60E+00	1.20E-05	6.46E-13	3.69E-14	6.83E-13	4.15E-01
Mn-54	1.20E-06	9.50E-01	7.30E-06	2.51E-13	1.32E-14	2.64E-13	1.60E-01
Nb-95	1.20E-05	8.80E+00	6.80E-05	1.62E-12	6.52E-14	1.68E-12	1.02E+00
Ru-103	6.60E-06	5.00E+00	3.90E-05	3.38E-12	1.19E-13	3.50E-12	2.13E+00
Ru-106	7.00E-06	5.30E+00	4.10E-05	5.45E-11	6.84E-13	5.52E-11	3.35E+01
Sn-113	2.00E-09	1.50E-03	1.20E-08	7.58E-14	2.46E-15	7.82E-14	4.75E-02
Sr-85	7.60E-06	5.80E+00	4.50E-05	7.15E-13	5.78E-14	7.73E-13	4.69E-01
Zn-65	5.20E-07	3.90E-01	3.00E-06	2.78E-13	4.16E-14	3.20E-13	1.94E-01

Zr-95	3.70E-06	2.80E+00	2.20E-05	2.18E-12	3.87E-14	2.22E-12	1.35E+00
Total	1.30E-04	1.00E+02	7.70E-04	1.62E-10	2.73E-12	1.65E-10	1.00E+02

B-3. Dose calculation result for Fragmentation of end parts

Table B-3. Dose calculation result for Fragmentation of end parts

Fragmentation of end parts (Working time: 1260 min, Working distance: 38 cm)							
Nuclide	External dose rate (mSv/h)	External dose nuclide contribution (%)	External working dose (mSv)	Internal exposure dose by inhalation (mSv)	Internal exposure dose by ingestion (mSv)	Total internal exposure dose (mSv)	Internal dose nuclide contribution (%)
Ce-141	3.70E-09	6.50E-03	6.50E-08	3.99E-13	8.74E-15	4.07E-13	7.40E-01
Co-57	4.40E-09	7.90E-03	7.80E-08	4.65E-15	1.16E-16	4.77E-15	8.66E-03
Co-58	4.10E-06	7.20E+00	7.20E-05	4.53E-12	1.86E-13	4.72E-12	8.57E+00
Co-60	2.80E-06	4.90E+00	4.90E-05	2.79E-11	3.64E-13	2.83E-11	5.14E+01
Fe-59	1.00E-06	1.90E+00	1.80E-05	2.16E-13	1.24E-14	2.28E-13	4.15E-01
Mn-54	1.50E-06	2.60E+00	2.60E-05	8.39E-14	4.41E-15	8.84E-14	1.60E-01
Nb-95	2.00E-05	3.60E+01	3.60E-04	5.41E-13	2.18E-14	5.63E-13	1.02E+00
Ru-103	1.90E-05	3.40E+01	3.40E-04	1.13E-12	3.99E-14	1.17E-12	2.13E+00
Ru-106	1.50E-06	2.70E+00	2.70E-05	1.82E-11	2.29E-13	1.85E-11	3.35E+01
Sn-113	1.00E-09	1.80E-03	1.80E-08	2.53E-14	8.22E-16	2.62E-14	4.75E-02
Sr-85	2.30E-06	4.00E+00	4.00E-05	2.39E-13	1.93E-14	2.58E-13	4.69E-01
Zn-65	2.70E-07	4.80E-01	4.80E-06	9.30E-14	1.39E-14	1.07E-13	1.94E-01

Zr-95	3.50E-06	6.20E+00	6.20E-05	7.29E-13	1.30E-14	7.42E-13	1.35E+00
Total	5.60E-05	1.00E+02	1.00E-03	5.41E-11	9.13E-13	5.51E-11	1.00E+02

B-4. Dose calculation result for Cutting and taking out upper part

Table B-4. Dose calculation result for Cutting and taking out upper part

Cutting and taking out upper part (Working time: 720 min, Working distance: 30 cm)							
Nuclide	External dose rate (mSv/h)	External dose nuclide contribution (%)	External working dose (mSv)	Internal exposure dose by inhalation (mSv)	Internal exposure dose by ingestion (mSv)	Total internal exposure dose (mSv)	Internal dose nuclide contribution (%)
Ce-141	2.10E-07	1.60E-01	6.50E-06	1.70E-13	1.89E-14	1.89E-13	7.33E-01
Co-57	1.50E-07	1.10E-01	4.70E-06	1.99E-15	2.21E-16	2.21E-15	8.60E-03
Co-58	1.00E-05	7.80E+00	3.20E-04	1.94E-12	2.15E-13	2.15E-12	8.36E+00
Co-60	7.60E-05	5.80E+01	2.40E-03	1.19E-11	1.33E-12	1.33E-11	5.16E+01
Fe-59	3.60E-06	2.70E+00	1.10E-04	9.24E-14	1.03E-14	1.03E-13	3.99E-01
Mn-54	6.70E-06	5.10E+00	2.10E-04	3.59E-14	3.99E-15	3.99E-14	1.55E-01
Nb-95	5.50E-06	4.10E+00	1.70E-04	2.31E-13	2.57E-14	2.57E-13	9.98E-01
Ru-103	2.40E-06	1.80E+00	7.50E-05	4.83E-13	5.37E-14	5.37E-13	2.09E+00
Ru-106	1.10E-05	8.00E+00	3.20E-04	7.80E-12	8.66E-13	8.66E-12	3.37E+01
Sn-113	3.10E-09	2.30E-03	9.50E-08	1.09E-14	1.21E-15	1.21E-14	4.69E-02
Sr-85	1.30E-06	9.90E-01	4.00E-05	1.02E-13	1.14E-14	1.14E-13	4.42E-01
Zn-65	6.70E-07	5.10E-01	2.10E-05	3.98E-14	4.43E-15	4.43E-14	1.72E-01

Zr-95	1.40E-05	1.10E+01	4.40E-04	3.12E-13	3.46E-14	3.46E-13	1.35E+00
Total	1.30E-04	1.00E+02	4.10E-03	2.31E-11	2.57E-12	2.57E-11	1.00E+02

B-5. Dose calculation result for Fragmentation of upper part

Table B-5. Dose calculation result for Fragmentation of upper part

Fragmentation of upper part (Working time: 1460 min, Working distance: 38 cm)							
Nuclide	External dose rate (mSv/h)	External dose nuclide contribution (%)	External working dose (mSv)	Internal exposure dose by inhalation (mSv)	Internal exposure dose by ingestion (mSv)	Total internal exposure dose (mSv)	Internal dose nuclide contribution (%)
Ce-141	2.80E-07	1.90E-01	4.20E-06	3.44E-13	3.82E-14	3.82E-13	7.33E-01
Co-57	1.10E-07	7.50E-02	1.60E-06	4.03E-15	4.48E-16	4.48E-15	8.60E-03
Co-58	1.70E-05	1.20E+01	2.60E-04	3.92E-12	4.36E-13	4.36E-12	8.36E+00
Co-60	8.30E-05	5.80E+01	1.30E-03	2.42E-11	2.69E-12	2.69E-11	5.16E+01
Fe-59	3.20E-06	2.20E+00	4.90E-05	1.87E-13	2.08E-14	2.08E-13	3.99E-01
Mn-54	5.30E-06	3.70E+00	8.00E-05	7.28E-14	8.08E-15	8.08E-14	1.55E-01
Nb-95	6.30E-06	4.40E+00	9.60E-05	4.68E-13	5.20E-14	5.20E-13	9.98E-01
Ru-103	3.30E-06	2.30E+00	5.10E-05	9.79E-13	1.09E-13	1.09E-12	2.09E+00
Ru-106	1.10E-05	7.70E+00	1.70E-04	1.58E-11	1.75E-12	1.75E-11	3.37E+01
Sn-113	3.50E-09	2.50E-03	5.40E-08	2.20E-14	2.44E-15	2.44E-14	4.69E-02
Sr-85	1.50E-06	1.00E+00	2.20E-05	2.07E-13	2.30E-14	2.30E-13	4.42E-01
Zn-65	5.20E-07	3.60E-01	8.00E-06	8.07E-14	8.96E-15	8.96E-14	1.72E-01

Zr-95	1.20E-05	8.30E+00	1.80E-04	6.31E-13	7.01E-14	7.01E-13	1.35E+00
Total	1.40E-04	1.00E+02	2.20E-03	4.69E-11	5.21E-12	5.21E-11	1.00E+02

B-6. Dose calculation result for Cutting heat exchange tube

Table B-6. Dose calculation result for Cutting heat exchange tube

Cutting heat exchange tube (Working time: 57.3 min, Working distance: 30 cm)							
Nuclide	External dose rate (mSv/h)	External dose nuclide contribution (%)	External working dose (mSv)	Internal exposure dose by inhalation (mSv)	Internal exposure dose by ingestion (mSv)	Total internal exposure dose (mSv)	Internal dose nuclide contribution (%)
Ce-141	2.60E-07	1.80E-01	1.00E-05	1.42E-14	3.12E-16	1.45E-14	7.36E-01
Co-57	1.10E-08	7.20E-03	4.10E-07	1.66E-16	4.13E-18	1.71E-16	8.64E-03
Co-58	2.70E-05	1.90E+01	1.10E-03	1.62E-13	6.66E-15	1.69E-13	8.54E+00
Co-60	6.80E-05	4.60E+01	2.60E-03	1.00E-12	1.31E-14	1.02E-12	5.14E+01
Fe-59	3.30E-07	2.20E-01	1.30E-05	7.73E-15	4.42E-16	8.17E-15	4.14E-01
Mn-54	6.10E-07	4.20E-01	2.40E-05	3.01E-15	1.58E-16	3.17E-15	1.60E-01
Nb-95	1.90E-05	1.30E+01	7.50E-04	1.93E-14	7.79E-16	2.01E-14	1.02E+00
Ru-103	1.60E-05	1.10E+01	6.10E-04	4.04E-14	1.43E-15	4.19E-14	2.12E+00
Ru-106	1.90E-06	1.30E+00	7.30E-05	6.53E-13	8.19E-15	6.61E-13	3.35E+01
Sn-113	7.40E-10	5.00E-04	2.90E-08	9.14E-16	2.96E-17	9.43E-16	4.78E-02
Sr-85	5.90E-06	4.00E+00	2.30E-04	8.57E-15	6.92E-16	9.26E-15	4.69E-01
Zn-65	4.30E-07	3.00E-01	1.70E-05	3.33E-15	4.98E-16	3.83E-15	1.94E-01

Zr-95	7.40E-06	5.00E+00	2.90E-04	2.61E-14	4.64E-16	2.65E-14	1.34E+00
Total	1.50E-04	1.00E+02	5.70E-03	1.94E-12	3.27E-14	1.97E-12	1.00E+02

B-7. Dose calculation result for Fragmentation of heat exchange tube

Table B-7. Dose calculation result for Fragmentation of heat exchange tube

Fragmentation of heat exchange tube (Working time: 1000 min, Working distance: 38 cm)							
Nuclide	External dose rate (mSv/h)	External dose nuclide contribution (%)	External working dose (mSv)	Internal exposure dose by inhalation (mSv)	Internal exposure dose by ingestion (mSv)	Total internal exposure dose (mSv)	Internal dose nuclide contribution (%)
Ce-141	2.30E-07	1.50E-01	5.10E-06	2.49E-13	5.45E-15	2.54E-13	7.36E-01
Co-57	1.40E-08	9.10E-03	3.20E-07	2.91E-15	7.23E-17	2.98E-15	8.64E-03
Co-58	3.60E-05	2.30E+01	8.00E-04	2.83E-12	1.16E-13	2.95E-12	8.54E+00
Co-60	6.90E-05	4.30E+01	1.50E-03	1.75E-11	2.28E-13	1.78E-11	5.14E+01
Fe-59	5.30E-07	3.30E-01	1.20E-05	1.35E-13	7.73E-15	1.43E-13	4.14E-01
Mn-54	8.70E-07	5.50E-01	1.90E-05	5.26E-14	2.77E-15	5.54E-14	1.60E-01
Nb-95	1.80E-05	1.20E+01	4.10E-04	3.38E-13	1.36E-14	3.52E-13	1.02E+00
Ru-103	1.70E-05	1.00E+01	3.70E-04	7.07E-13	2.49E-14	7.32E-13	2.12E+00
Ru-106	2.50E-06	1.60E+00	5.50E-05	1.14E-11	1.43E-13	1.16E-11	3.35E+01
Sn-113	1.30E-09	8.40E-04	3.00E-08	1.60E-14	5.18E-16	1.65E-14	4.78E-02
Sr-85	7.60E-06	4.80E+00	1.70E-04	1.50E-13	1.21E-14	1.62E-13	4.69E-01
Zn-65	4.20E-07	2.60E-01	9.30E-06	5.83E-14	8.71E-15	6.70E-14	1.94E-01

Zr-95	7.40E-06	4.70E+00	1.60E-04	4.56E-13	8.11E-15	4.64E-13	1.34E+00
Total	1.60E-04	1.00E+02	3.50E-03	3.39E-11	5.72E-13	3.45E-11	1.00E+02

B-8. Dose calculation result for Dismantling preparation of collector

Table B-8. Dose calculation result for Dismantling preparation of collector

Dismantling preparation of collector (Working time: 18.1 min, Working distance: 170 cm)							
Nuclide	External dose rate (mSv/h)	External dose nuclide contribution (%)	External working dose (mSv)	Internal exposure dose by inhalation (mSv)	Internal exposure dose by ingestion (mSv)	Total internal exposure dose (mSv)	Internal dose nuclide contribution (%)
Ce-141	1.80E-07	1.40E-01	2.20E-04	4.50E-15	9.86E-17	4.60E-15	7.36E-01
Co-57	1.10E-08	8.80E-03	1.40E-05	5.27E-17	1.31E-18	5.40E-17	8.64E-03
Co-58	5.40E-05	4.20E+01	6.70E-02	5.12E-14	2.11E-15	5.33E-14	8.54E+00
Co-60	4.50E-05	3.50E+01	5.60E-02	3.17E-13	4.13E-15	3.21E-13	5.14E+01
Fe-59	1.10E-06	8.40E-01	1.30E-03	2.45E-15	1.40E-16	2.58E-15	4.14E-01
Mn-54	1.00E-06	7.90E-01	1.30E-03	9.51E-16	5.00E-17	1.00E-15	1.60E-01
Nb-95	6.40E-06	5.00E+00	7.90E-03	6.11E-15	2.46E-16	6.36E-15	1.02E+00
Ru-103	7.10E-06	5.50E+00	8.80E-03	1.28E-14	4.51E-16	1.32E-14	2.12E+00
Ru-106	4.40E-06	3.40E+00	5.40E-03	2.07E-13	2.59E-15	2.09E-13	3.35E+01
Sn-113	2.50E-09	2.00E-03	3.10E-06	2.89E-16	9.37E-18	2.98E-16	4.78E-02
Sr-85	5.40E-06	4.20E+00	6.70E-03	2.71E-15	2.19E-16	2.93E-15	4.69E-01
Zn-65	2.40E-07	1.90E-01	2.90E-04	1.05E-15	1.57E-16	1.21E-15	1.94E-01

Zr-95	3.20E-06	2.50E+00	4.00E-03	8.25E-15	1.47E-16	8.39E-15	1.34E+00
Total	1.30E-04	1.00E+02	1.60E-01	6.14E-13	1.03E-14	6.24E-13	1.00E+02

B-9. Dose calculation result for Cutting and taking out collector

Table B-9. Dose calculation result for Cutting and taking out collector

Cutting and taking out collector (Working time: 20 min, Working distance: 30 cm)							
Nuclide	External dose rate (mSv/h)	External dose nuclide contribution (%)	External working dose (mSv)	Internal exposure dose by inhalation (mSv)	Internal exposure dose by ingestion (mSv)	Total internal exposure dose (mSv)	Internal dose nuclide contribution (%)
Ce-141	2.60E-07	1.80E-01	3.00E-05	4.96E-15	1.09E-16	5.07E-15	7.36E-01
Co-57	1.10E-08	7.20E-03	1.20E-06	5.81E-17	1.44E-18	5.95E-17	8.64E-03
Co-58	2.70E-05	1.90E+01	3.10E-03	5.65E-14	2.32E-15	5.88E-14	8.54E+00
Co-60	6.80E-05	4.60E+01	7.70E-03	3.50E-13	4.55E-15	3.54E-13	5.14E+01
Fe-59	3.30E-07	2.20E-01	3.70E-05	2.70E-15	1.54E-16	2.85E-15	4.14E-01
Mn-54	6.10E-07	4.20E-01	6.90E-05	1.05E-15	5.52E-17	1.10E-15	1.60E-01
Nb-95	1.90E-05	1.30E+01	2.20E-03	6.74E-15	2.72E-16	7.01E-15	1.02E+00
Ru-103	1.60E-05	1.10E+01	1.80E-03	1.41E-14	4.97E-16	1.46E-14	2.12E+00
Ru-106	1.90E-06	1.30E+00	2.10E-04	2.28E-13	2.86E-15	2.31E-13	3.35E+01
Sn-113	7.40E-10	5.00E-04	8.40E-08	3.19E-16	1.03E-17	3.29E-16	4.78E-02
Sr-85	5.90E-06	4.00E+00	6.70E-04	2.99E-15	2.41E-16	3.23E-15	4.69E-01
Zn-65	4.30E-07	3.00E-01	4.90E-05	1.16E-15	1.74E-16	1.34E-15	1.94E-01

Zr-95	7.40E-06	5.00E+00	8.30E-04	9.09E-15	1.62E-16	9.25E-15	1.34E+00
Total	1.50E-04	1.00E+02	1.70E-02	6.77E-13	1.14E-14	6.88E-13	1.00E+02

B-10. Dose calculation result for Fragmentation of collector

Table B-10. Dose calculation result for Fragmentation of collector

Fragmentation of collector (Working time: 40.3 min, Working distance: 38 cm)							
Nuclide	External dose rate (mSv/h)	External dose nuclide contribution (%)	External working dose (mSv)	Internal exposure dose by inhalation (mSv)	Internal exposure dose by ingestion (mSv)	Total internal exposure dose (mSv)	Internal dose nuclide contribution (%)
Ce-141	2.30E-07	1.50E-01	1.30E-04	1.00E-14	2.19E-16	1.02E-14	7.36E-01
Co-57	1.40E-08	9.10E-03	8.00E-06	1.17E-16	2.91E-18	1.20E-16	8.64E-03
Co-58	3.60E-05	2.30E+01	2.00E-02	1.14E-13	4.69E-15	1.19E-13	8.54E+00
Co-60	6.90E-05	4.30E+01	3.80E-02	7.05E-13	9.19E-15	7.15E-13	5.14E+01
Fe-59	5.30E-07	3.30E-01	2.90E-04	5.44E-15	3.11E-16	5.75E-15	4.14E-01
Mn-54	8.70E-07	5.50E-01	4.80E-04	2.12E-15	1.11E-16	2.23E-15	1.60E-01
Nb-95	1.80E-05	1.20E+01	1.00E-02	1.36E-14	5.48E-16	1.42E-14	1.02E+00
Ru-103	1.70E-05	1.00E+01	9.20E-03	2.85E-14	1.00E-15	2.95E-14	2.12E+00
Ru-106	2.50E-06	1.60E+00	1.40E-03	4.60E-13	5.77E-15	4.65E-13	3.35E+01
Sn-113	1.30E-09	8.40E-04	7.40E-07	6.43E-16	2.09E-17	6.64E-16	4.78E-02
Sr-85	7.60E-06	4.80E+00	4.20E-03	6.03E-15	4.87E-16	6.52E-15	4.69E-01
Zn-65	4.20E-07	2.60E-01	2.30E-04	2.34E-15	3.50E-16	2.70E-15	1.94E-01

Zr-95	7.40E-06	4.70E+00	4.10E-03	1.83E-14	3.26E-16	1.87E-14	1.34E+00
Total	1.60E-04	1.00E+02	8.80E-02	1.37E-12	2.30E-14	1.39E-12	1.00E+02

C. Smelting decontamination and recycling operation

Table C-1 to C-15 indicates steam generator smelting decontamination and recycling processes and exposure dose calculation results for each operation. This process is composed of cutting component loading, transfer, treatment, smelting decontamination as smelting preparation, loading, operation, ingot, slag, product treatment, transfer, loading operations are considered. Also, radionuclide partitioning factor by product form was considered by calculating change of nuclide's radioactivity in Table 11 [16]. Below table shows certain radionuclide's partitioning ratio by product form, in each smelting decontamination and recycling operations, operation related with certain form of product, for example, ingot, baghouse contents and slag, different radionuclide existence ratio was applied refers to below table 11. After smelter decontamination and recycling process, left radioactive waste would be treated or transported to waste storage or disposal site [23]. In case of Maine Yankee Decommissioning, it had done from 1999 to 2005 for 6 years [24], similarly, Kori-1 decommissioning would proceed from 2022 to 2028 for 6 years. For accurate and safe decommissioning process, detailed infrastructure preparation for decontamination, cutting, smelting is mandatory.

Table 10. Radionuclide partitioning factor by product form [16]

Radionuclide	Ingot (%)	Baghouse Contents (%)	Slag (%)
Co-57	100	1	1
Co-60	100	1	1
Mn-54	100	1	1
Ru-106	0	0	100
Zn-65	1	100	1

C-1. Dose calculation result for Cutting component loading

Table C-1. Dose calculation result for Cutting component loading

Cutting component loading (Working time: 240 min, Working distance: 400 cm)							
Nuclide	External dose rate (mSv/h)	External dose nuclide contribution (%)	External working dose (mSv)	Internal exposure dose by inhalation (mSv)	Internal exposure dose by ingestion (mSv)	Total internal exposure dose (mSv)	Internal dose nuclide contribution (%)
Ce-141	8.20E-08	8.70E-02	3.30E-07	5.96E-14	6.62E-15	6.62E-14	7.33E-01
Co-57	3.40E-09	3.60E-03	1.40E-08	6.97E-16	7.75E-17	7.75E-16	8.58E-03
Co-58	4.40E-05	4.60E+01	1.80E-04	6.78E-13	7.54E-14	7.54E-13	8.34E+00
Co-60	3.40E-05	3.60E+01	1.40E-04	4.20E-12	4.67E-13	4.67E-12	5.16E+01
Fe-59	3.90E-07	4.10E-01	1.50E-06	3.24E-14	3.60E-15	3.60E-14	3.98E-01
Mn-54	5.80E-07	6.20E-01	2.30E-06	1.26E-14	1.40E-15	1.40E-14	1.55E-01
Nb-95	3.20E-06	3.30E+00	1.30E-05	8.10E-14	9.00E-15	9.00E-14	9.96E-01
Ru-103	2.10E-06	2.30E+00	8.50E-06	1.69E-13	1.88E-14	1.88E-13	2.08E+00
Ru-106	4.50E-06	4.80E+00	1.80E-05	2.74E-12	3.04E-13	3.04E-12	3.36E+01
Sn-113	6.20E-10	6.60E-04	2.50E-09	3.83E-15	4.25E-16	4.25E-15	4.71E-02
Sr-85	2.70E-06	2.90E+00	1.10E-05	3.59E-14	3.99E-15	3.99E-14	4.41E-01

Zn-65	3.70E-07	3.90E-01	1.50E-06	1.40E-14	1.55E-15	1.55E-14	1.72E-01
Zr-95	2.70E-06	2.90E+00	1.10E-05	1.09E-13	1.21E-14	1.21E-13	1.34E+00
Total	9.40E-05	1.00E+02	3.80E-04	8.13E-12	9.04E-13	9.04E-12	1.00E+02

C-2. Dose calculation result for Cutting component transfer

Table C-2. Dose calculation result for Cutting component transfer

Cutting component transfer (Working time: 240 min, Working distance: 200 cm)							
Nuclide	External dose rate (mSv/h)	External dose nuclide contribution (%)	External working dose (mSv)	Internal exposure dose by inhalation (mSv)	Internal exposure dose by ingestion (mSv)	Total internal exposure dose (mSv)	Internal dose nuclide contribution (%)
Ce-141	2.28E+00	4.99E-02	2.33E+00	5.96E-14	6.62E-15	6.62E-14	7.33E-01
Co-57	2.66E-02	6.62E-04	2.73E-02	6.97E-16	7.75E-17	7.75E-16	8.58E-03
Co-58	2.59E+01	1.07E+00	2.70E+01	6.78E-13	7.54E-14	7.54E-13	8.34E+00
Co-60	1.59E+02	2.07E+00	1.61E+02	4.20E-12	4.67E-13	4.67E-12	5.16E+01
Fe-59	1.24E+00	7.08E-02	1.31E+00	3.24E-14	3.60E-15	3.60E-14	3.98E-01
Mn-54	4.82E-01	2.53E-02	5.07E-01	1.26E-14	1.40E-15	1.40E-14	1.55E-01
Nb-95	3.09E+00	1.24E-01	3.22E+00	8.10E-14	9.00E-15	9.00E-14	9.96E-01
Ru-103	6.48E+00	2.28E-01	6.71E+00	1.69E-13	1.88E-14	1.88E-13	2.08E+00
Ru-106	1.05E+02	1.31E+00	1.06E+02	2.74E-12	3.04E-13	3.04E-12	3.36E+01
Sn-113	1.45E-01	4.71E-03	1.50E-01	3.83E-15	4.25E-16	4.25E-15	4.71E-02
Sr-85	1.37E+00	1.11E-01	1.48E+00	3.59E-14	3.99E-15	3.99E-14	4.41E-01

Zn-65	5.34E-01	7.95E-02	6.13E-01	1.40E-14	1.55E-15	1.55E-14	1.72E-01
Zr-95	4.16E+00	7.37E-02	4.24E+00	1.09E-13	1.21E-14	1.21E-13	1.34E+00
Total	3.10E+02	5.22E+00	3.15E+02	8.13E-12	9.04E-13	9.04E-12	1.00E+02

C-3. Dose calculation result for Cutting component treatment

Table C-3. Dose calculation result for Cutting component treatment

Cutting component treatment (Working time: 720 min, Working distance: 200 cm)							
Nuclide	External dose rate (mSv/h)	External dose nuclide contribution (%)	External working dose (mSv)	Internal exposure dose by inhalation (mSv)	Internal exposure dose by ingestion (mSv)	Total internal exposure dose (mSv)	Internal dose nuclide contribution (%)
Ce-141	1.90E-08	1.40E-02	2.30E-07	1.79E-13	1.99E-14	1.99E-13	7.33E-01
Co-57	3.70E-09	2.70E-03	4.50E-08	2.09E-15	2.32E-16	2.32E-15	8.58E-03
Co-58	6.20E-05	4.40E+01	7.40E-04	2.04E-12	2.26E-13	2.26E-12	8.34E+00
Co-60	5.70E-05	4.10E+01	6.90E-04	1.26E-11	1.40E-12	1.40E-11	5.16E+01
Fe-59	3.50E-07	2.50E-01	4.20E-06	9.72E-14	1.08E-14	1.08E-13	3.98E-01
Mn-54	1.00E-06	7.20E-01	1.20E-05	3.78E-14	4.20E-15	4.20E-14	1.55E-01
Nb-95	3.00E-06	2.10E+00	3.60E-05	2.43E-13	2.70E-14	2.70E-13	9.96E-01
Ru-103	3.20E-06	2.30E+00	3.80E-05	5.08E-13	5.65E-14	5.65E-13	2.08E+00
Ru-106	5.10E-06	3.70E+00	6.20E-05	8.21E-12	9.12E-13	9.12E-12	3.36E+01
Sn-113	1.10E-09	8.00E-04	1.30E-08	1.15E-14	1.28E-15	1.28E-14	4.71E-02

Sr-85	2.80E-06	2.00E+00	3.40E-05	1.08E-13	1.20E-14	1.20E-13	4.41E-01
Zn-65	7.10E-07	5.10E-01	8.50E-06	4.19E-14	4.65E-15	4.65E-14	1.72E-01
Zr-95	3.40E-06	2.50E+00	4.10E-05	3.28E-13	3.64E-14	3.64E-13	1.34E+00
Total	1.40E-04	1.00E+02	1.70E-03	2.44E-11	2.71E-12	2.71E-11	1.00E+02

C-4. Dose calculation result for Smelting operation preparation

Table C-4. Dose calculation result for Smelting operation preparation

Smelting operation preparation (Working time: 4800 min, Working distance: 1000 cm)							
Nuclide	External dose rate (mSv/h)	External dose nuclide contribution (%)	External working dose (mSv)	Internal exposure dose by inhalation (mSv)	Internal exposure dose by ingestion (mSv)	Total internal exposure dose (mSv)	Internal dose nuclide contribution (%)
Ce-141	7.10E-08	1.70E-01	5.70E-06	1.19E-12	1.32E-13	1.32E-12	7.33E-01
Co-57	2.30E-09	5.60E-03	1.80E-07	1.39E-14	1.55E-15	1.55E-14	8.58E-03
Co-58	1.60E-05	3.90E+01	1.30E-03	1.36E-11	1.51E-12	1.51E-11	8.34E+00
Co-60	1.60E-05	3.80E+01	1.30E-03	8.40E-11	9.33E-12	9.33E-11	5.16E+01
Fe-59	4.00E-07	9.70E-01	3.20E-05	6.48E-13	7.20E-14	7.20E-13	3.98E-01
Mn-54	2.90E-07	6.90E-01	2.30E-05	2.52E-13	2.80E-14	2.80E-13	1.55E-01
Nb-95	1.80E-06	4.30E+00	1.40E-04	1.62E-12	1.80E-13	1.80E-12	9.96E-01
Ru-103	1.30E-06	3.20E+00	1.10E-04	3.39E-12	3.76E-13	3.76E-12	2.08E+00
Ru-106	2.60E-06	6.20E+00	2.10E-04	5.47E-11	6.08E-12	6.08E-11	3.36E+01
Sn-113	5.30E-10	1.30E-03	4.20E-08	7.65E-14	8.50E-15	8.50E-14	4.71E-02

Sr-85	1.60E-06	3.90E+00	1.30E-04	7.18E-13	7.98E-14	7.98E-13	4.41E-01
Zn-65	1.50E-07	3.60E-01	1.20E-05	2.79E-13	3.10E-14	3.10E-13	1.72E-01
Zr-95	1.10E-06	2.70E+00	9.10E-05	2.18E-12	2.43E-13	2.43E-12	1.34E+00
Total	4.10E-05	1.00E+02	3.30E-03	1.63E-10	1.81E-11	1.81E-10	1.00E+02

C-5. Dose calculation result for Smelter loading

Table C-5. Dose calculation result for Smelter loading

Smelter loading (Working time: 240 min, Working distance: 400 cm)							
Nuclide	External dose rate (mSv/h)	External dose nuclide contribution (%)	External working dose (mSv)	Internal exposure dose by inhalation (mSv)	Internal exposure dose by ingestion (mSv)	Total internal exposure dose (mSv)	Internal dose nuclide contribution (%)
Ce-141	8.20E-08	8.70E-02	3.30E-07	5.96E-14	6.62E-15	6.62E-14	7.33E-01
Co-57	3.40E-09	3.60E-03	1.40E-08	6.97E-16	7.75E-17	7.75E-16	8.58E-03
Co-58	4.40E-05	4.60E+01	1.80E-04	6.78E-13	7.54E-14	7.54E-13	8.34E+00
Co-60	3.40E-05	3.60E+01	1.40E-04	4.20E-12	4.67E-13	4.67E-12	5.16E+01
Fe-59	3.90E-07	4.10E-01	1.50E-06	3.24E-14	3.60E-15	3.60E-14	3.98E-01
Mn-54	5.80E-07	6.20E-01	2.30E-06	1.26E-14	1.40E-15	1.40E-14	1.55E-01
Nb-95	3.20E-06	3.30E+00	1.30E-05	8.10E-14	9.00E-15	9.00E-14	9.96E-01
Ru-103	2.10E-06	2.30E+00	8.50E-06	1.69E-13	1.88E-14	1.88E-13	2.08E+00
Ru-106	4.50E-06	4.80E+00	1.80E-05	2.74E-12	3.04E-13	3.04E-12	3.36E+01
Sn-113	6.20E-10	6.60E-04	2.50E-09	3.83E-15	4.25E-16	4.25E-15	4.71E-02

Sr-85	2.70E-06	2.90E+00	1.10E-05	3.59E-14	3.99E-15	3.99E-14	4.41E-01
Zn-65	3.70E-07	3.90E-01	1.50E-06	1.40E-14	1.55E-15	1.55E-14	1.72E-01
Zr-95	2.70E-06	2.90E+00	1.10E-05	1.09E-13	1.21E-14	1.21E-13	1.34E+00
Total	9.40E-05	1.00E+02	3.80E-04	8.13E-12	9.04E-13	9.04E-12	1.00E+02

C-6. Dose calculation result for Furnace operation

Table C-6. Dose calculation result for Furnace operation

Furnace operation (Working time: 300 min, Working distance: 300 cm)							
Nuclide	External dose rate (mSv/h)	External dose nuclide contribution (%)	External working dose (mSv)	Internal exposure dose by inhalation (mSv)	Internal exposure dose by ingestion (mSv)	Total internal exposure dose (mSv)	Internal dose nuclide contribution (%)
Ce-141	6.40E-08	5.60E-02	3.20E-07	7.45E-14	8.27E-15	8.27E-14	7.33E-01
Co-57	3.70E-09	3.20E-03	1.80E-08	8.72E-16	9.69E-17	9.69E-16	8.58E-03
Co-58	5.30E-05	4.60E+01	2.70E-04	8.48E-13	9.42E-14	9.42E-13	8.34E+00
Co-60	4.30E-05	3.70E+01	2.10E-04	5.25E-12	5.83E-13	5.83E-12	5.16E+01
Fe-59	3.40E-07	2.90E-01	1.70E-06	4.05E-14	4.50E-15	4.50E-14	3.98E-01
Mn-54	7.30E-07	6.40E-01	3.60E-06	1.57E-14	1.75E-15	1.75E-14	1.55E-01
Nb-95	3.30E-06	2.90E+00	1.60E-05	1.01E-13	1.12E-14	1.12E-13	9.96E-01
Ru-103	2.50E-06	2.20E+00	1.30E-05	2.12E-13	2.35E-14	2.35E-13	2.08E+00
Ru-106	5.00E-06	4.40E+00	2.50E-05	3.42E-12	3.80E-13	3.80E-12	3.36E+01
Sn-113	8.00E-10	6.90E-04	4.00E-09	4.78E-15	5.31E-16	5.31E-15	4.71E-02

Sr-85	2.90E-06	2.50E+00	1.50E-05	4.49E-14	4.98E-15	4.98E-14	4.41E-01
Zn-65	4.90E-07	4.30E-01	2.50E-06	1.74E-14	1.94E-15	1.94E-14	1.72E-01
Zr-95	3.10E-06	2.70E+00	1.60E-05	1.37E-13	1.52E-14	1.52E-13	1.34E+00
Total	1.10E-04	1.00E+02	5.70E-04	1.02E-11	1.13E-12	1.13E-11	1.00E+02

C-7. Dose calculation result for Baghouse processing

Table C-7. Dose calculation result for Baghouse processing

Baghouse processing (Working time: 60 min, Working distance: 200 cm)							
Nuclide	External dose rate (mSv/h)	External dose nuclide contribution (%)	External working dose (mSv)	Internal exposure dose by inhalation (mSv)	Internal exposure dose by ingestion (mSv)	Total internal exposure dose (mSv)	Internal dose nuclide contribution (%)
Ce-141	1.90E-08	1.40E-02	1.90E-08	2.49E-13	5.45E-15	2.54E-13	7.36E-01
Co-57	3.70E-09	2.70E-03	3.70E-09	2.91E-15	7.23E-17	2.98E-15	8.64E-03
Co-58	6.20E-05	4.40E+01	6.20E-05	2.83E-12	1.16E-13	2.95E-12	8.54E+00
Co-60	5.70E-05	4.10E+01	5.70E-05	1.75E-11	2.28E-13	1.78E-11	5.14E+01
Fe-59	3.50E-07	2.50E-01	3.50E-07	1.35E-13	7.73E-15	1.43E-13	4.14E-01
Mn-54	1.00E-06	7.20E-01	1.00E-06	5.26E-14	2.77E-15	5.54E-14	1.60E-01
Nb-95	3.00E-06	2.10E+00	3.00E-06	3.38E-13	1.36E-14	3.52E-13	1.02E+00
Ru-103	3.20E-06	2.30E+00	3.20E-06	7.07E-13	2.49E-14	7.32E-13	2.12E+00
Ru-106	5.10E-06	3.70E+00	5.10E-06	1.14E-11	1.43E-13	1.16E-11	3.35E+01
Sn-113	1.10E-09	8.00E-04	1.10E-09	1.60E-14	5.18E-16	1.65E-14	4.78E-02

Sr-85	2.80E-06	2.00E+00	2.80E-06	1.50E-13	1.21E-14	1.62E-13	4.69E-01
Zn-65	7.10E-07	5.10E-01	7.10E-07	5.83E-14	8.71E-15	6.70E-14	1.94E-01
Zr-95	3.40E-06	2.50E+00	3.40E-06	4.56E-13	8.11E-15	4.64E-13	1.34E+00
Total	1.40E-04	1.00E+02	1.40E-04	3.39E-11	5.72E-13	3.45E-11	1.00E+02

C-8. Dose calculation result for Refining operation

Table C-8. Dose calculation result for Refining operation

Refining operation (Working time: 300 min, Working distance: 300 cm)							
Nuclide	External dose rate (mSv/h)	External dose nuclide contribution (%)	External working dose (mSv)	Internal exposure dose by inhalation (mSv)	Internal exposure dose by ingestion (mSv)	Total internal exposure dose (mSv)	Internal dose nuclide contribution (%)
Ce-141	6.40E-08	5.60E-02	3.20E-07	1.49E-14	1.65E-15	1.65E-14	4.86E+00
Co-57	3.70E-09	3.20E-03	1.80E-08	1.74E-18	1.94E-19	1.94E-18	5.69E-04
Co-58	5.30E-05	4.60E+01	2.70E-04	1.70E-13	1.88E-14	1.88E-13	5.53E+01
Co-60	4.30E-05	3.70E+01	2.10E-04	1.05E-14	1.17E-15	1.17E-14	3.43E+00
Fe-59	3.40E-07	2.90E-01	1.70E-06	8.10E-15	9.00E-16	9.00E-15	2.64E+00
Mn-54	7.30E-07	6.40E-01	3.60E-06	3.15E-17	3.50E-18	3.50E-17	1.03E-02
Nb-95	3.30E-06	2.90E+00	1.60E-05	2.02E-14	2.25E-15	2.25E-14	6.61E+00
Ru-103	2.50E-06	2.20E+00	1.30E-05	4.23E-14	4.70E-15	4.70E-14	1.38E+01
Ru-106	5.00E-06	4.40E+00	2.50E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sn-113	8.00E-10	6.90E-04	4.00E-09	9.57E-16	1.06E-16	1.06E-15	3.12E-01

Sr-85	2.90E-06	2.50E+00	1.50E-05	8.97E-15	9.97E-16	9.97E-15	2.93E+00
Zn-65	4.90E-07	4.30E-01	2.50E-06	3.49E-15	3.88E-16	3.88E-15	1.14E+00
Zr-95	3.10E-06	2.70E+00	1.60E-05	2.73E-14	3.03E-15	3.03E-14	8.91E+00
Total	1.10E-04	1.00E+02	5.70E-04	3.06E-13	3.40E-14	3.40E-13	1.00E+02

C-9. Dose calculation result for Ingot gathering

Table C-9. Dose calculation result for Ingot gathering

Ingot gathering (Working time: 150 min, Working distance: 150 cm)							
Nuclide	External dose rate (mSv/h)	External dose nuclide contribution (%)	External working dose (mSv)	Internal exposure dose by inhalation (mSv)	Internal exposure dose by ingestion (mSv)	Total internal exposure dose (mSv)	Internal dose nuclide contribution (%)
Ce-141	1.40E-07	4.90E-02	3.40E-07	3.72E-14	4.14E-15	4.14E-14	1.13E+00
Co-57	1.60E-08	5.60E-03	3.90E-08	4.36E-16	4.84E-17	4.84E-16	1.32E-02
Co-58	1.20E-05	4.30E+00	3.00E-05	4.24E-13	4.71E-14	4.71E-13	1.28E+01
Co-60	2.40E-04	8.60E+01	6.00E-04	2.62E-12	2.92E-13	2.92E-12	7.94E+01
Fe-59	2.90E-06	1.00E+00	7.30E-06	2.02E-14	2.25E-15	2.25E-14	6.12E-01
Mn-54	1.30E-06	4.70E-01	3.30E-06	7.87E-15	8.75E-16	8.75E-15	2.38E-01
Nb-95	2.50E-06	8.80E-01	6.20E-06	5.06E-14	5.62E-15	5.62E-14	1.53E+00
Ru-103	1.30E-05	4.50E+00	3.10E-05	1.06E-13	1.18E-14	1.18E-13	3.20E+00
Ru-106	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sn-113	4.00E-09	1.40E-03	1.00E-08	2.39E-15	2.66E-16	2.66E-15	7.24E-02

Sr-85	4.10E-06	1.50E+00	1.00E-05	2.24E-14	2.49E-15	2.49E-14	6.79E-01
Zn-65	4.40E-10	1.60E-04	1.10E-09	8.72E-15	9.69E-16	9.69E-15	2.64E-01
Zr-95	3.20E-06	1.20E+00	8.10E-06	6.83E-16	7.58E-17	7.58E-16	2.07E-02
Total	2.80E-04	1.00E+02	7.00E-04	3.30E-12	3.67E-13	3.67E-12	1.00E+02

C-10. Dose calculation result for Slag treatment

Table C-10. Dose calculation result for Slag treatment

Slag treatment (Working time: 1500 min, Working distance: 150 cm)							
Nuclide	External dose rate (mSv/h)	External dose nuclide contribution (%)	External working dose (mSv)	Internal exposure dose by inhalation (mSv)	Internal exposure dose by ingestion (mSv)	Total internal exposure dose (mSv)	Internal dose nuclide contribution (%)
Ce-141	5.80E-07	4.00E+00	1.40E-05	3.72E-13	4.14E-14	4.14E-13	1.51E+00
Co-57	1.30E-11	9.20E-05	3.40E-10	4.36E-17	4.84E-18	4.84E-17	1.77E-04
Co-58	2.70E-06	1.90E+01	6.80E-05	4.24E-12	4.71E-13	4.71E-12	1.72E+01
Co-60	7.70E-07	5.30E+00	1.90E-05	2.62E-13	2.92E-14	2.92E-13	1.06E+00
Fe-59	2.90E-06	2.00E+01	7.20E-05	2.02E-13	2.25E-14	2.25E-13	8.20E-01
Mn-54	6.20E-09	4.30E-02	1.60E-07	7.87E-16	8.75E-17	8.75E-16	3.19E-03
Nb-95	3.30E-08	2.20E-01	8.10E-07	5.06E-13	5.62E-14	5.62E-13	2.05E+00
Ru-103	1.30E-07	9.10E-01	3.30E-06	1.06E-12	1.18E-13	1.18E-12	4.29E+00
Ru-106	0.00E+00	0.00E+00	0.00E+00	1.71E-11	1.90E-12	1.90E-11	6.93E+01
Sn-113	5.60E-09	3.80E-02	1.40E-07	2.39E-14	2.66E-15	2.66E-14	9.69E-02

Sr-85	1.00E-06	7.00E+00	2.50E-05	2.24E-13	2.49E-14	2.49E-13	9.09E-01
Zn-65	1.10E-11	7.70E-05	2.80E-10	8.72E-16	9.69E-17	9.69E-16	3.54E-03
Zr-95	6.40E-06	4.40E+01	1.60E-04	6.83E-13	7.58E-14	7.58E-13	2.77E+00
Total	1.50E-05	1.00E+02	3.60E-04	2.47E-11	2.74E-12	2.74E-11	1.00E+02

C-11. Dose calculation result for Ingot loading

Table C-11. Dose calculation result for Ingot loading

Ingot loading (Working time: 120 min, Working distance: 400 cm)							
Nuclide	External dose rate (mSv/h)	External dose nuclide contribution (%)	External working dose (mSv)	Internal exposure dose by inhalation (mSv)	Internal exposure dose by ingestion (mSv)	Total internal exposure dose (mSv)	Internal dose nuclide contribution (%)
Ce-141	1.10E-07	1.10E-01	2.20E-07	2.98E-14	3.31E-15	3.31E-14	1.13E+00
Co-57	1.10E-08	1.20E-02	2.30E-08	3.49E-16	3.87E-17	3.87E-16	1.32E-02
Co-58	1.20E-05	1.30E+01	2.40E-05	3.39E-13	3.77E-14	3.77E-13	1.28E+01
Co-60	6.70E-05	7.00E+01	1.30E-04	2.10E-12	2.33E-13	2.33E-12	7.94E+01
Fe-59	1.60E-06	1.70E+00	3.20E-06	1.62E-14	1.80E-15	1.80E-14	6.12E-01
Mn-54	5.60E-07	5.90E-01	1.10E-06	6.30E-15	7.00E-16	7.00E-15	2.38E-01
Nb-95	2.50E-06	2.70E+00	5.00E-06	4.05E-14	4.50E-15	4.50E-14	1.53E+00
Ru-103	6.10E-06	6.40E+00	1.20E-05	8.47E-14	9.41E-15	9.41E-14	3.20E+00
Ru-106	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sn-113	1.70E-09	1.80E-03	3.30E-09	1.91E-15	2.13E-16	2.13E-15	7.24E-02

Sr-85	3.90E-06	4.10E+00	7.80E-06	1.79E-14	1.99E-15	1.99E-14	6.79E-01
Zn-65	1.30E-09	1.30E-03	2.50E-09	6.98E-15	7.75E-16	7.75E-15	2.64E-01
Zr-95	1.20E-06	1.30E+00	2.50E-06	5.46E-16	6.07E-17	6.07E-16	2.07E-02
Total	9.50E-05	1.00E+02	1.90E-04	2.64E-12	2.94E-13	2.94E-12	1.00E+02

C-12. Dose calculation result for Ingot transfer

Table C-12. Dose calculation result for Ingot transfer

Ingot transfer (Working time: 300 min, Working distance: 200 cm)							
Nuclide	External dose rate (mSv/h)	External dose nuclide contribution (%)	External working dose (mSv)	Internal exposure dose by inhalation (mSv)	Internal exposure dose by ingestion (mSv)	Total internal exposure dose (mSv)	Internal dose nuclide contribution (%)
Ce-141	1.60E-07	7.70E-02	7.80E-07	7.45E-14	8.27E-15	8.27E-14	1.13E+00
Co-57	1.60E-08	7.80E-03	7.80E-08	8.72E-16	9.69E-17	9.69E-16	1.32E-02
Co-58	1.20E-05	6.00E+00	6.10E-05	8.48E-13	9.42E-14	9.42E-13	1.28E+01
Co-60	1.60E-04	8.20E+01	8.20E-04	5.25E-12	5.83E-13	5.83E-12	7.94E+01
Fe-59	2.70E-06	1.30E+00	1.30E-05	4.05E-14	4.50E-15	4.50E-14	6.12E-01
Mn-54	1.10E-06	5.60E-01	5.60E-06	1.57E-14	1.75E-15	1.75E-14	2.38E-01
Nb-95	2.80E-06	1.40E+00	1.40E-05	1.01E-13	1.12E-14	1.12E-13	1.53E+00
Ru-103	1.00E-05	5.20E+00	5.20E-05	2.12E-13	2.35E-14	2.35E-13	3.20E+00
Ru-106	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sn-113	3.20E-09	1.60E-03	1.60E-08	4.78E-15	5.31E-16	5.31E-15	7.24E-02

Sr-85	4.90E-06	2.40E+00	2.40E-05	4.49E-14	4.98E-15	4.98E-14	6.79E-01
Zn-65	7.40E-10	3.70E-04	3.70E-09	1.74E-14	1.94E-15	1.94E-14	2.64E-01
Zr-95	2.40E-06	1.20E+00	1.20E-05	1.37E-15	1.52E-16	1.52E-15	2.07E-02
Total	2.00E-04	1.00E+02	1.00E-03	6.61E-12	7.34E-13	7.34E-12	1.00E+02

C-13. Dose calculation result for Storage operation

Table C-13. Dose calculation result for Storage operation

Storage operation (Working time: 2400 min, Working distance: 1000 cm)							
Nuclide	External dose rate (mSv/h)	External dose nuclide contribution (%)	External working dose (mSv)	Internal exposure dose by inhalation (mSv)	Internal exposure dose by ingestion (mSv)	Total internal exposure dose (mSv)	Internal dose nuclide contribution (%)
Ce-141	4.20E-08	1.10E-01	1.70E-06	5.96E-13	6.62E-14	6.62E-13	7.33E-01
Co-57	5.10E-09	1.40E-02	2.00E-07	6.97E-15	7.75E-16	7.75E-15	8.58E-03
Co-58	8.00E-06	2.10E+01	3.20E-04	6.78E-12	7.54E-13	7.54E-12	8.34E+00
Co-60	2.20E-05	5.90E+01	8.90E-04	4.20E-11	4.67E-12	4.67E-11	5.16E+01
Fe-59	6.40E-07	1.70E+00	2.60E-05	3.24E-13	3.60E-14	3.60E-13	3.98E-01
Mn-54	2.30E-07	6.10E-01	9.30E-06	1.26E-13	1.40E-14	1.40E-13	1.55E-01
Nb-95	1.80E-06	4.70E+00	7.20E-05	8.10E-13	9.00E-14	9.00E-13	9.96E-01
Ru-103	2.40E-06	6.30E+00	9.40E-05	1.69E-12	1.88E-13	1.88E-12	2.08E+00
Ru-106	0.00E+00	0.00E+00	0.00E+00	2.74E-11	3.04E-12	3.04E-11	3.36E+01
Sn-113	6.60E-10	1.80E-03	2.70E-08	3.83E-14	4.25E-15	4.25E-14	4.71E-02

Sr-85	1.80E-06	4.90E+00	7.40E-05	3.59E-13	3.99E-14	3.99E-13	4.41E-01
Zn-65	9.40E-10	2.50E-03	3.80E-08	1.40E-13	1.55E-14	1.55E-13	1.72E-01
Zr-95	6.30E-07	1.70E+00	2.50E-05	1.09E-12	1.21E-13	1.21E-12	1.34E+00
Total	3.80E-05	1.00E+02	1.50E-03	8.13E-11	9.04E-12	9.04E-11	1.00E+02

C-14. Dose calculation result for End product loading

Table C-14. Dose calculation result for End product loading

End product loading (Working time: 1200 min, Working distance: 400 cm)							
Nuclide	External dose rate (mSv/h)	External dose nuclide contribution (%)	External working dose (mSv)	Internal exposure dose by inhalation (mSv)	Internal exposure dose by ingestion (mSv)	Total internal exposure dose (mSv)	Internal dose nuclide contribution (%)
Ce-141	1.10E-07	1.10E-01	2.20E-06	2.98E-13	3.31E-14	3.31E-13	7.33E-01
Co-57	1.10E-08	1.20E-02	2.30E-07	3.49E-15	3.87E-16	3.87E-15	8.58E-03
Co-58	1.20E-05	1.30E+01	2.40E-04	3.39E-12	3.77E-13	3.77E-12	8.34E+00
Co-60	6.70E-05	7.00E+01	1.30E-03	2.10E-11	2.33E-12	2.33E-11	5.16E+01
Fe-59	1.60E-06	1.70E+00	3.20E-05	1.62E-13	1.80E-14	1.80E-13	3.98E-01
Mn-54	5.60E-07	5.90E-01	1.10E-05	6.30E-14	7.00E-15	7.00E-14	1.55E-01
Nb-95	2.50E-06	2.70E+00	5.00E-05	4.05E-13	4.50E-14	4.50E-13	9.96E-01
Ru-103	6.10E-06	6.40E+00	1.20E-04	8.47E-13	9.41E-14	9.41E-13	2.08E+00
Ru-106	0.00E+00	0.00E+00	0.00E+00	1.37E-11	1.52E-12	1.52E-11	3.36E+01
Sn-113	1.70E-09	1.80E-03	3.30E-08	1.91E-14	2.13E-15	2.13E-14	4.71E-02

Sr-85	3.90E-06	4.10E+00	7.80E-05	1.79E-13	1.99E-14	1.99E-13	4.41E-01
Zn-65	1.30E-09	1.30E-03	2.50E-08	6.98E-14	7.75E-15	7.75E-14	1.72E-01
Zr-95	1.20E-06	1.30E+00	2.50E-05	5.46E-13	6.07E-14	6.07E-13	1.34E+00
Total	9.50E-05	1.00E+02	1.90E-03	4.07E-11	4.52E-12	4.52E-11	1.00E+02

C-15. Dose calculation result for End product transfer

Table C-15. Dose calculation result for End product transfer

End product transfer (Working time: 480 min, Working distance: 200 cm)							
Nuclide	External dose rate (mSv/h)	External dose nuclide contribution (%)	External working dose (mSv)	Internal exposure dose by inhalation (mSv)	Internal exposure dose by ingestion (mSv)	Total internal exposure dose (mSv)	Internal dose nuclide contribution (%)
Ce-141	1.60E-07	7.70E-02	1.20E-06	1.19E-13	1.32E-14	1.32E-13	7.33E-01
Co-57	1.60E-08	7.80E-03	1.30E-07	1.39E-15	1.55E-16	1.55E-15	8.58E-03
Co-58	1.20E-05	6.00E+00	9.70E-05	1.36E-12	1.51E-13	1.51E-12	8.34E+00
Co-60	1.60E-04	8.20E+01	1.30E-03	8.40E-12	9.33E-13	9.33E-12	5.16E+01
Fe-59	2.70E-06	1.30E+00	2.20E-05	6.48E-14	7.20E-15	7.20E-14	3.98E-01
Mn-54	1.10E-06	5.60E-01	8.90E-06	2.52E-14	2.80E-15	2.80E-14	1.55E-01
Nb-95	2.80E-06	1.40E+00	2.30E-05	1.62E-13	1.80E-14	1.80E-13	9.96E-01
Ru-103	1.00E-05	5.20E+00	8.40E-05	3.39E-13	3.76E-14	3.76E-13	2.08E+00
Ru-106	0.00E+00	0.00E+00	0.00E+00	5.47E-12	6.08E-13	6.08E-12	3.36E+01
Sn-113	3.20E-09	1.60E-03	2.60E-08	7.65E-15	8.50E-16	8.50E-15	4.71E-02

Sr-85	4.90E-06	2.40E+00	3.90E-05	7.18E-14	7.98E-15	7.98E-14	4.41E-01
Zn-65	7.40E-10	3.70E-04	6.00E-09	2.79E-14	3.10E-15	3.10E-14	1.72E-01
Zr-95	2.40E-06	1.20E+00	1.90E-05	2.18E-13	2.43E-14	2.43E-13	1.34E+00
Total	2.00E-04	1.00E+02	1.60E-03	1.63E-11	1.81E-12	1.81E-11	1.00E+02

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2018 년 7 월

성 낙 원