RECYCLE EXPERIENCE OF DISMANTLED CASK HANDLING CRANE BY SURFACE REMOVAL SAMPLING AT KORI #1

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ABSTRACT

The Kori #1, which began operation in 1978, replaced its cask handling crane in 2000. To prove the safety of recycling and reuse of crane scrap, a particular calculation method for surface contamination was used. Because surface radioactive contamination of steel is limited to a few-microns-thick layer, we can calculate the total(removable and fixed contamination) activity of the sample conservatively by this surface removal sampling means. If we multiply the ratio of total surface and the area of the selected surface by its activity, total activity of the scrap can be estimated. Conservatively, the sampled portion can be used as a representative sample of the scrap. Both the inner and outer part of the scrap was sampled separately, and gamma spectra were analyzed to check whether activation had occurred. Before sampling, the entire surface of the steel is scan surveyed by several kinds of GM and GP detectors. Contaminated parts were segregated, or decontaminated to the background. Almost one sample per one ton of steel was collected. Gamma spectra of 62 samples were analyzed by 100% efficiency HP Ge detector. Only ^{60}Co was detected, and its highest activity was 0.01 Bq/g,. This level of activity is much lower than the 'clearance levels' outlined in IAEA TecDoc-855.(4). The total alpha and total beta for 6 samples were measured in the laboratory by low background alpha, using a beta gas proportional counter. Activities were much lower than 0.005 Bq/g. A representative sample was taken from the complete mixture of 62 samples. Gamma activities of nuclides were measured to estimate the dose to the public. This study revealed that activities of nuclides were lower than 'clearance levels' if decontaminated until the lower limit of detection level of the portable field instrument. New surface removal sampling method was tested. This method allows us to easily calculate the specific activity for the solid material.

INTRODUCTION

It has been demonstrated that if activity is lower than general clearance levels, any material can be released from regulatory control with negligible risk from a radiation protection point of view. The physical risk to workers from workplace accidents, and to the public from transportation accidents is greater than the risk from the recycled/reused steel below 'clearance levels' (1). Because 'clearance levels' are derived based on 10μSv/y to the public. The effect of recycling and reuse of the steel to the public is negligible. A number of case studies to determine the safety-effectiveness of pursuing the recycling and reuse option revealed that the recycling and reuse of steel results in significant savings with respect to its both cost and safety, when compared to direct disposal alternatives. The most difficult matter for the unconditional release of the scrap is representative sampling, and the measurement of radioactivity for each nuclide. There are several international (e.g., International Atomic Energy Agency, European Union) and U.S. (e.g., Nuclear Regulatory Commission, American National Standards Institute, National Council

on Radiation Protection and Measurements) standards (1,4,7,10) for unrestricted release, therefore we may adapt or follow their concept. But, even though a clearance standard has been developed, it is important to remember that it is not easy to sample and detect the activity of the scrap.

SAFE RELEASE PLAN FOR KORI #1

Contamination of scrap metals from commercial nuclear power plants that are potentially available for recycling primarily exists in the form of surface contamination, which is limited to a few-microns-thick layer of radioactivity on the metal surface.(3) Kori #1 is going to safely release the slightly contaminated steel scrap to the scrap market. It can be reused or turned into ingot in the smelter. Among three reasonable recommendations (IAEA TECDOC-855(4), OECD/NEA Recycle and Reuse of Scrap Metal(1) and EC Guidance on General Clearance Levels for Practice)(8), clearance levels of IAEA TECDOC-855(4) are enough for interim use. Potential radiological impact from the radioactive scrap steel can also be assessed in terms of total effective dose. Health effects can be estimated by the health effects conversion factor of 5E10-2 fatal cancers per Sv.(2).

The only remaining difficult part is sampling and detection of the radioactivity of the scrap steel. It is not easy to sample the steel, because of hardness. Even the advanced scintillation detector can not cover all low energy alpha nuclides and beta nuclides. Furthermore, because the shape of scrap steel is not always same, the geometry of the sample can change. To solve this kind of problem, mechanical surface removal sampling method was tested. Most contamination arose on the surface of the material. If the contaminated surface is removed and its radioactivity is measured, total contamination activity can be calculated. This method is totally different from the smear method, which shows the variation of radioactivity. Variation caused by difference of transferability, and this method is indirect measurement. Furthermore, it only shows the activity of removable contamination. Kori #1 wants to release the scrap steel to the scrap market without any restrictions. If the scrap of crane is mixed with other scrap, it will be very difficult to determine the characteristic of contamination. All scrap from the cask-handling crane was collected separately in the fuel building to measure radioactivity.

Contaminated parts of the dismantled crane were decontaminated by physical process (CO_2 blast, and grinding). After decontamination, the entire surface of the scrap was thoroughly scanned for total beta and total gamma contamination, using a thin-window 'pancake', 'frisker' and gamma probe Geiger-Mueller(GM) detector, or a GP counter with a potable scaler. The smear method was also used to demonstrate the level of residual contamination on the surface. If any contamination was detected, the decontamination process was applied again until contamination was reduced to background level.

The detector was passed over the surface at the speed of 5 to 10 cm per second at a relatively constant distance of 1 cm or less for the survey of total beta counting, and the gamma detector was also passed at the speed of 15 cm per second at a the relatively constant distance of 5 cm, and moved in a serpentine pattern to survey for total gamma contamination.

The capability of detecting localized areas of contamination using scan surveys is not only affected by the sensitivity of the survey instrumentation, but also by the surveyor's ability. But when contamination within or on the surface of scrap is below the 0.01 mSv/y derived concentration limit most radionuclides are detectable, but some radionuclides not detectable are very low energy (beta) emitters, due to their low counting efficiencies.(3)

MEASUREMENT OF CONTAMINATION

For a considerably smaller fraction of potentially releasable scrap of the nuclear power plant, the volumetric activity is caused by activation of metal during the reactor operation. Radioactive scrap can be categorized by the anticipated level of radioactivity, which depends on facility design, operating history and maintenance. Cranes for fuel handling and fuel-handling machines are classified as surface-contamination-removable(5). In some cases, cask-handling crane is associated with the spent nuclear fuel, but usually not associated with the primary coolant system. A health physics survey may not

be necessary to confirm that the spent crane is not activated, but must show the evidence. Almost one-fifth of the crane volume is radioactively contaminated (above background). Because of economical efficiency, severely contaminated parts were cut and stored in the 55 gallon DOT drums.
Most of the metal scrap resulting from the dismantling of nuclear power plants is not radioactive. However, just by being a nuclear power plant site, all steel is suspected to have been exposed to activity from fission product, coolant and gas, or even from neutrons passing through the biological shielding. Therefore, all steel on the site must be treated as suspect, and surveyed before being moved off the site. Nevertheless, cask-handling crane is a good example of non-radioactive scrap. Though total gamma and total beta were surveyed until radioactivity is not detected, it does not mean that the scrap from the crane is not contaminated. So we proceed. :

1. Check volumetric activity, which was caused by neutron activation.
2. For the measurement of surface-contaminated, sample the surface of the scrap.
3. Direct measurement with laboratory analysis was carried out
   - to assess the radionuclide spectra
   - to assess the gross alpha and gross beta

If steel is activated by neutrons the contamination is not confined to the surface of the steel. The distance from the cask handling crane to the possible neutron generator, (i.e. spent fuel) is normally over 20m, and spent fuel almost stops neutron generation, except residual fission. The residual neutron is caught in boron in the spent fuel pool, or shielded by water and building material. To prove that activation had not occurred in the steel of the crane, the interior and exterior of the steel were sampled for laboratory gamma radionuclide analysis by a high purity germanium(HPGe) detector. As you can see in the **table I**, activity of the exterior was slightly contaminated, but the interior was not contaminated at all. Both activities were far lower than clearance levels of IAEA TECDOC-855 (4) It means that whether activation occurred or not is not important. Activated nuclides of steel cannot be found. There are four non-radioactive ferrous isotopes in the nature (^{54}Fe : 5.9 %, ^{56}Fe : 91.72 %, ^{57}Fe : 2.1 %, ^{58}Fe : 0.28 %,). Major activated radionuclides of the carbon steel are ^{55}Fe (^{54}Fe(n,γ)^{55}Fe) and ^{59}Fe (^{58}Fe(n,γ)59Fe) and (^{54}Fe(n,p)^{54}Mn). ^{60}Co can be produced by the activation of impurities in the PWR. ^{60}Co is only detected on the surface of the scrap as activated nuclide. ^{60}Co is produced by activation reaction of (^{59}Co(n,γ) ^{60}Co), but existence of ^{60}Co does not always mean activation. ^{60}Co of the surface was believed to be transferred from the activated medium. Because ^{60}Co was not detected inside the scrap, it can be concluded that activation had not occurred in the crane scrap.

Table I. Activities of ^{60}Co on the surface and Inside of scrap

Unit : Bq/g

	No. 1	No. 2	No. 3	No. 4	
Exterior	0.015	0.005	0.010	0.106	
Interior	lower than LLD	lower than LLD	Lower than LLD	Lower than LLD	LLD : 1.20 E-3

If activation occurred in the scrap steel, three gamma emitters (^{54}Fe(n,p)^{54}Mn), (^{58}Fe(n,γ)^{59}Fe) (from the steel composition), and (^{59}Co(n,γ)^{60}Co) (from the impurity) would have been found. No activated radionuclide was detected inside the steel.

SPECIAL SAMPLING AND RADIOACTIVITY

Sampling of metal is not as easy as sampling of resin, soil, coolant and gas. One indirect sampling method, the smear method can be used, but it is not adequate because of variable sampling efficiency (usually use 10% if it is not determined experimentally). Surface-contaminated-removable can be sampled by the

smear method, while surface-contaminated-fixed is not easily sampled. To improve this steel rotary carbide burr(**figure 1**), which is used to grind and to plane, was used for surface removal sampling. Grinded material was collected by a super-magnetic collector. Unlike the regular sampling process, this destructive sampling method can be used on the recycling and reuse of the scrap steel. This sampling method has not been used with recycling and reuse of the scrap, even though it is a very efficient and direct method. Because surface contamination is limited to a few-microns-thick layer of radioactivity on the metal surface, we can collect all the activity by removing only 0.1 to 1.0mm of the surface.

Fig. 1 : Shape of the rotary carbide burr

Total activity is almost the same regardless of sample volume. Because of the specific character of the gamma ray, a slight change of the sample's volume does not greatly change the total activity. When the sample is not activated, this scabbling method is very efficient to measure average radioactivity even for the total beta and total alpha cases.

Number of samples is also an important matter for analysis. For the solid, clearance levels are expressed in terms of activity concentration. These values are intended to be averaged over a moderate quantity of material. It is also assumed that the radionuclides are evenly distributed. Therefore a method is required to determine the significance of estimated average activity.

For multiple volumetric measurement, American National Standard ANSI/HPS N13.12-1999 (7) requires concentration averaged over a total volume not to exceed $1m^2$ or mass of one metric ton, and it also requires that averaged over a surface not to exceed 1 m^2. But because decontamination was proceeded until background level for this case, it is not necessary to collect many samples; that is 1 sample per 1 ton of scrap is enough, even though the most severe guidance for survey unit is followed.(7,9). 62 samples were collected for the crane scrap of Kori #1. Total(fixed and movable) surface activity can be estimated directly by measuring the sample.

Because sampling was made on the surface of the scrap, the specific radioactivity of the sample does notmean average activity of the scrap. Sampling was made on the surface area of 100 cm^2(10 cm $\times$10 cm). Under the assumption that : 1) the activity of the sample is 10 Bq, and 2) the shape of crane is a regular hexahedron, 3) all surface is evenly contaminated, the unit(100 cm^2) surface activity is multiplied by ratio of sample surface to total surface to get total radioactivity. And total activity divided by the weight (volume $\times$ specific gravity) to get specific radioactivity.

the average specific activity =

$$\frac{Total\ Surface}{100\ cm^2} \times 10\ Bq \times \frac{1}{Volume \times Specific\ Gravity} = \frac{10 \times 10 \times 6 cm^2}{100\ cm^2} \times 10\ Bq \times \frac{1}{1000 \times 7.9}$$

$$\cong 0.01\ Bq\ /\ g$$

62 samples were collected and measured, and activities of the sample from the surface samples were much lower than clearance levels of IAEA TECDOC-855 (4). We did not used average specific activity calculated by the procedure above, but specific activity is necessary, to be calculated by the surface removal method, for the contamination of much higher than minimum detectable activity. The high purity germanium(HPGe) detector with 20cm lead shield with tin/copper was calibrated by a mixed source of ^{109}Cd, ^{57}Co, ^{139}Ce, ^{51}Cr, ^{113}Sn, ^{85}Sr, ^{137}Cs, ^{60}Co and ^{88}Y.

For the total alpha and total beta counting, an alpha, beta proportional counter was used. Only 8 samples among the 62 samples were measured. Both total alpha and total beta were lower than the minimum detectable activity. Minimum detectable activity for total alpha and total beta of low background proportional counter were 0.002 Bq/g and 0.005Bq/g, respectively.

DOSE TO THE PUBLIC

RESRAD-Recycle was used to estimate the dose to the public from recycling and reuse. To calculate the public dose, we need activity for radionuclides. To release the scrap as clearance, a representative homogeneous sample is needed in relation to both material and origin. The primary objective of sampling is to obtain a small quantity of material which is representative of whole material. In practice, true homogeneity is rarely achieved. From the mixed samples, one representative sample was collected. These data were overestimated because the radioactivities of the surface sample were used without correction. Activities of major radionuclides in the representative homogenized sample are shown in the **Table II**, in comparison with clearance level of IAEA TecDoc-855.

Table II. Activities of sample and clearance level of IAEA TecDoc-855

Nuclides	Clearance level of IAEA TecDoc-855.		Activity of representative Sample	
	Bq/g	Bq/cm^2	Bq/g	Bq/ cm^2
Mn-54	7	40	1.58 E-2	1.58 E-4
Fe-59	5	40	-	-
Co-58	6	50	-	-
Co-60	2	10	-	-
Cs-134	4	20	1.11E-2	1.11E-4
Cs-137	10	40	4.88E-3	4.88E-5
Eu-152	5	20	1.06E-2	1.06E-4

Calculation of the RESRAD-Recycle code included numerous scenarios for individual and collective radiation exposure, including workers in the smelter, scrap cutter, and users of the product.
Multiple exposure pathways were also considered, including direct exposure of penetrating radiation, inhalation of airborne and secondary ingestion of contaminated dust transferred to the mouth. The doses and risk for the nuclides, and doses for each scenario are shown in **Table III and IV,** respectively.
Collective dose from consumer scenario was 9.05E-3 person-Sv/y. The most severe scenario per individual was the slag worker, during the scrap smelting process (3.81E-3 mSv/y per individual). Consumer product usage cases for room/office were the second limiting scenario (8.61E-4 mSv/y per individual). The most limiting scenario of for the public was the consumer product usage scenario for home furniture (4.49E-3 person-Sv/y). The consumer product use cases for office furniture were the second limiting scenario (2.77E-3 person-Sv/y).
The dose per individual and the collective dose from consumer scenario were lower than the dose limit of 'clearance levels', 0.01 mSv/y per individual and 1 person-Sv/y, respectively even if surface sample was used instead of volumetric samples, for the calculation of their radioactivity.

Table III. Overall Impact From Consumer Scenarios

Unit : person-Sv/y

	Collective			Cumulative		
Nuclide	Dose (person-Sv/y	Risk	Fraction	Dose (person-Sv/y)	Risk	Fraction
Am-241	1.02E-07	7.71E-08	0.00E+00	1.01E-06	7.71E-08	0.00E+00
Ce-144	2.74E-07	3.51E-08	0.00E+00	4.61E-07	3.51E-08	0.00E+00
Co-57	1.43E-05	1.77E-06	1.60E-03	2.33E-05	1.77E-06	6.00E-04
Cs-134	4.63E-07	1.18E-07	1.00E-04	1.56E-06	1.18E-07	0.00E+00
Cs-137	8.60E-08	5.89E-08	0.00E+00	7.75E-07	5.89E-08	0.00E+00
Eu-152	1.20E-05	7.29E-06	1.30E-03	9.59E-05	7.29E-06	2.70E-03
Eu-154	1.09E-05	5.97E-06	1.20E-03	7.85E-05	5.97E-06	2.20E-03
Mn-54	1.14E-03	1.55E-04	1.26E-01	2.04E-03	1.55E-04	5.67E-02
Nb-94	1.15E-05	8.74E-06	1.30E-03	1.15E-04	8.74E-06	3.20E-03
Np-237	3.54E-05	2.69E-05	3.90E-03	3.54E-04	2.69E-05	9.80E-03
Pu-239	6.00E-09	4.56E-09	0.00E+00	6.00E-08	4.56E-09	0.00E+00
Ra-226	1.13E-04	9.44E-05	1.25E-02	1.24E-03	9.44E-05	3.46E-02
Sb-125	7.70E-03	2.43E-03	8.51E-01	3.20E-02	2.43E-03	8.90E-01
Tc-99	5.16E-08	4.02E-08	0.00E+00	5.29E-07	4.02E-08	0.00E+00
U-235	9.19E-07	6.98E-07	1.00E-04	9.18E-06	6.98E-07	3.00E-04
Zn-65	1.07E-05	1.24E-06	1.20E-03	1.64E-05	1.24E-06	5.00E-04
Total	9.05E-03	2.73E-03	1.00E+00	3.59E-02	2.73E-03	1.00E+00

Table IV. Dose from the RESRAD-RECYCLE Default Scenario & Parameters for Steel

Unit : μSv/y & person-Sv/y

Scenario	Individual		Collective		Cumulative	
	Dose	Rank	Dose	Rank	Dose	Rank
Scrap Smelting: Slag Worker	3.81E 00	1	3.81E-06	8	3.81E-06	8
Consumer Product : Room/Office	8.61E-01	2	3.27E-04	5	1.35E-03	6
Consumer Product : Automobile	6.83E-01	4	5.47E-04	4	2.09E-03	4
Consumer Product : Office Furniture	3.96E-01	5	2.77E-03	2	1.06E-02	2
Consumer Product : Home Funiture	7.19E-01	3	4.49E-03	1	1.72E-02	1
Consumer Product : Frying Pan	1.51E-02	19	6.20E-04	3	2.49E-03	3

CONCLUSION

This study showed that the radioactivity of cask-handling crane scrap was lower than 'clearance level' after decontamination was performed until background level. By comparing inner part and outer part in the gamma spectrum of the scrap, we could understand activation had not occurred. The new surface removal sampling method for the metal was tested, which allowed us to easily calculate the specific activity for the solid.

The total beta and total gamma scan survey were carried out, the level of contamination was determined. 62 samples were collected and measured for their gamma spectra. However, the activities of the surface samples were much lower than clearance levels of IAEA TECDOC-855 (4). 62 samples were thoroughly mixed and one representative sample was taken. Gamma activities of nuclides were used to calculate the dose to the public. The radioactivity level is lower than clearance level, which corresponds to 0.01 mSv/y per individual, even if activity of the surface sample was used instead of volumetric sample for the calculation of their radioactivity. Estimated collective dose from consumer scenario was 9.05E-3 person-Sv/y, and the most severe scenario was the slag worker case (3.81E-3 mSv/y) of scrap melting for individuals, and the home furniture use scenario (4.49E-3 person-Sv/y) for the public, respectively.

For all scenarios, the dose per individual and the collective dose to the public were lower than the dose limits of 'clearance levels', 0.01 mSv/y per individual and 1 person-Sv/y, respectively, even the surface sample was used instead of volumetric sample, for the calculation of their radioactivity.

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