3-7
Study on Safety Evaluation for Unrestricted Recycling Criteria of Radioactive Waste from Dismantling Operation

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ABSTRACT

The study on safety evaluation was done, under contracting with the Science and Technology Agency, for recycling scrap metal arising from dismantling of reactor facilities. An object of this study is to contribute to the examination of establishing criteria and safety regulation for unrestrected recycling steel scrap.

To define amount of market flow of iron material in Japan and the amount of radioactive waste generated from dismantling of reactor facilities, investigation had been carried out. On basis of these investigation results and data in several literature, individual doses to workers and to the members of the public have been calculated as well as collective doses.

1. Introduction

The issue about exemption of very low level radioactive materials from the regulatory control has investigated by some organs to the goverment of Japan.

The Atomic Energy Commission and the Nuclear Safety Commission have pointed out the possibility of the exemption from the regulatory concern. For example, very low level radioactive materials, which cause the trivial dose to the members of public, are able to dispose of as usual municipal trash or to reuse.

In 1987, the Radiation Council has established the exemption criteria for solid radioactive waste in shallow land burial as follows:

(1) The annual individual dose to the critical group shall be less than 10 μSv from each source;

(2) The disposal methods of solid radioactive waste should also be examined from the viewpoit of optimization.

It is expected that this criteria can be applied for recycling and reuse of materials slightly conataminated with radionuclides.

Establishment of activity concentration limits for exemption is under investigation by the Nuclear Safety Commission. And some scientific investigations for the recycling of contaminated steel scrap are also being carried out by JAERI under contract from the Science and Technology Agency.

2. Amount of market flow of iron material

Crude steel output is shown in Fig.1. Annual output of crude steel is about 100 Mt in Japan. There is a economical fluctuation in total output and in output of steel converter.Crude steel output of electric furnace which is used relatively large amount of scrap increses to over 30 %.

The supply and demand of scrap is shown in Fig.2. There are also economical fluctuation in total amount of consumption and consumption for steel-making. 50 Mt of scrap steel is dissipated, and about 80 % of scrap steel is used for steel making. Therefore on the calculation, it is assumed that 80 % recycled steel is used to manufacture a reinforecement. The remainder is assumed to be used to manufacture each items of evaluation.

The market flow of iron material in 1990 is shown in Fig.3. Most of scrap iron will be melted by electric furnuce and will be manufacturing steel material. The avelage capacity of electric furnace is 50 t. A daily throughput of steel products is 150 t. An annual working days of steel woks are 250 days. Consequently the steel plant has a yearly throughput 37,500 t. Therefore on the calculation, the total activity of the recycled steel is assumed to be spred uniformly over the whole production, namely 37,500 t.

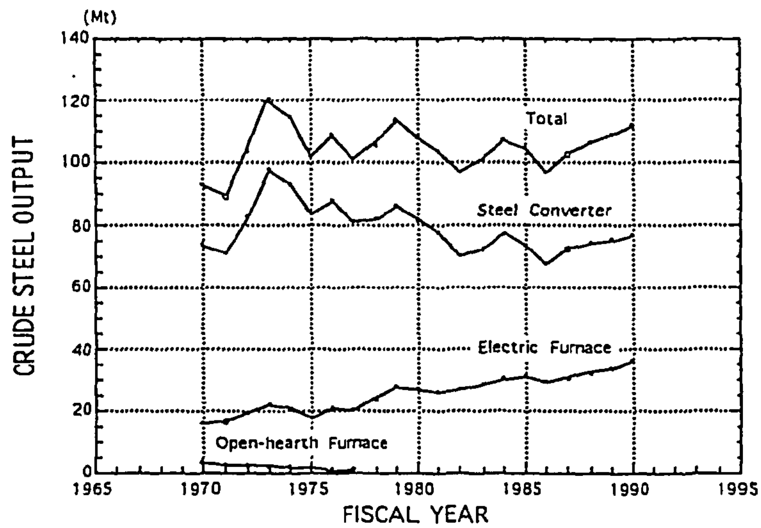

Fig.1. Crude steel output in JAPAN.

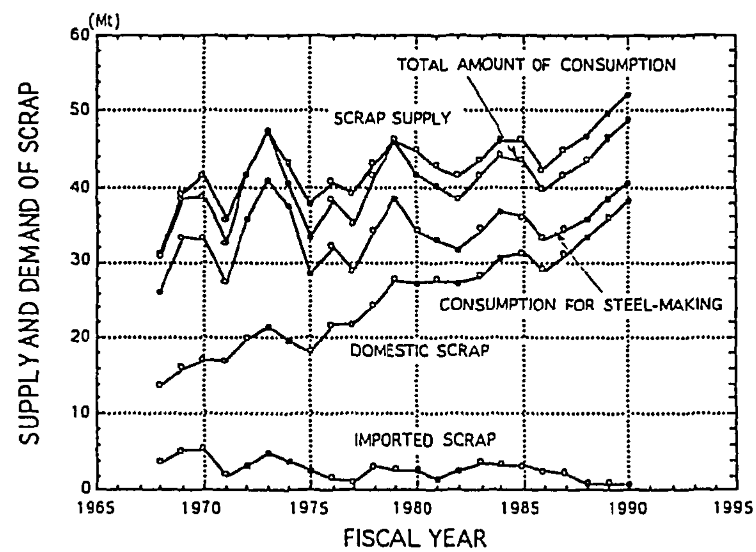

Fig.2. Supply and demand of scrap.

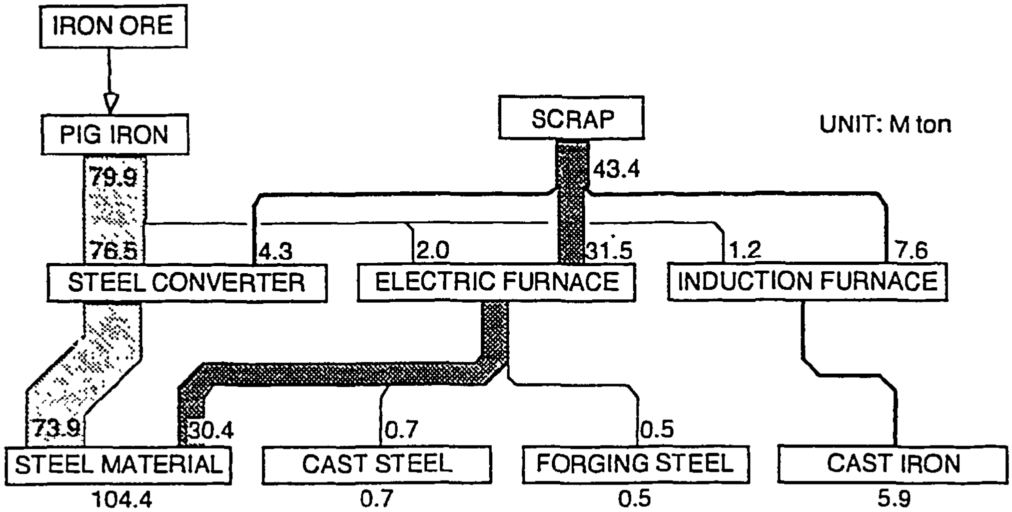

Fig.3. Flow of Iron Material in JAPAN

3. Contaminated scrap metal arising from dismantling of reactor facilities

In Japan, commercial nuclear power reactor has been increased since the first reactor was constracted in 1966. Over 40 reactors are operating now. It is assumed that these reactor had been operating for 30 or 40 years and mothballing 5 or 10 years after shutdown. And it is expected that two reactors will be dismantled in a year and will start in the year 2000.

The amount of recyclable scrap arising from dismantling reactor facility is assumed to be from 1,200 to 1,600 t. Thus, in the calculation, it is setuped 1,500 t of steel scrap generating from dismantling operation of one reactor. This value is based on litelature data shown in Table 1.(1) It is assumed that average concentration of steel scrap is less than 1 Bq/g.

Consideration of the composition of contaminated steel and activated steel scrap led to the selection of 30 nuclides for the calculation of potential doses due to recycling. The radionuclides composition used in the evaluation of activity concentration for recycling steel scrap is shown in Table 2.

Table 1. Typical masses and activities in steels from a 1000 MWe PWR containing very low level of activity [1].

Activity Range		Time from Reactor Shutdown					
		5 Years		25 Years		100 Years	
Surface Contamina -tion (Bq/cm^2)	Average Concentra -tion (Bq/g)	Steel Mass (t)	Total Activity (Bq)	Steel Mass (t)	Total Activity (Bq)	Steel Mass (t)	Total Activity (Bq)
37-370	10	800	8×10^9	440	4.4×10^9	240	2.4×10^9
3.7 -37	1	1600	1.6×10^9	880	8.8×10^8	480	4.8×10^8
0.37-3.7	0.1	3200	3.2×10^8	1760	1.8×10^8	960	9.6×10^7

Table 2. Radionuclides composition considered in surface contaminants and radioactivated carbon steel.

(5 Years after Reactor Shutdown)

Nuclide		Surface Contaminants (%)	Rddioactivated Carbon Steel (%)
β/γ Emitters	^{55}Fe	6.5	95
	^{60}Co	65.3	5
	^{63}Ni	1.3	-
	^{90}Sr	3.3	-
	^{125}Sb	6.5	-
	^{134}Cs	2.6	-
	^{137}Cs	6.5	-
	^{147}Pm	6.5	-
	^{241}Pu	2.6	-
α Emitters	^{238}Pu	48.1	-
	^{239}Pu	5.8	-
	^{240}Pu	7.7	-
	^{241}Am	16.0	-
	^{244}Cm	22.4	-

4. Exposure Scenarios

In order to evaluate the radiological impact of recycling of steel scrap, individual doses to workers and to the members of the public have been calculated as well as collective doses.

The scenarios have been chosen assuming that Steel Scrap will be recycled by means of melting in steel works. Therefore workers could be exposed during the pre-treatment process of steel scrap, before the melting process, the melting process and the casting process.

The members of the public could be exposed to items made of recycled steel. In addition, the public could be exposed to slag arising from the melting process.

4.1 Compaction and Cutting Process

The steel scrap are classified, cut and compacted in the pre-treatment works of steel scrap. The average monthly capacity of in these pre-treatment works is from 4000 to 4500 t.

It is assumed that 1500 t of contaminated Steel Scrap could be treated for 10 days, and the daily labour hours in these works are 8 hours.

The exposure scenarios and parameters consided in compaction and cutting process is shown in Table 3-1.

Table 3-1 Exposure Scenarios and Parameters for Compaction and Cutting Process

Exposure Scenarios	Number of Pepole Exposed	Exposure Duration (hr/year)	Source Geometry	Dimention of the Source (m)		Distance from the Source (m)	Density of the Source (g/cm³)	Shielding	Inhalanor	Ingestion
				Radius	Height					
1) Load Trucks	2	15	P	1.1	6.8	0.5	0.5	None	O	O
2) Drive to Compaction and Cutting Works	1	10	A	1.1	6.8	1.0	0.5	None		
3) Unload Trucks	2	15	P	1.1	6.8	0.5	0.5	None	O	O
4) Store Scrap	4	80	P	10.0	2.0	10.0	0.5	None	O	O
5) Selection of Scrap	2	80	P	1.7	3.0	1.0	0.5	None	O	O
6) Compaction and Cutting	1	80	P	1.7	3.0	1.0	0.5	None	O	O
7) Transfer to Stock Yard	2	80	P	0.3	0.7	1.0	1.5	None	O	O
8) Loading Trucks	2	15	P	1.1	6.8	0.5	1.5	None	O	O
9) Drive to Steel Foundry	1	10	A	0.6	6.8	1.0	1.5	None	O	O

Note of the source geometry
P: Cylindrical, homogeneous self absorbing volume source with or without shielding, dose point on the perpendicular bisector of the axis.
A: Cylindrical, homogeneous self absorbing volume source with or without shielding, dose point on the axis.

4.2 Smelting Process

Each 1000 t of steel-throughput is assumed to produce 100 t of slag and 10 t of dust (3),(4). The distribution coefficients of radionuclides between steel and slag or dust during the smelting process are set as shown in Table 4 based on several literatures data (4),(5),(6). And the parameters used in internal dose are set as follows:

- The Dust Concentration in Working Area is 1 mg/m^3. It is the recommendation value for the dust concentration of ferro-oxide in the woking atomosphere in Japan,
- The respiratory flow of woker is 1.2 m^3/h,
- The rate of secondery ingestion of removable surface contamination is 0.01 g/h (7).

The internal exposure duration is the same as the external exposure.

Table 4. Distribution of the Contaminants during the Smelting Process.

Element	Distribution Coefficient		
	Ingot	Slag	Fume
Fe	1	1×10^{-2}	5×10^{-3}
Co	1	1×10^{-2}	5×10^{-3}
Ni	1	1×10^{-2}	5×10^{-3}
Sr	1	1	1×10^{-1}
Sb	1	1×10^{-2}	1
Cs	1×10^{-1}	1	1
Pm	1	1	1
α Emitters	1×10^{-1}	1	5×10^{-3}

The exposure scenarios and parameters consided in smelting process is shown in Table 3-2.

Table 3-2 Exposure Scenarios and Parameters for Smelting Process

Exposure Scenarios	Number of Pepole Exposed	Exposure Duration (hr/year)	Source Geometry	Dimention of the Source (m)		Distance from the Source (m)	Density of the Source (g/cm³)	Shielding	Inhalation	Ingestion
				Radius	Height					
1) Unload Trucks	2	275	P	1.1	6.8	0.5	1.5	None	O	O
2) Store Processed Scrap	2	2200	P	10.0	0.7	10.0	1.5	None	O	O
3) Transfer to Furnace	2	825	P	1.0	1.1	0.5	1.5	None	O	O
4) Charge Furnace	2	412.5	A	2.4	0.4	5.0	7	None	O	O
5) Operate Furnace	2	1650	P	2.4	0.4	5.0	7	Concrete*	O	O
6) Sampling	2	412.5	A	2.4	0.4	0.5	7	None	O	O
7) Tap Furnance	3	275	A	2.4	0.4	0.5	7	None	O	O
8) Store Slag	3	275	P	1.5	1.0	5.0	3	None	O	O
9) Transfer Slag	3	275	P	1.5	1.0	1.0	3	None	O	O
10) Treatment of Dust	1	187.5	P	1.5	0.7	0.5	3	None	O	O

Note of the source geometry
P: Cylindrical, homogeneous self absorbing volume source with or without shielding, dose point on the perpendicular bisector of the axis.
A: Cylindrical, homogeneous self absorbing volume source with or without shielding, dose point on the axis.
*1: Density 2.3g/cm³, Thickness 0.25m

Table 3-3 Exposure Scenarios and Parameters for Casting Process

Exposure Scenarios	Number of Pepole Exposed	Exposure Duration (hr/year)	Source Geometry	Dimention of the Source (m)		Distance from the Source (m)	Density of the Source (g/cm³)	Shielding	Inhalation	Ingestion
				Radius	Height					
1) Transfer of Melted Steel	3	962.5	P	1.25	1.5	3.0	7	Concrete*1	O	O
2) Pour Ingots	2	550	A	1.25	1.5	0.5	7	None	O	O
3) Strip Molds (1) *2	2	550	P	0.34	2.0	0.5	7.2	None	O	O
4) Strip Molds (2) *3	2	550	P	0.57	2.2	0.5	7.2	None	O	O
5) Transfer in Steel Works (1)*2	1	550	A	0.34	2.0	0.5	7.2	None	O	O
6) Transfer in Steel Works (2)*3	1	550	A	0.57	2.2	0.5	7.2	None	O	O
7) Grind Ingots	1	1100	P	0.57	2.2	2.5	7.2	None	O	O
8) Stock Ingots	4	2200	P	2.50	2.2	10.0	7.2	None	O	O
9) Load Trucks	2	275	P	0.57	2.2	0.5	7.2	None	O	O
10) Drive to Manufacturer	1	250	A	0.57	2.2	1.0	7.2	None		

Note of the source geometry
P: Cylindrical, homogeneous self absorbing volume source with or without shielding, dose point on the perpendicular bisector of the axis.
A: Cylindrical, homogeneous self absorbing volume source with or without shielding, dose point on the axis.
*1: Density 2.3g/cm³, Thickness 0.25m *2: 5 ton casting mould *3: 16 ton casting mould

4.3 Casting Process

The exposure scenarios consided in casting process are shown in Table 3-3. We considered two types of casting mould.

4.4 Use of Items Made with Recycled Steel

(1) Use of reinforcement in building concrete

It is assumed that reinforced concrete contains 80 kg of steel per cubic meter of concrete and the reinforcement is located 2 cm depth in walls, floor and ceiling.

We assumed that the floor area of the room is 15 m^2, the height is 3 m, and the thickness of concrete is 18 cm.

and 30,000 t of steel used in the building industory to construct about 30,000 rooms each housing 4 person.

120,000 person will be exposed in this scenario.

(2) Use of car made with recycled steel

The body of the car is represented by a sphere, having 1.5 m radius and 2 mm thickness, and the driver is assumed to be located at the center of the sphere.

And 7,500 t of steel used in the manufacturing of cars.

About 420,000 cars will be made and 420,000 persons will be exposed.

(3) Use of railroad carriage made with recycled steel

The body of the railroad carriage is represented by a rectangular form, having 3 m width, 20 m length, 2.5 m height, and 0.5 mm thickness, and a passenger is assumed to be located at the center of the carrige and at the 1 m heigt of the floor.

7,500 t of Steel used in the manufacturing of about 2,200 railroad carriages.

In fiscal 1986, Japanese avrage railroad passenger number is 440,000 persons per carriage. Thus 970 Million persons will be exposed. But in the calculation for collective dose, an average railroad bording time in fiscal 1987, which is about 25 minutes, is used.

(4) Use of furniture

The furniture concerned is assumed to be a 50 kg cylinder having 100 cm height and 45 cm radius.

7,500 t of steel used in the manufacturing of furniture. About 15,000 pieces of furniture will be made and 15,000 persons will thus be exposed.

(5) Use of steel desk

The steel desk is assumed to be made from three steel plates having 1 mm thickness.

An office woker is assumed to use it 1,500 hours per year.

7,500 t of steel used in the manufacturing of steel desks.

About 250,000 desks will be made and 250,000 persons will thus be exposed.

(6) Use of flying pan

The frying pan concerned is auumed to be a 3 kg cylinder having 0.5

cm height and 15 cm radius.

A housewife is assumed to use it 300 hours per year for meal preparation at 30 cm away.

The frying pan is assumed to corrode during meal preparation.

The corroded steel could be released to foodstuffs.

The housewife could ingest contaminated steel.

In the calculation we assumed that corrion rates of cast iron is 0.127 cm/y and 1 % of corroded iron is ingested.

This is equivalent to ingest 0.167 g contaminated steel per year by her.

750 t of steel used in the manufacturing of frying pans.

About 250,000 pans will be made and 250,000 persons will thus be exposed.

(7) Use of slag as a base material of pavement

In the calculation, slag is assumed to be used as a base material of a paved parking lot.

The slag layer, having a thick of 35 cm, is located under the surface asphalt layer 25 cm thickness.

The manager of the parking lot is assumed to spend 2,000 hours per year.

In the calculation, the parking lot is represented semi-infinite volume.

5. Results

Table 5 show the calculation results of the activity concentration which corrsponds to annual individual-dose level 10 μSv. In the derivation of the surface activity from the mass activity, it is assumed that the average ratio of contaminated surface to the mass is 10 m^2/t. Consequently, the activity concentration for ?/γ nuclides is similara to the value, 1 Bq/g for β/γ nuclides, which is indicated in the CEC Radiation Protection No.43.

Table 6 shows the calculation results of collective dose for typical exposure scenarios. The total number of the collective dose is the sum of the result of the reinforced building scenario and the biggest numerical value in the other scenarios concerned. This results exceed 1 man-Sv/y, but it can be considered as thin board manufactured by scrap are almost nothing. Because it is weak in bendingd. Therefore, we think this results is not a serious problem.

Table 5. Recommend Clearance Level for Recycling Steel Scrap.

	Surface Contaminants		Radioactivated Carbon Steel
	(Bq/g)	(Bq/cm^2)	(Bq/g)
β/γ Emitters	0.7	7.0	2.7
α Emitters	0.8	8.0	-

Table 6. Calculation Results of Collective Dose for Typical Exposure Scenarios. (Using Recommended Clearance Levels)

Exposure Scenarios	Number of Peoples	Surface Contaminats (man Sv)	Activated Carbon Steel (man Sv)
Reinforcement in Building Concrete	1.2×10^{5}	1.2×10^{0}	3.4×10^{-1}
Car Driving	4.4×10^{4}	1.4×10^{-1}	4.2×10^{-1}
Boarding on Railroad Carriage	9.7×10^{8}	2.9×10^{0}	8.9×10^{0}
Use of Furniture	1.5×10^{4}	1.1×10^{-2}	3.0×10^{-2}
Use of Steel Desk	2.5×10^{5}	1.9×10^{-1}	5.8×10^{-1}
Use of Flying Pan	2.5×10^{5}	1.2×10^{-3}	3.4×10^{-4}
Total		4.1×10^{0}	9.2×10^{0}

Refernce

(1) G.M.Smith, C.R.Hemming, M.J.Clark, A.M.Chapuis and H.Garbay, "Methdology for Evaluating Radiological Consequences of the Management of Very Low Level Solid Waste Arising from the Decommissioning of Nuclear Power Plants", EUR 1058-EN(1985).

(2) J.C.Evans, et al., "Long-Lived Activation Products in Rector Materials", NUREG/CR-3474, (1984).

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(4) Commission of the European Communities (CEC), "Radiological Protection Criteria for the Recycling of Materials from the Dismantling of Nuclear Installations", Radiation Protection No.43., Luxembourg, (1988).

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(6) D.S.Harvey, "Research into the melting/refining of contaminated steel scrap arising in the dismantling of nuclear installations", EUR 12605(1990).

(7) International Atomic Energy Agency (IAEA), "Working Document on Exemption Principles Applied to the Recycling of Materials from Nuclear Facilities", (1990).