ENVIRONMENTAL RISK ASSESSMENT FOR AN KOREAN INTERMEDIATE AND LOW - LEVEL RADIOACTIVE WASTE VITRIFICATION FACILITY

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Abstract

Vitrification is emerging as one of the most promising options for treatment of intermediate and low level radioactive wastes due to high volume reduction, and its excellent characteristics of final waste form. The technology even considered being economically competitive nowadays when we compare with treatment cost of other volume reduction technology. Korea Electric Power Research Institute(KEPRI) has been developing a vitrification process, which combines both a Cold Crucible Induction Melter and a Plasma Torch System. The former is designed to destruct organic combustible wastes and incorporate contained metal oxides into the glass whereas the latter is devised to melt non-combustible wastes at high temperature with production of high leach-resistant slag. During normal operation and accident conditions, small amounts of radionuclides and toxic gases can be released to the environment. Therefore, it is required to assess environmental risk resulting from operation of the vitrification facility. In this study, the environmental risk caused by the operation of the Korean vitrification facility is estimated. The risk is calculated in terms of individual dose for public at 80km from the facility. Since the facility is still under development, spent ion exchange resin generated from the Korea nuclear power plant is considered as a main target material to be vitrified with glass. Accidental gas or radioactive material release based on the abnormal operation of the vitrification facility is utilized as a source term for the public exposure evaluation. The environmental risk of the facility is estimated with the simulation code named as VERAS(Vitrification Facility’s Environmental Risk Assessment

System) which can calculate radioactive and toxic risk simultaneously. The pathway of exposure is considered as the dispersion of radioactive and toxic materials through air. The risk can be analyzed in a view of exposure pathway, dose of exposed organ and total individual or population dose. Finally, the average individual doses are calculated for a well-defined scenario of assumed accident scenario.

INTRODUCTION

Vitrification of intermediate and low level radioactive wastes is emerging as one of the most promising option for treatment due to its excellent attributes. These attributes are high volume reduction, mechanically and chemically stable end product, reduction of long term release, and capturing long lived nuclides(1). The technology is even considered to be economically competitive nowadays when we compare with treatment cost of other volume reduction technology.

NETEC(Nuclear Environment Technology Institute) is under process of developing a vitrification process system, which combines both a Cold Crucible Induction Melter(CCM) and a Plasma Torch System. The former is designed to destruct organic combustible wastes and incorporate contained metal oxides into the glass whereas the latter is devised to melt non-combustible wastes at high temperature with production of high leach-resistant slag. At normal operation and accident conditions, small amounts of radionuclides and toxic gases are expected to be released to the environment. Population around the facility can be exposed to the released materials. Therefore, it is required to assess environmental risk resulting from operation of the vitrification plant.

In this study, a simulation code named as VERAS (Vitrification Facility's Environmental Risk Assessment System) was developed for the assessment of risk due to the operation of vitrification facility. Using VERAS, an environmental risk is estimated in terms of public dose for a sample accident could be occurred at the facility.

SYSTEM DESCRIPTION

Vitrification facility under development by NETEC is shown schematically in Fig. 1. This facility is to treat intermediate and low level radioactive waste generated from the operation of Korean nuclear power plants. These wastes are DAW(Dry Active Waste), spent ion exchange resin, etc. DAW may include burnable wastes such as papers, wooden materials, plastics, vinyl and cottons generated from the operation of nuclear power plant.

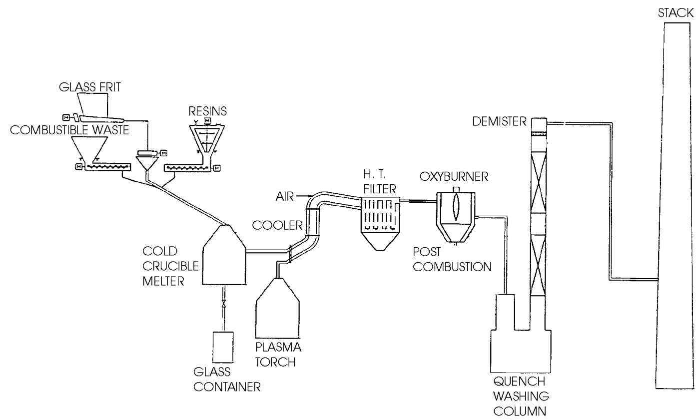

Fig. 1. Schematic diagram of Korean vitrification facility

As shown in Fig. 1, two melting systems; a Cold Crucible Induction Melter and a Plasma Torch System are combined together. The former is designed to destruct organic combustible wastes and incorporate the contained metal oxides into the glass whereas the latter is devised to melt non-combustible wastes at high temperature with production of high leach-resistant slag.

For the off-gas treatment, high temperature filter (H.T. filter), post combustion chamber (PCC), quench/scrubber and HEPA filter systems are utilized in the facility. Off-gas that is discharged from the melter passes through cooler and air dilution system, and then moves to the H. T. filter. In the H. T. filter, particulate materials are captured. When off-gas containing unburned organic material is loaded into PCC, perfect combustion of organic material can be carried out and carbon monoxide and hydrocarbon generation will be reduced. After that, off-gas goes into quench/scrubber. Inside quench/scrubber, acidic gases will be eliminated from the off-gas stream. Following these processes, the off-gas will be reheated and pass through HEPA system, then finally released to the environment.

OBJECTIVE RADIOACTIVE NUCLIDES AND TOXIC MATERIALS

Since the facility mainly treats intermediate and low- level radioactive wastes generated from nuclear power plants, target radioactive nuclides include all radioactive nuclides generated from the operation of nuclear power plants. During the normal operation, only the volatile nuclides are to be released to the environment and considered in the risk assessment. On the other hand, when the malfunction or accident of facility outbreaks, volatile and semi-volatile radioactive nuclides contained in the wastes will be released to the environment and considered in the risk analysis.

As the wastes are treated and converted into glasses in the facility, byproducts such as toxic chemicals and air pollutants are generated. Of those byproducts, materials with carcinogenic risk are considered in the risk estimation. Since the facility is still under development stage, the total inventory or the types of byproducts are not exactly estimated yet. So, in this study, metals with carcinogenic risk such as Cr, Cd and As are considered.

SCENARIO SELECTION

The source term analysis is not completed yet because the facility is still under development stage. So, in this study, scenario selection for the emission of materials is carried out for the environmental risk assessment. The scenario is briefly described below.

During the process of waste melting, coolant of CCM leaks out to CCM. As a result of coolant leakage, steam is generated and the pressure in CCM increases rapidly. The steam pressure exceeds design pressure of CCM. Finally, the CCM system failure breaks out and melted glass materials in the CCM are released.

In the risk estimation, the spent ion exchange resin generated from nuclear power plant of Ulchin unit 3 & 4 in Korea is assumed to be melted. This assumption is necessary to determine the characteristics of emitted radioactive nuclides. Though the CCM operates at very high temperatures, volatile and semi-volatile radionuclides and metals included in the spent resin are expected to be released. As a conservative estimation, whole quantity of these nuclides and metals are assumed to be released to the environment.

RISK ESTIMATION

For the determination of source term, characteristics of the resin are analyzed in terms of the radioactive nuclide activities and quantity of toxic materials. Activities of nuclides in spent purification ion exchange resin are listed in Table I.

The activity of the spent ion exchange resin is estimated with the waste volume of 144 ft^3. About one percent of these activities is considered in the risk estimation. Of those nuclides in Table I, the radionuclides found to be responsible for contributing at least 99 percent of the dose are used in the accident analyses. These are ^{90}Sr, ^{106}Ru, ^{125}Sb, ^{125m}Te, ^{129}I, ^{134}Cs, ^{137}Cs, ^{144}Ce, ^{147}Pm, and ^{241}Am.

Inventories of released radionuclides selected for the estimation of accident considered in this study are listed in Table II (9).

On the other hand, the quantity of metals in the spent ion exchange resin is assumed equivalent to those contained in the resin of SAC, CANDEREM (4). In Table III, the elemental composition of the resin is listed. The only carcinogenic material included in the resin is chromium (594 ppm). The unit cancer risk factor by inhalation for chromium is 1.2×10^{-2} $(\mu g/m^3)^{-1}$ (5).

Table I. Annual activity data of solid radwaste management system in PWR for spent ion exchange resin (purification ion exchange), [Ci] (3)

Nuclide	Activity	Nuclide	Activity	Nuclide	Activity	Nuclide	Activity
Br-84	2.1E-01	Cr-51	4.1E+00	Y-91m	6.1E-04	Te-131	7.8E-02
I-131	1.8E+02	Mn-54	1.1E+01	Y-93	5.1E-03	Te-132	2.7E+00
I-132	1.1E+01	Fe-55	1.0E+01	Zr-95	1.2E+01	Ba-140	7.9E+01
I-133	6.2E+01	Fe-59	6.3E-01	Nb-95	4.7E+00	La-140	2.1E+01
I-134	7.2E+00	Co-58	1.5E+01	Mo-99	8.7E+00	Ce-141	2.3E+00
I-135	3.9E+01	Co-60	4.8E+00	Tc-99m	6.3E-01	Ce-143	1.9E+00
Rb-88	8.2E-01	Zn-65	3.3E+01	Ru-103	1.4E+02	Ce-144	2.8E+02
Cs-134	3.9E+02	Sr-89	3.3E+00	Ru-106	6.7E+03	W-187	1.3E+00
Cs-136	3.5E+00	Sr-90	1.1E+00	Ag-110m	8.6E+01	Np-239	2.5E+00
Cs-137	5.8E+02	Sr-91	2.0E-01	Te-129m	3.1E+00	Ba-137m	5.7E+02
Na-24	1.5E+01	Y-91	5.7E-06	Te-129	6.6E-01	Total	9.29E+03

Table II. Inventories for released radioactive nuclides [Ci]

Radionuclides	^{90}Sr	^{106}Ru	^{134}Cs	^{137}Cs	^{144}Ce	Total
Activity [Ci]	1.1E-02	6.7E+01	3.9E+00	5.8E+00	2.8E+00	7.95E+01

Table III. Composition of the waste [ppm] (4)

Element	Composition	Element	Composition	Element	Composition
Al	103	Mn	6	V	9
Ca	283	Na	101	Zn	28
Ce	12	Nd	18	Mg	85
Cr	594	Ni	1337	Ti	117
Fe	1314	Si	43		
K	1342	SO_3	546		

Since the release is occurred only through the air, the pathway considered here is the exposure to the population by the dispersion of radioactive and toxic materials through the air.

As a sample case, the facility is assumed to be located at Yong-Gwang nuclear power plant site in Korea. The population within 80km of the facility is used for the population dose calculation (6). All the populations are grouped dependent on the directions and the distances from the facility. The distance is divided into 10 sectors while direction is divided into 16 sectors.

CODE DEVELOPMENT

For the estimation of the environmental risk by the operation of the vitrification facility, a computer simulation code named as VERAS (Vitrification Facility's Environmental Risk Assessment System) is developed. VERAS can calculate the radioactive and toxic risk simultaneously.

In the VERAS code, the radiological risk is estimated following the methods of the GENII code developed by Pacific Northwest Laboratory in USA (7). For the chemical risk estimation, air transport scheme of GENII code is modified to describe the chemical transport.

The flow chart of the VERAS is shown in Fig. 2.

As the facility treats wastes generated from the nuclear power plant, all kind of the radionuclides generated from the operation of power plant is considered in the RADRISK module. In the CHEMRISK module, Cr, Cd and As are considered because these are known as human carcinogens by EPA study(8).

Environmental dispersion of material is estimated first. Then, dose occurred by the release of material is calculated in terms of radiological risk and chemical risk. For the dispersion estimation, Gauss plume model is utilized and both dry and wet depositions are included for the decay out process.

External dose, inhalation dose and ingestion dose through the food is chosen as main exposure pathways. The variables related to the scenario is set up in 'User Input' module. In this module, parameters such as inventories of materials, exposure pathways, characteristics of material release and time variables are included as input variables.

The ENVIN module controls the input files prepared by the 'User Input' module. The ENVIN module interprets the basic input data, and reads the data libraries and other optional input file that can be used by module AIRTRAN.

Environmental transport of materials is analyzed in the module named as AIRTRAN. Since the vitrification facility release only gaseous materials to the environment, material dispersion through the air is only considered for release pathway. AIRTRAN calculates the environmental transfer, uptake, and human exposure by the released materials that result from the scenario. As the result of AIRTRAN, the temporary information on annual concentrations and intake rates are taken to data transfer file.

For radioactive nuclides, the DOSE module reads the annual intake and exposure rates defined by the AIRTRAN and calculates them as radiation dose. In DOSE, international radiation dose calculations are performed using the methods recommend by the ICRP 26 and 30. As the cancer risk due to chemicals is occurred through chronic exposure to the material, chemical risk is estimated with the assumption that people are exposed to the materials for a long time with a constant concentration.

As a result, VERAS code gives dose for radioactive nuclides and cancer risk for carcinogenic chemicals.

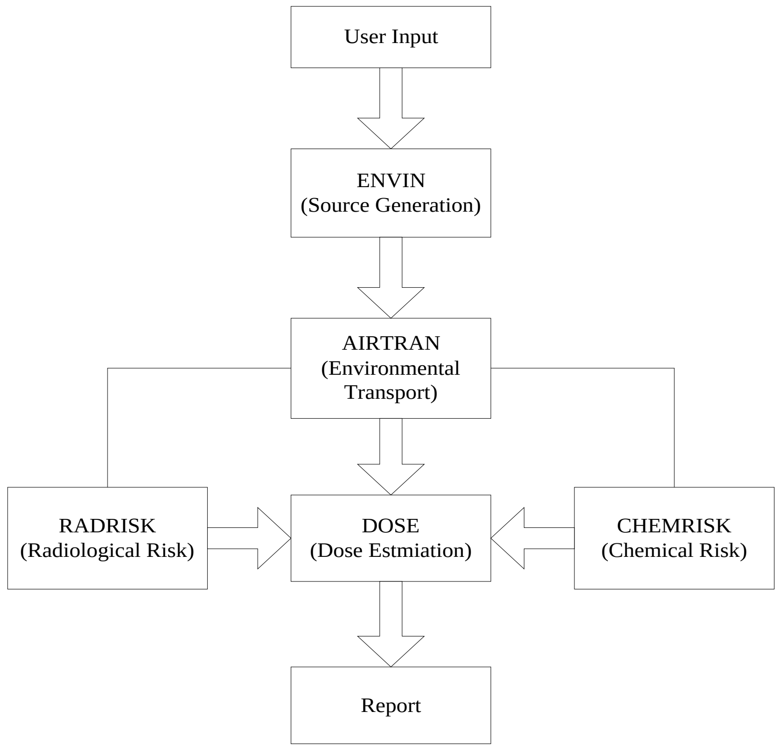

Fig. 2. Flow chart of VERAS

RESULT AND DISCUSSION

With the data and assumptions described above, the risk is estimated in terms of dose by the radioactive nuclides and additional cancer risk increase by the carcinogenic metals. Since detailed design parameters for the facility have not been determined yet, the result could not predict the characteristics of facility exactly.

Because we are concerned mainly here of the accident case, risk analysis for the accident is only assessed and acute dose is estimated for annual dose of individual around the facility.

The result in Table IV shows that for case of wind toward south, average cumulative individual dose for 50 year at 80km from the facility is estimated as 1.17×10^{-3} Sv. This dose is composed of internal dose of 1.17×10^{-3} Sv and external dose of 7.2×10^{-6} Sv. Inhalation dose and ingestion dose is counted as an internal dose and will take most of effective doses. The annual effective dose equivalent for this case is shown in Table IV for each radionuclide. As dose limit for public is 1mSv/yr, the result shows that individual could be little bit overexposed in case of accident.

The cancer risk increase caused by chromium in the resin shows 8.1×10^{-4} by chromium release.

The individual doses for the cases of different wind directions are shown in Table V. In the table the direction represent the wind blow toward that direction.

In this study, the environmental risk of Korean vitrification facility is estimated. Since the facility is under development stage, many parameters related to the risk assessment have not been decided yet. Hence the result contains some uncertainties and limitations. After the construction of vitrification facility, more precise and meaningful study will be followed.

Table IV. Annual effective dose equivalent for average individual dose for accident scenario [Sv]

Nuclide	Dose Equivalent	Nuclide	Dose equivalent	Nuclide	Dose Equivalent	Nuclide	Dose equivalent
^{90}Sr	4.63E-07	^{106}Ru	6.61E-04	^{137}Cs	2.76E-04	^{144}mPr	4.34E-10
^{90}Y	3.39E-08	^{134}Cs	2.23E-04	^{144}Ce	2.01E-05	^{144}Pr	9.97E-08

Table V. Annual effective dose equivalent for different wind directions [Sv] (dose for 50 years)

Direction	Dose equivalnet	Direction	Dose equivalnet	Direction	Dose Equivalnet	Direction	Dose equivalnet
S	1.17E-03	W	1.43E-03	N	1.46E-03	E	1.12E-03
SW	1.18E-03	NW	1.46E-03	NE	1.17E-03	SE	8.93E-04

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