Criticality Analysis for Uranium-Scrap Recycling Facilities

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1. Introduction

KNFC planned to build a uranium scrap recycling facility in order to make its fuel manufacturing process efficient. An engineering design has been done by Human & Technologies Corp. during 6 months of the last year. A criticality analysis has been performed with Kyung Hee University and report was reviewed by KINS. This paper summarized a criticality analysis part of this work for licensing.

A criticality analysis was done for all processes in scrap recycling system with data from design specifications based on reasonable assumptions. As the first step, parametric study was done for a normal operational condition in order to find crucial variables which would be sensitive to the criticality safety. Hypothetical accident was also simulated with double contingency principle and multi-parameter control principle.

Calculation was performed with Monte Carlo code, MCNP-4C/2 with point data cross section data library.

2. Assumptions and Models

2.1 Assumptions

If each facility in recycling system of uranium scrap is failed in control of mass flow, there would be a danger of over packing of fissile materials in a confined geometry resulting in super-criticality above the safety limit. Safety design has already considered these abnormal conditions with design margin. However, in some case of accidents such as flooding and/or fire, there could be an optimum neutron moderating condition because of moderator layer outside of facility canisters. Therefore, criticality analysis should cover all possible hypothetical conditions. For a conservative conclusion, design parameters should be chosen to make criticality unfavorable in geometry and composition data; size, density, material mass flow rate, reaction condition and outside conditions.

- Double contingency principle

For all kinds of accidents, double contingency principles were applied in addition to a conservative design parameter condition. For example, flooding condition is additionally applied to the over mass flow into canister with unconditional uranium mixture density.

- Multiparameter control principle

In accident analysis, basic operational condition was chosen to have unfavorable combination of design parameters in three variables. They are material composition with maximum fissile loading into a control volume, water contents within a control volume under a hypothetical water flow-in and an optimum water density outside of a control volume. Water density can be changed from 1.0 gm/cm^3 to 0 when a spring cooler act after a fire, or fire after a flooding.

2.2 Calculation Model for each process

Seven material processes were simulated for a uranium scrap recycling system.

1) Hopper that transfer U_3O_8 to the Dissolving Vessel
2) Dissolving vessel which dissolve U_3O_8 to HNO_3 within a flat canister with heating steam liner
3) Precipitation process to precipitate UNH solution into ADU slurry in a flat canister with heating steam liner
4) Filtering process for ADU slurry with decanter
5) Residual liquid process to recycled residual liquid
6) Calcinations process for ADU with 3 tray geometry in a furnace
7) Reduction process for oxidized UO_3/ U_3O_8 with 3 tray geometry in a furnace
8) Sifter of UO_3/ U_3O_8 powder
9) All kinds of transfer pipes

Table 1 showed conditions used for a criticality analysis both for normal operation and abnormal accidents. The amount of uranium mixture for one batch is assumed to be the amount for three days. The period of 1 day is assumed to be eight hours. In case of UNH storage process, it was assumed that four tanks stands in parallel put into together with pitch of 0 cm in case of mechanical damage accident in a facility.

In this study all detail canisters were not calculated, instead of this, ideal geometry was simulated with double contingency principle. Fuel mixture mass in a canister was assumed to be 2~3 times larger than a design value with conservatively high physical density. Also, in some cases it was assumed that water flowed into a control volume which makes control volume with well moderated condition for neutrons. They are calcinations furnace, reduction furnace, feeding cyclone and sifter. In this situation, criticality became high. In order to find an optimum moderation condition, criticality calculation were done with various water contents or steam density contained in a control volume.

Table 1. Assumptions used for Accidental Conditions

Process	Material	Normal Condition (Volume/U-mass)	Most Severe Accident Conditions
Hopper	U_3O_8	$0.117m^3$ 122.45kg/Batch	30cm Water Reflector ($1.0g/cm^3$) 287.75 kg-U
Dissolver vessel	U_3O_8	$0.546m^3$ 122.45kg/Batch	30cm Water Reflector ($1.0g/cm^3$) Steam Condensation in 3cm Line ($1.0g/cm^3$) 218.4kg-U
UNH solution storage tank	$UO_2(NO_3)_2$ + H_2O	$4 \times 0.311m^3$ 122.45kg/Batch	30cm Water Reflector ($0.4g/cm^3$) 4 Tanks are put together 489.8kg-U
ADU precipitator vessel	$(NH_4)_2U_2O_7$	$0.585m^3$ 40.816kg/Day	30cm Water Reflector ($1.0g/cm^3$) Steam Condensation in 1cm Line ($1.0g/cm^3$) 232.65kg-U
Furnace off-gas absorber	$(NH_4)_2U_2O_7$	$3 \times 0.025m^3$ 40.816kg/Day	30cm Water Reflector ($0.4g/cm^3$) 89.80kg-U
Reduction furnace	UO_3	$3 \times 0.025m^3$ 40.816kg/Day	30cm Water Reflector ($0.4g/cm^3$) 142.56kg-U
Feeding cyclone	UO_2	$0.056m^3$ 40.816kg/Day	30cm Water Reflector ($1.0g/cm^3$) Steam Inside ($0.3185g./cm^3$) 88.83kg-U
Sifter	UO_2	$0.1776cm^3$ 40.816kg/Day	30cm Water Reflector ($1.0g/cm^3$) Steam Inside ($0.6804g/cm^3$) 71.064kg-U

3. Results

Table 2 showed calculation results corresponding cases in Table 1. Criticality values in table are eigen values added with 2σ.

Table 2. Criticality+ 2 σ Values

Processes		Normal Condition	Accident Condition
Preparation	Hopper	0.04000	0.43409
Dissolver	Dissolver vessel	0.51398	0.70007
Precipitation	UNH solution storage tank	**	0.90590
	ADU precipitator vessel	0.51487	0.87087
Calcination	Furnace off-gas absorber	0.08102	0.69724
Reduction	Reduction furnace	0.04229	0.67807
Powder process	Feeding cyclone	***	0.92672
	Sifter	***	0.93056

** Normal condition is unknown.
*** k_{eff} can't be obtained because of low value.

Fig 1 is showed eigenvalue change for a material transport pipes. K-effective increases as the radius increase but not above the 7.6.

This value can be applied for all kinds of cylindrical shape canisters as a safety parameter. The accident conditions are situation with regular pure fuel powder of UO_2 with theoretically maximum density of $10.96g/cm^3$ in a pipe with water reflector around a pipe. This condition can not be exist in uranium scrap recycle system because uranium powder has a much less density that the above value. Because radii of all pipes in a U scrap recycling system are shorter than 40 cm, all pipe geometry can not be critical in any cases.

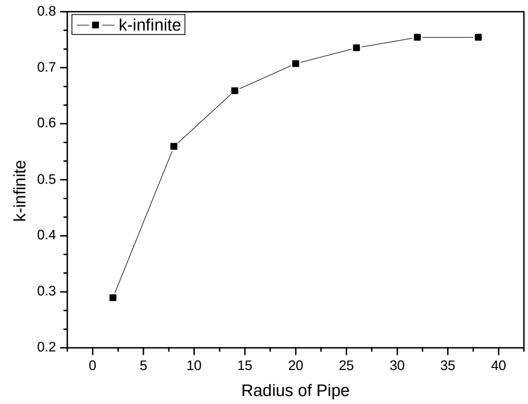

Fig. 1 Criticality by Pipe Radius change

4. Conclusion

Based on conservative assumptions with double contingency principle, all facilities in a uranium scrap recycling system are safe in criticality and has enough margin to criticality.

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