The constructing status and preliminary evaluation for the criticality safety design of Okuma Analysis and Research Center

Japan Atomic Energy Agency

Okuma Analysis and Research Center

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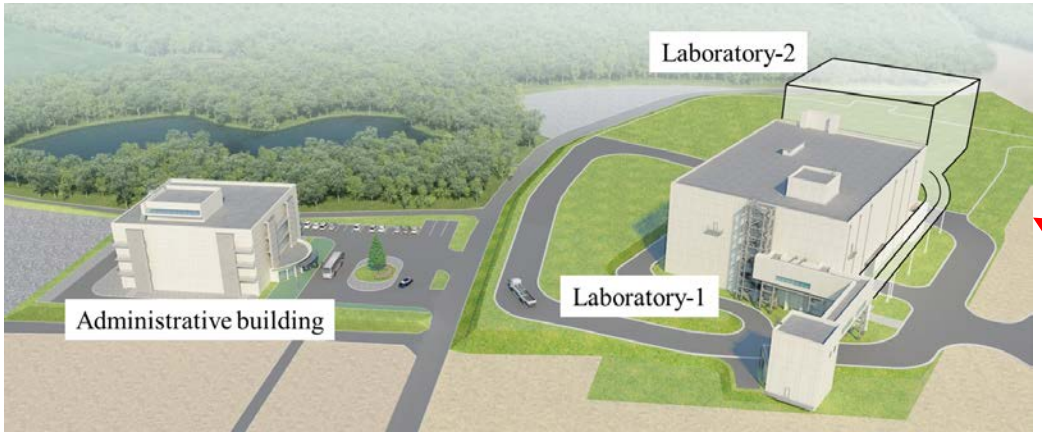
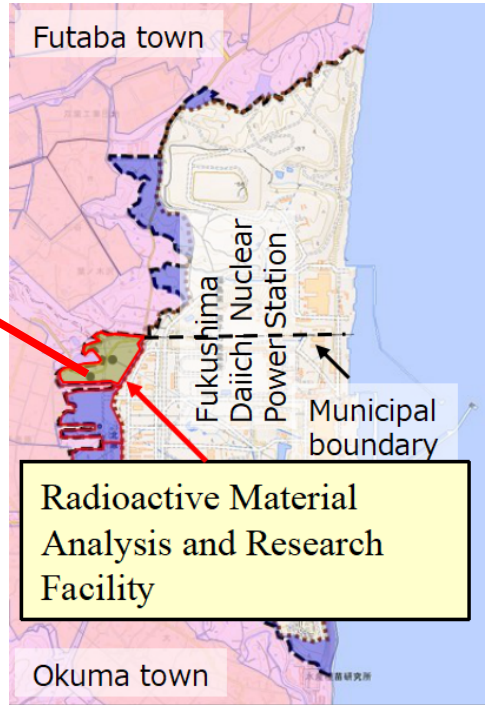
Over view of facilities

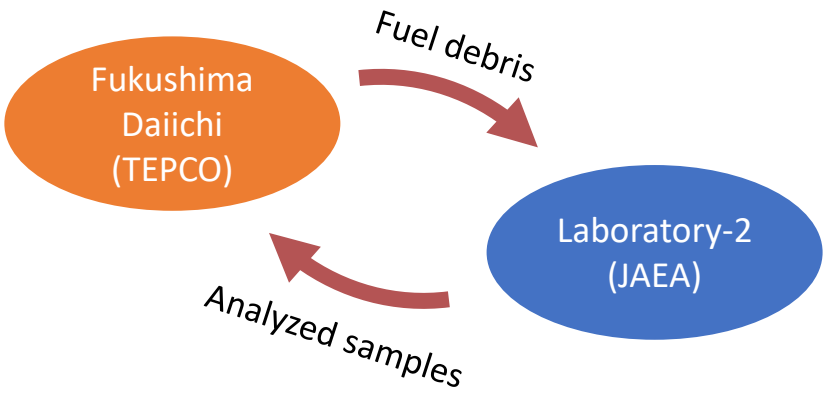




JAEA is constructing “Radioactive Material Analysis and Research Facility” which is adjoined with Fukushima Daiichi site.

- Administrative building : (Start operation in March 2018)
  It provides office space, meeting rooms for researchers, and mock-up apparatus for training.
- Radioactive Material Analysis and Research Facility Laboratory-1 : (Under construction)
  The scope of this laboratory is radioactive analysis of low and medium level radioactive rubbles and secondary wastes.
- Radioactive Material Analysis and Research Facility Laboratory-2 : (Under design)
  This facility is dedicated hot laboratory for radioactive analysis, chemical and mechanical characterization of fuel debris.

The Fuel debris flow between Fukushima Daiichi and Laboratory-2



- Maximum 5kg fuel debris is transported at once.
- Laboratory-2 receipts of fuel debris is scheduled to be 12 times/year.
- Analyzed samples are returned to the TEPCO.

The issues related to safety design in Laboratory-2

- Laboratory-2 will be equipped with concrete cells, iron cells, glove boxes and fume hoods.
- The maximum of 5 kg/analysis of fuel debris is handled.
- The fuel debris also contain fissile material derived from nuclear fuel.

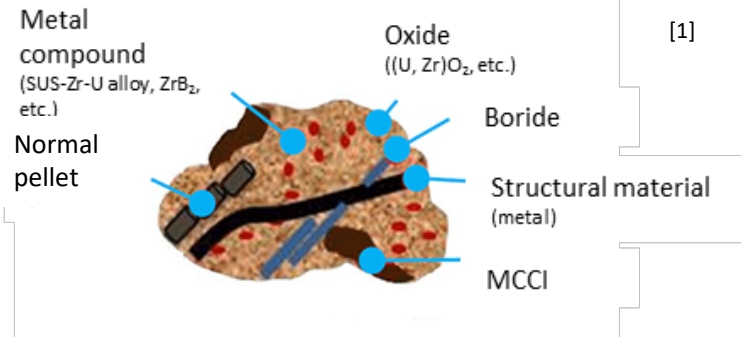
➢It is necessary to examine the criticality safety of fuel debris.
➢To examine the safety of handling 5 kg/analysis of fuel debris, the critical mass limit of fuel debris must be evaluated.

The properties of fuel debris

Assumed condition of fuel debris

・The parameters of the fuel debris for the criticality safety analysis such as "shape", "density" and "composition" are not clear.

➢The most conservative condition is applied in this analysis.



[1]

Image of fuel debris

The composition of fuel debris

・Fuel debris are the mixture of the following materials:
Normal condition pellet
Melted pellet
MCCI（Molten Core Concrete Interaction）
Mixture with structural materials
etc.

・The fuel debris have different composition depending on the location in the reactor.

➢In criticality safety analysis, the fuel debris will be modeled as pure nuclear fuel.

➢The fissile material (uranium and plutonium) in nuclear fuel are modeled as metals (not oxide).

Density of uranium：19.1 g/cm^3　Density of plutonium： 19.8 g/cm^3

[1] https://www.mri.co.jp/opinion/column/fukuichi/fukuichi_20170526.html [In Japanese]

Criticality safety analysis model (1/2)

The shape of the analysis system

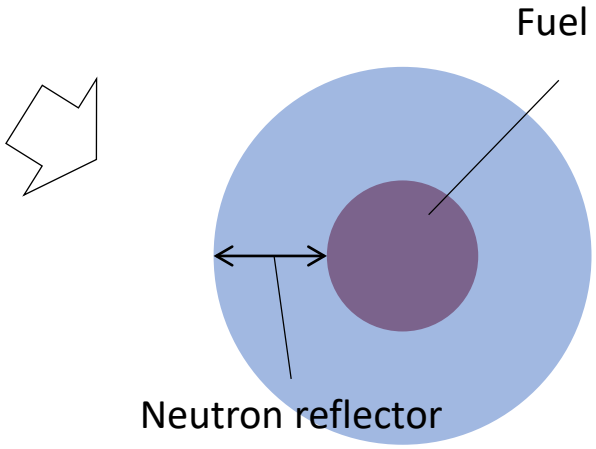
・The part of 5 kg fuel debris will be dissolved to analysis chemical characteristics.

➢In Laboratory-2, the criticality safety analysis is promoted in solution condition (mixture of water and fuel debris).

・In criticality safety analysis, the less neutron leakage gives more conservative result.

➢The analysis system is modeled as sphere since the surface area is the smallest in a constant volume.

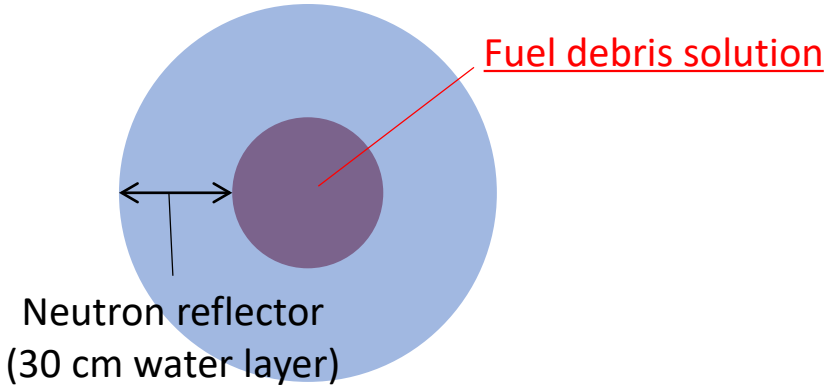
➢As a conservative assumption, the fuel debris solution is surrounded by the 30 cm thickness water layer as neutron reflector.



Criticality safety analysis model

Criticality safety analysis model (2/2)

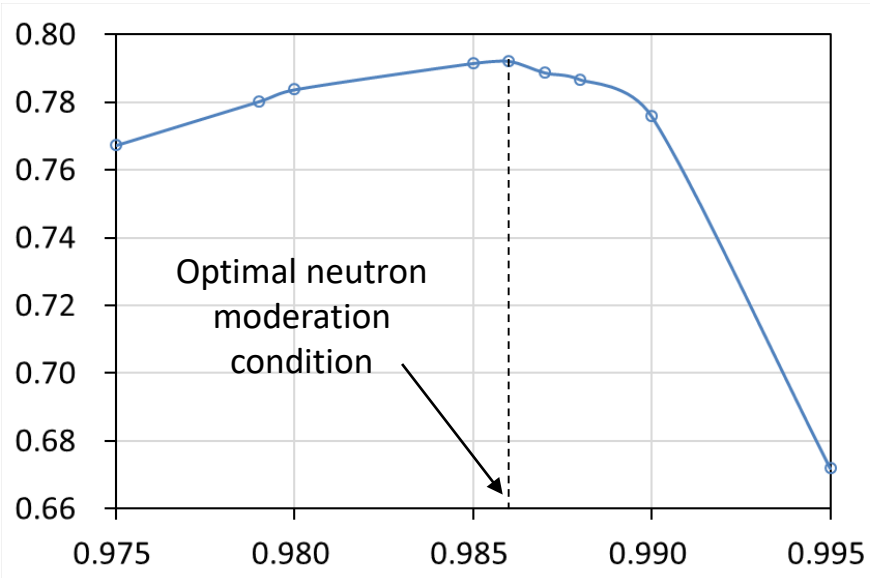
The condition of the nuclear fuel solution



Criticality safety analysis model

- The volume ratio of water-to-fuel debris should be considered.

➢The moderator-to-fuel debris ratio is evaluated to find the optimal ratio.

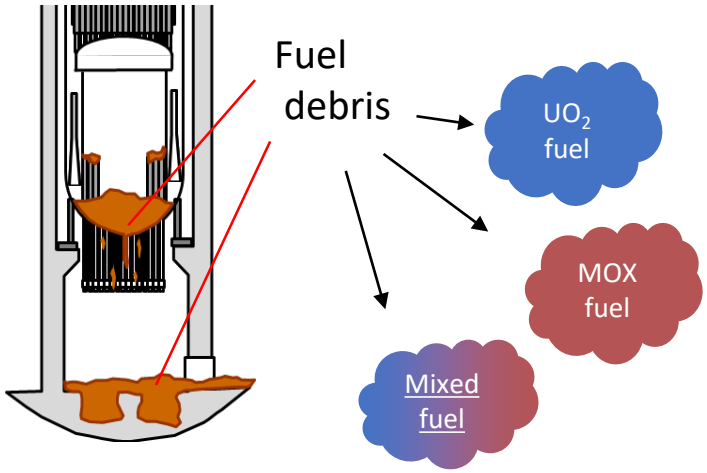


- In this analysis, the mass of fuel debris in solution is set as constant.
- And, the volume ratio of water-to-fuel debris is a parameter of this evaluation.
- k_{eff} was evaluated on each volume ratio.

➢The graph made upper curve and we get only one peek.

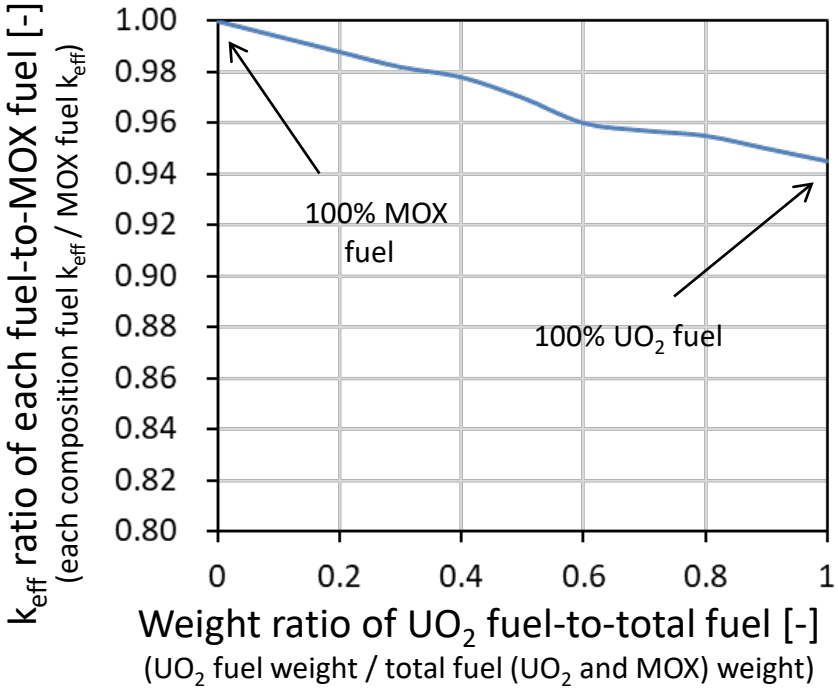
➢The volume ratio with largest k_{eff} is the optimal neutron moderation condition.

Effects of mixing different types fuel



- In unit 1 and 2, only UO_2 fuel was loaded, in unit 3, UO_2 fuel and MOX fuel were loaded.
- The two different types fuel were melted and mixed in the process of the Fukushima Daiichi accident.

➢ It is necessary to consider the mixture of different type of fuels.



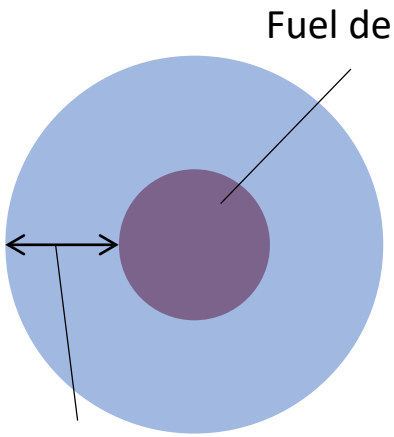
- The ratio of UO_2 fuel in the mixed fuel was changed as the parameter.
- The right end of this graph means 100% UO_2 fuel and the left end means 100% MOX fuel.
- The total fuel weight was set the constant value.
- The optimal neutron moderation condition was surveyed for each fuel.

➢ The 100% MOX fuel is the most conservative condition.

➢ Fuel debris containing 100% MOX fuel may be little, but in criticality safety design, the condition is considered.

Criticality safety of 5 kg fuel debris handling

Examination of the critical mass limit of fuel debris



Critical mass limit evaluation model

The critical mass limit of fuel debris (equivalent to MOX fuel) was evaluated the following conditions.

The fuel debris
- modeled as 100% MOX fuel
- Fissile material is modeled as metal (not oxide)
  Density of uranium：19.1 g/cm^3
  Density of plutonium： 19.8 g/cm^3

Analysis model
- Sphere model
- The fuel debris (equivalent to MOX fuel) is modeled as optimal neutron moderation condition.
- The fuel debris solution is surrounded by 30 cm water layer as neutron reflector.

Result

- The critical mass limit was over 10 kg.

➢The result is gives to us that the 5kg fuel debris handling is possible in Laboratory-2 even if double batches are considered.

Summary

Status of Radioactive Material Analysis and Research Facility

- The goal of Radioactive Material Analysis and Research Facility is to clarify the prospects of treatment and disposal methods and technologies regarding the safety of radioactive materials.
- Currently, Administrative building starts operation, Laboratory-1 is under construction, and Laboraotry-2 is under design.
- In Laboratory-2, the fuel debris will be handled as the analysis samples.

Criticality safety analysis

- The properties of fuel debris (shape, density and composition) were assumed to be conservative.
- When the mixing of UO_2 fuel and MOX fuel is considered, it is found that the analysis using 100% MOX fuel is more conservative.
- The critical mass limit of 100% MOX fuel is over 10 kg, and it was clarified that 5 kg fuel debris can be handled in Laboratory-2.

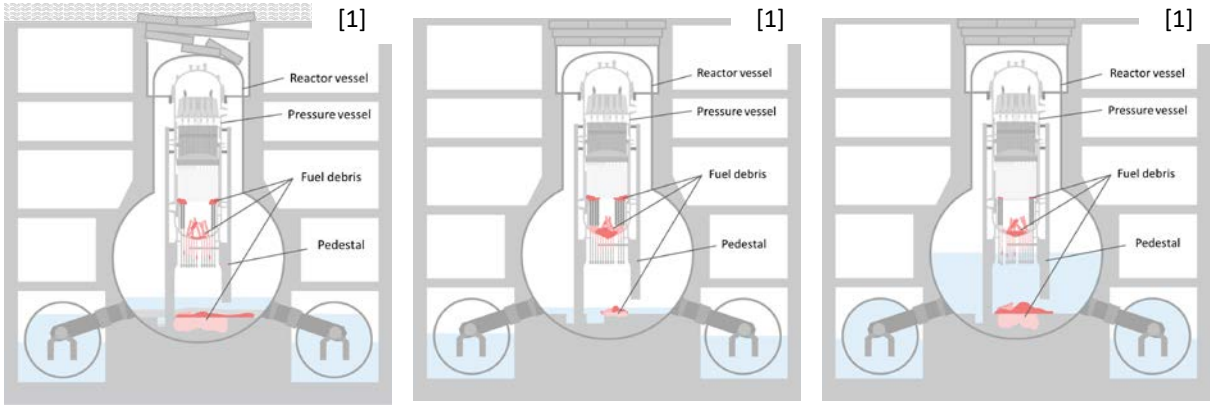
Future work

- The feasibility of criticality safety control method in consideration of the analysis operations of the fuel debris in Laboratory-2 will be confirmed.

Thank you for your attention!

Fukushima Daiichi accident

Fukushima Daiichi Accident (March 11, 2011 ~)



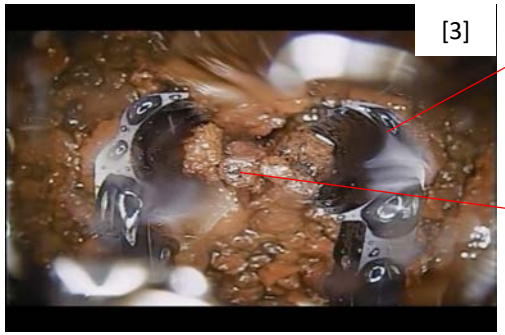
Unit 1 Unit 2 Unit 3

- The emergency generators were lost due to flooding caused by the tsunami.
- The cooling function of unit 1-3 was lost.

➢In Units 1-3, the fuel melted down to the pedestal and the fuel debris was formed.

Fuel debris sampling (in Unit 2)

The inside images of unit2 (January, 2018)



First contact to the fuel debris (February, 2019)

- The variety shape sediment (fuel debris) locate in pedestal.
- Efforts were started sampling the fuel debris inside the pedestal.

[1] Tokyo Electric Power Company Holdings Inc., http://www.tepco.co.jp/decommission/progress/retrieval/.
[2] Tokyo Electric Power Company Holdings Inc., https://www4.tepco.co.jp/library/movie/detail-j.html?catid=107299&video_uuid=kr64q5rj .
[3] Tokyo Electric Power Company Holdings Inc., https://www4.tepco.co.jp/library/movie/detail-j.html?catid=107299&video_uuid=yq53a9f4 .

The apparatuses of Laboratory-2

- Laboratory-2 receipts of fuel debris is scheduled to be 12 times/year (less than 5 kg per each receipt).
- Laboratory-2 will be equipped with concrete cells, iron cells, GB and fume hoods. And these equipment will be used for the following purposes.

Concrete sell
(handling 5kg fuel debris)

Iron sell
(handling 10g fuel debris)

GB
(handling 1 mg fuel debris)

- Works at each apparatus are as following;
  Concrete cell : Some part of mechanical experiment and pretreatment (Cutting, Milling, Polishing and Dissolving)
  Iron cell : Mechanical experiment and surface observation (Optical microscope, EPMA, etc.)
  GB and fume hood : Chemical analysis

- Fuel debris contains nuclear fuel material.

➢ criticality safety evaluation is necessary for the design of Laboratory-2 which handles fuel debris.

The analysis contents of Laboratory-2

【Reflection Destination of Analysis Data】	⑤	④	③	②	①
① Confirmation of Critical Safety while fuel debris retrieval					
② Understanding of dose ratio/behavior, etc. while fuel debris retrieval					
③ Feedback to investigation of fuel debris retrieval method					
④ Confirmation/Evaluation of Safety of collection, transfer and storage of fuel debris					
⑤ R&D for waste treatment and disposal					
【Analysis Items in Laboratory-2】					
Dose rate			○	○	
Nuclide inventory/Composition	○	○		○	○
Morphology, Chemical form, Surface			○		
Geometry (Particle size)			○		
Density (Porosity)		○			
Hardness, Fracture toughness			○		
Thermal conductivity, Thermal expansion	○				
Composition (Cl, Fe, etc.)	○	○	○		
Organic ingredient	○	○			
Moisture content		○			○
Hydrogen generation amount		○			
FP gas release behavior while heating	○	○		○	