Radiation-Shielding Properties of Heavy Bentonite-Based Slurry for the Decommissioning of the Fukushima First Nuclear Power Plant

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Abstract: The 2011 off the Pacific coast of Tohoku earthquake has impacted Japan, and it made serious damage to nuclear power plant in Fukushima. At present, Japanese government and engineers proceed decommissioning of the power plant, and ensuring safety of workers is the most important matter especially in fuel debris retrieval. On these backgrounds, the authors focus on heavy bentonite based slurry for filling material of nuclear reactor. Heavy slurry is capable of shielding gamma ray and neutron beam from its high specific gravity and water content. The purpose of this research is to investigate and define the properties of heavy bentonite based slurry by soil mechanics experiment. That is, the research described in this paper is a proposal to use it for decommissioning of the Fukushima I nuclear power plant. For quantifying the radiation shielding properties, the authors measured the transmitted radiation dose through heavy slurry. The result shows the heavy slurry has definite radiation shielding properties. In conclusion, the heavy bentonite based slurry may be useful for radiation shielding, and save workers health in particular.

1. INTRODUCTION

Whole of Japan was impacted by the 2011 off the Pacific coast of Tohoku earthquake. There has been severe situation because of the radioactive contamination around and inside of the nuclear reactors in Fukushima I nuclear power plant. Moreover, there must be some people who struggle to cope with difficult problems on the surrounding spot. Under such circumstance, radiation shielding material is necessary from the point of view of reducing the possibility of exposure to the workers in fuel debris retrieval and construction of soil covered facility of radioactive waste. Since the accident occurred, Nuclear Emergency Response Headquarters had decided the medium- and long-term roadmap for decommissioning of Units 1 to 4. FIG.1 shows one of the methods to protect workers from radiation in fuel debris retrieval proposed in the roadmap. It makes a suggestion that filling a reactor vessel with water to cooling a reactor and radiation shielding. However, the radiation shielding by water is not fully effective.

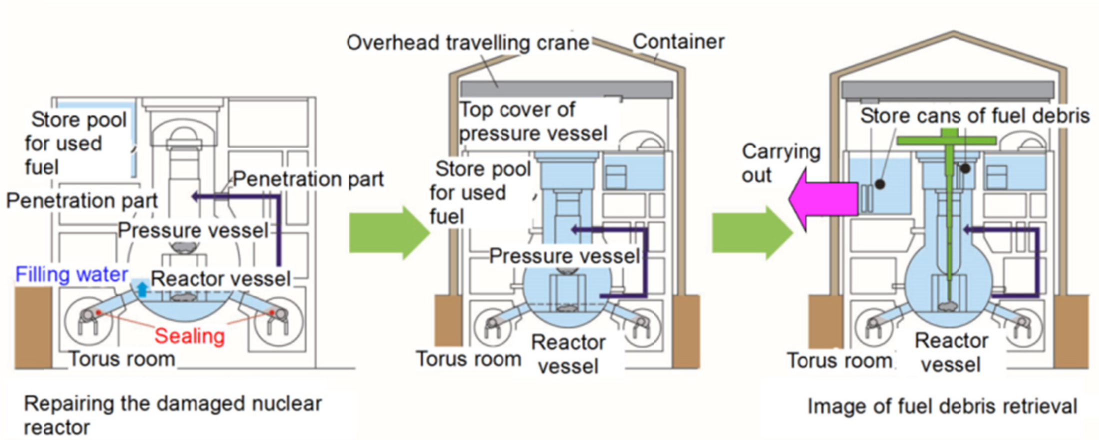

FIG.1. Method of fuel debris retrieval that filling the nuclear reactor with water according to medium- and long-term roadmap

Water can shield only neutron beam as almost same mass as hydrogen atom. Consequently, the authors focus on heavy bentonite based slurry for filling material of nuclear reactor, because of its exceptional shielding properties. It was confirmed that the high specific gravity material shows excellent characteristic of radioactive reduction related to gamma ray. In addition, if the high specific gravity material has high water content, shielding effect of neutron beam increases. As a familiar fact, gamma ray and neutron beam have prominent penetration of substance in comparison with alpha and beta rays. Note that such radiation shielding concerned with gamma ray and neutron beam is indispensable to the construction of decommissioning. Accordingly, based on the previous research (Komine, 2015), the heavy slurry can be used for radiation shielding.

2. PRODUCT HEAVY SLURRY

2.1 Materials of heavy bentonite based slurry

Heavy slurry is composed of water, sodium pyrophosphate, barite and sodium-type bentonite. Barite is a mineral composed mainly of barium sulfate and the high specific gravity that is the greatest feature of heavy slurry is due to barite. Particle density of barite is about 4.21. Sodium pyrophosphate is dispersing agent and bentonite is added to heavy slurry for preventing precipitation of particles. Table 1 and 2 show fundamental parameter of bentonite and mixing ratio of heavy bentonite based slurry.

Table 1. Fundamental parameter of bentonite (Super clay)

Soil particle density (Mg/m^3)	2.62
Liquid limit (%)	547.0
Plastic limit (%)	47.39
Plasticity index	499.61

Table 2. Mixing ratio of heavy bentonite based slurry

Case	Water (g)	Sodium pyrophosphate (g)	Barite (g)	Bentonite (Super clay) (g)	Specific gravity
A	100	0.2	400	7	2.5
B	100	0.2	140	10	1.8
C	100	0.2	10	12	1.1

2.2 Method of producing heavy bentonite based slurry

The method of manufacturing the heavy bentonite slurry is presented as below. An electric stirrer is used to production of heavy slurry. FIG.2 shows a method of producing heavy bentonite based slurry and FIG.3 is a picture of heavy bentonite based slurry .

1) Required amount of water in stirring vessel is stirred 2 minutes on about 400rpm after added sodium pyrophosphate.
2) The slurry is stirred 2 minutes on 400rpm after added bentonite.
3) The slurry is stirred 2 minutes on 400rpm after added barite.

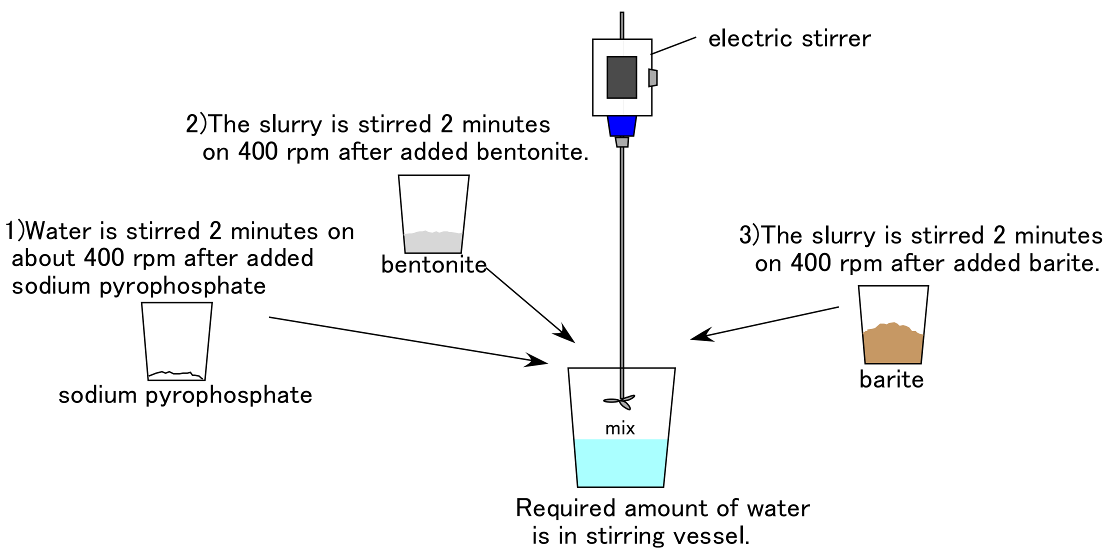

FIG.2. Method of producing heavy bentonite based slurry

FIG.3. Picture of heavy bentonite based slurry

3. RADIATION SHILDING PROPERTIES TEST

3.1 Method of experiment

Measurement method of transmitted radiation dose is presented the below. Gamma ray source and neutron beam source are used in the test. Main theme of the test is to confirm a relation between specific gravity of heavy slurry and effect of radiation shielding. FIG.4 and 5 show the setup of the experiment of gamma ray test and neutron beam test.

1) After preparing the heavy bentonite based slurry, acrylic containers filled up with heavy slurry. (Inside dimensions of acrylic container is 300mm x 300mm x 100mm.)
2) A source of gamma ray or neutron beam is put on the side of acrylic container, and survey meter is put on the contrast side. The distance between radiation source and detector is fixed to 150 mm both of gamma ray and neutron beam test.
3) When measured value becomes steady, record the transmitted radiation dose.
4) When a case of test has been completed, the test passes next case.

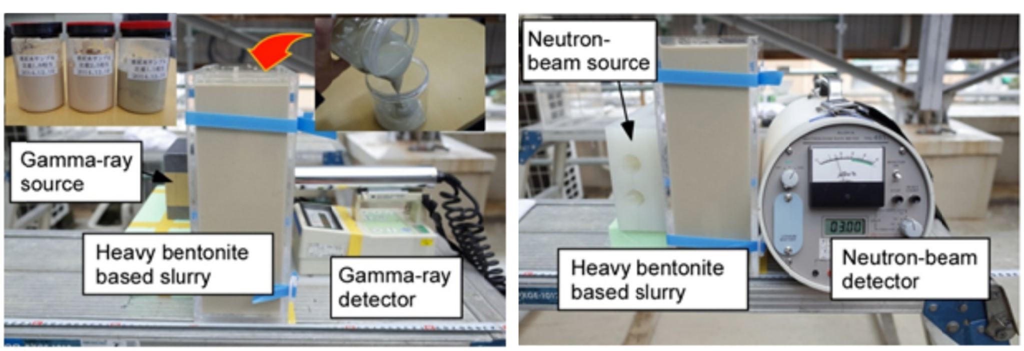

FIG. 4. Picture of setup of radiation shielding properties test (left: gamma ray test, right: neutron beam test)

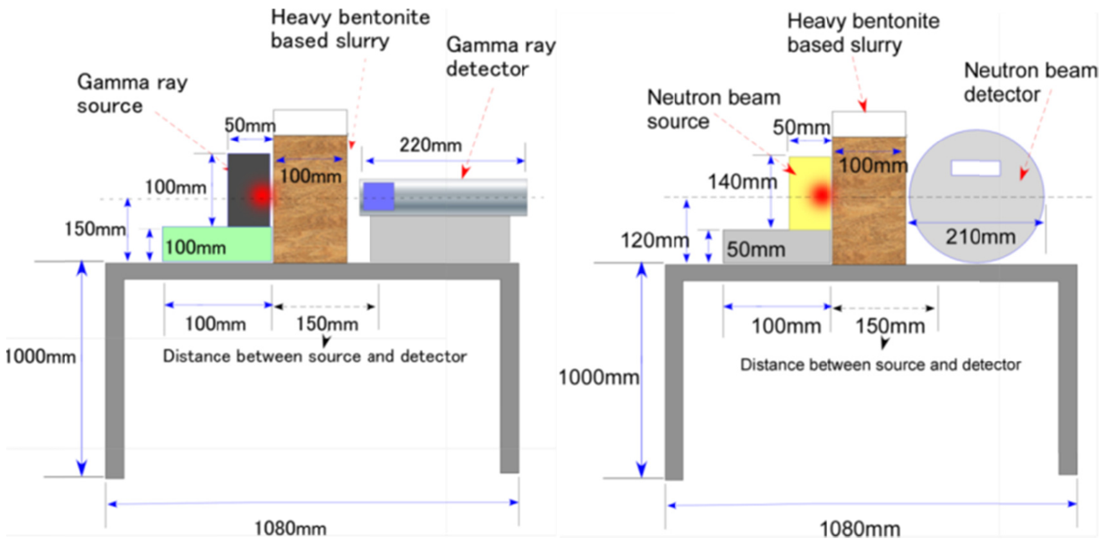

FIG.5. Image of setup of radiation shielding properties test (left: gamma ray test, right: neutron beam test)

3.2 Test Result and discussion

FIG.6 shows the relation between the gamma ray dose and the specific gravity of heavy slurry in case of heavy slurry thickness is 100mm fixed.

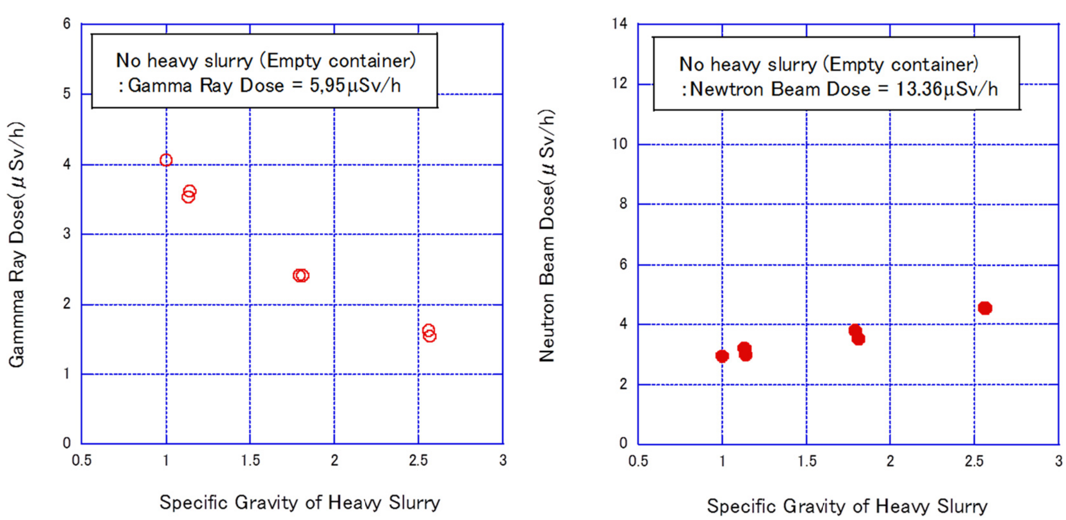

FIG.6. Relation between the gamma ray dose (left graph) or the neutron beam dose (right graph) and the specific gravity of heavy slurry

Following the study, it is clarified that gamma ray shielding is due to specific gravity of the heavy slurry. Gamma ray dose decreases with increasing of specific gravity. On the other hand, neutron beam dose increases with increasing of specific gravity because neutron beam dose is caused by water content. That is penetrated material has high neutron beam shielding property when it has low specific gravity. The test result shows specific gravity of heavy slurry has opposite effect between gamma ray and neutron beam shielding. Based on the study, the authors will pursue the most suitable mixing ratio of heavy slurry with the perspective of the shielding properties of gamma ray and neutron beam.

4. CONCLUSIONS

In this paper, author describes fundamental data to confirm the radiation shielding properties of bentonite based heavy slurry. The following conclusions were drawn from this study.

1) Gamma ray shielding is due to high specific gravity of the heavy slurry.
2) Neutron beam dose is caused by water content and it means material has high neutron beam shielding property when it has low specific gravity.
3) The specific gravity of heavy slurry must be considered from a point of view of difference shielding effect between gamma ray and neutron beam. On the actual construction, a balance of each radiation shielding is a matter of great importance.

5. REFERENCES

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