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DEVELOPMENT OF FUNCTIONAL RADIATION SHIELDING MATERIAL

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ABSTRACT
In order to reduce the radiation exposure of the personnel engaged in the decontamination of the high-dose regions of Fukushima, a new type of γ-ray shielding material made from aluminum and tungsten has been developed.
This γ-ray shielding material (MAXUS-w™) possesses favorable material properties (uniform dispersibility of tungsten, mechanical and thermal characteristics, γ-ray shielding performance). It was confirmed that the radiation shielding booth made of MAXUS-w™ (Al-50vol%W, 10mm) which was used in the decontamination area of Fukushima allowed the radiation dose rate in the air to be reduced by 60-74%.

INTRODUCTION
The accident that occurred at Fukushima Daiichi Nuclear Power Plant because of the Tohoku Earthquake had considerable effects on the surrounding residential environment and infrastructures. As a part of the recovery efforts, the soil of the neighborhood is currently being decontaminated [1], and the construction of an interim storage facility(*) for this recovered soil is under consideration. On the other hand, it is planned to take out the spent fuel from the common pool of Fukushima Daiichi Nuclear Power Plant and move it outside of the site. Therefore, growing demand of dry casks for transportation and storage is anticipated. Assuming that the spent fuel will be carried by land, the high radiation dose rate of the surrounding area may become an obstacle for the land transportation of the casks.
Decontamination of the soil requires tremendous amounts of time and money. Most of all, a further decrease in the radiation exposure of workers in the high dose zone is expected. For these challenges, it is effective to use easily-portable γ-ray shielding material which has superior durability, and we tried to develop such new material.

(*)Such facility is dedicated to the storage of the soil that has been collected during decontamination operations and differs from a used fuel interim storage facility.

EXPERIMENTAL PROCEDURES

Design of the New γ-Ray Shielding Material

It is preferable for the γ-ray shielding material to be easily movable along with the progress of decontamination work. Concrete, water or heavy metal may be options as shielding materials, but a metal-base material is suitable because of its portability.

Furthermore, corrosion resistance also becomes a necessary property for the shielding material considering its long-term exterior use. Since it is used in areas with relatively high air-dose rate of γ-ray, a maintenance-free material with long-term corrosion resistance is suitable.

Lead and iron are common metal radiation shielding materials, but for both of them it is difficult to ensure long-term corrosion resistance, especially in the case of lead. Considering that the γ-ray shielding performance may decrease because of the wastage due to corrosion and considering the heavy burden to environment, lead is absolutely not appropriate as a shielding material to be used outdoor.

For all these reasons, a "new γ-ray shielding material made from aluminum and tungsten" has been developed. Figure 1 shows the cross section of this new composite material. A three-layer clad structure enables it to be used outside for long term because the aluminum clads, those have good corrosion resistance, protect the γ-ray shielding layer from the corrosion. Furthermore, by adding pure aluminum to the tungsten in the core, it was aimed to provide this new material with adequate workability. In the past, Nippon Light Metal Co., Ltd. /Nikkeikin ACT Co., Ltd. have developed MAXUS® [2], a neutron absorber material designed for dry casks and spent fuel pools. MAXUS® is fabricated by a powder metallurgy process and features a three-layer clad structure. Since the structure of this new shielding material is very similar to that of MAXUS®, we have tried to produce the new γ-ray shielding material with the same fabrication process as MAXUS®.

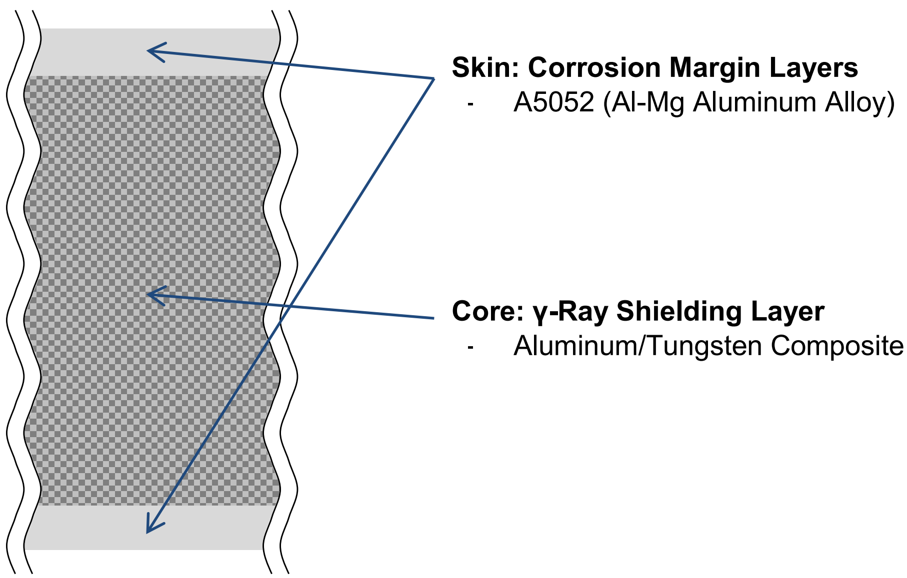


Figure 1. Cross Sectional Schematic Image of the New γ-Ray Shielding Material.

Material Properties

Table 1 shows the detail of the evaluation test of the new γ-ray shielding material MAXUS-w™.

Table 1. Evaluation of the New γ-Ray Shielding Material (MAXUS-w^{TM}).

Item	Method
Uniformity of Tungsten	Observation of the Microstructures
Mechanical Properties	Tensile Test (JIS Z2241)
Thermal Properties	Thermal Conductivity Test with the Gradient Method (ASTM E1225)
γ-Ray Shielding Properties	γ-Ray Transmission Measurements Radiation source: ^{137}Cs / ^{60}Co Detector: Portable Scintillation Counter Type Survey Meter.

Shielding Performance at Fukushima

The radiation dose rate of the Joban Expressway which both opened section and under-construction section remains over 3.8 μSv/h part. In the context of the decontamination at Joban Expressways implemented by The Ministry of the Environment, Taisei Corporation, as a main actor, is proceeding with this work on the section between Hirono Interchange (IC) and Minami Souma IC (about 24 km long). MAXUS-w^{TM} was brought in this area and its real shielding performance was actually measured. The spot of shielding performance testing at Fukushima is shown in Figure 2.

Quoted from a map of East Nippon Expressway Company Limited

Figure 2. Spot of Shielding Performance Testing at Fukushima.

RESULTS

Evaluation of the Material Properties

The result of microstructure observation of MAXUS-w^{TM} is shown in Figure 3. Although the density of aluminum and tungsten is very different, it was observed that tungsten particles are uniformly distributed within the aluminum matrix of the core.

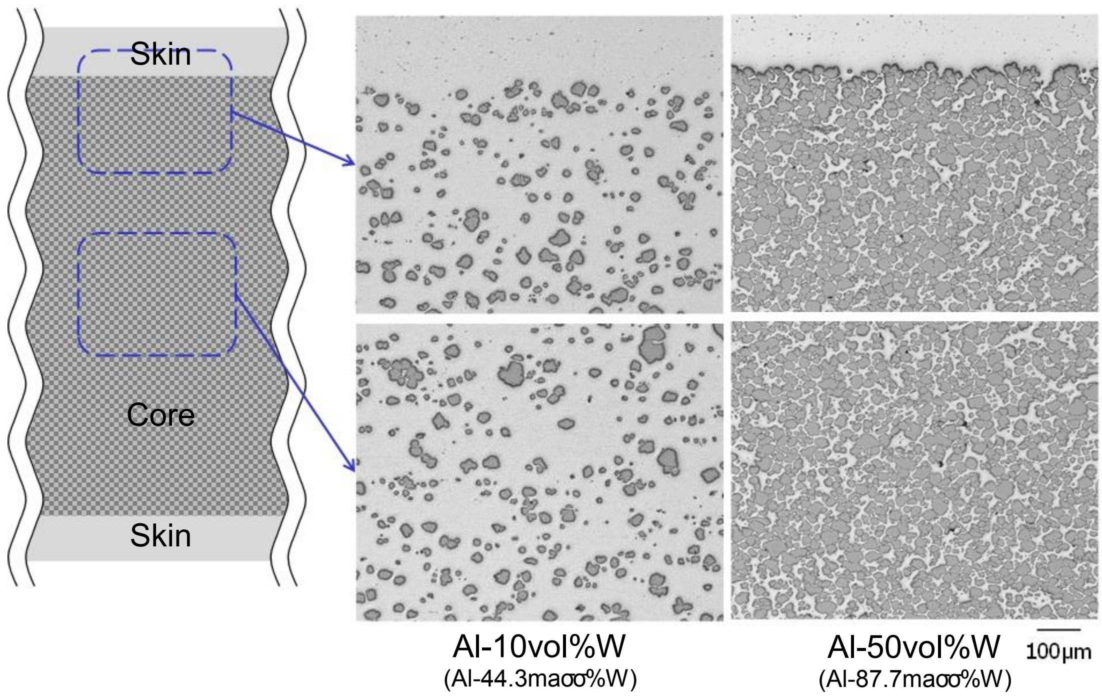


Figure 3. Cross Sectional Microstructures of MAXUS-w^{TM}.

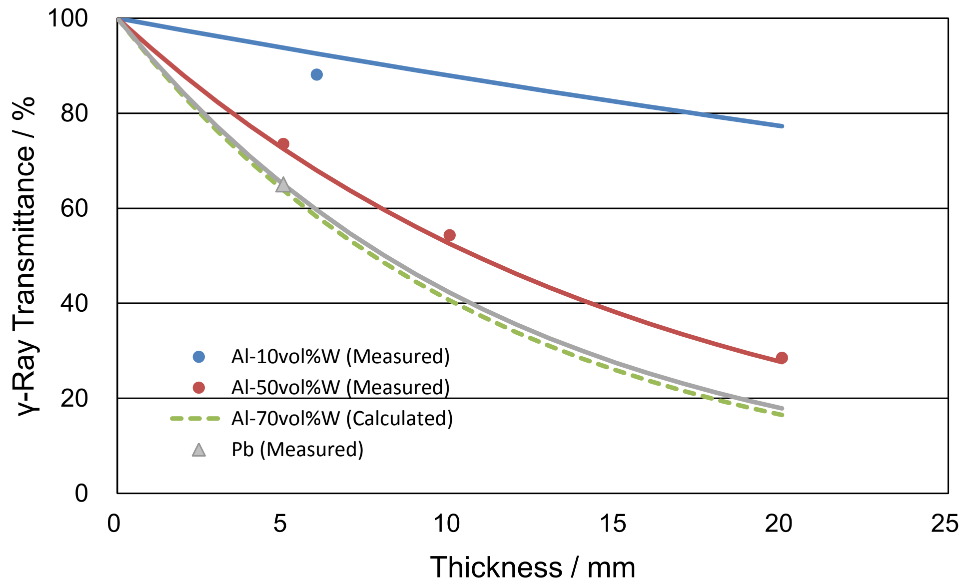
Mechanical and thermal properties of MAXUS-w^{TM} are shown in Table 2. It is evident from the results that MAXUS-w^{TM} is producible by economical process and has mechanical properties suitable to workability, unlike the plate of lead (too soft to stand by itself) or tungsten (too hard to work). As a composite of aluminum and tungsten, it is presumed to be able to be easily processed not only during the production but also on site where the radiation dose is high.

Furthermore, although it is not related with the intended use this time, superior thermal property of MAXUS-w^{TM} was also confirmed. It might thus be diverted to a γ-ray shielding material for industrial equipments that produce heat.

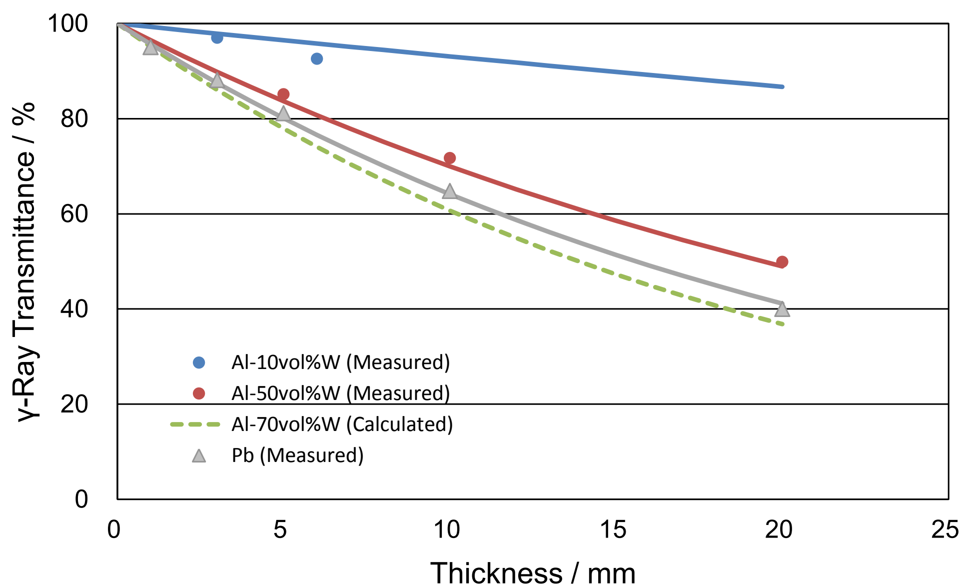
Table 2. Evaluation of the New γ-Ray Shielding Material (MAXUS-w^{TM}).

	Tensile Strength (MPa)	0.2%Yield Strength (MPa)	Strain (%)	Thermal Conductivity (W/m・K)
Al-10vol%W (Al-44.3mass%W)	172	131	18.3	205
Al-50vol%W (Al-87.7mass%W)	195	167	2.3	166
Pb [3]	18	-	52	35
W [4]	970	760	2	160

Results of γ-ray transmission measurements of MAXUS-w^{TM} are shown in Figure 4. The lines show approximate curve calculated from the results. The differences between measurement values and calculated values are less than 5%. In order to achieve almost the same level of shielding performance as lead, the volume fraction of tungsten of MAXUS-w™ should be 70%. Considering that the lead panel must be stuck to some other plate since lead panel cannot stand by itself, it could be concluded that using MAXUS-w™ (Al-70vol%W) enables to make the material's thickness thinner than using the lead panel.



(a) Radiation Source: ^{137}Cs



(b) Radiation Source: ^{60}Co

Figure 4. Results of the γ-Ray Transmission Measurements of MAXUS-w™.

Confirmation of the Shielding Performance at Fukushima

Figure 5 shows a schematic Image of the C-shaped γ-ray shielding booth made of MAXUS-w™ (Al-50vol%W, 10mm). And it was brought inside the decontamination zone of Joban Expressway in Fukushima to verify its γ-ray shielding performance (Figure 6). This booth was designed to be prefabricated off-site, hence it is possible to assemble it by humans on site without the use of heavy equipment. The radiation dose rate (1cm dose equivalent rate) in the air was measured at the 1000 mm height from the ground level with the portable scintillation counter type survey meter.

The measurement results of the shield factor using MAXUS-w™ (Al-50vol%W, 10mm) as a single plate with a collimator is shown in Table 3. It was confirmed that MAXUS-w™ (Al-50vol%W, 10mm) as a plate has a performance to shield about 67% of radiation. The measurement results of the shield factor using the C-shaped shielding booth is shown in Table 4. These results demonstrated that the radiation dose rate inside the C-shaped booth decreased 60-74% compared to those of the surrounding area.

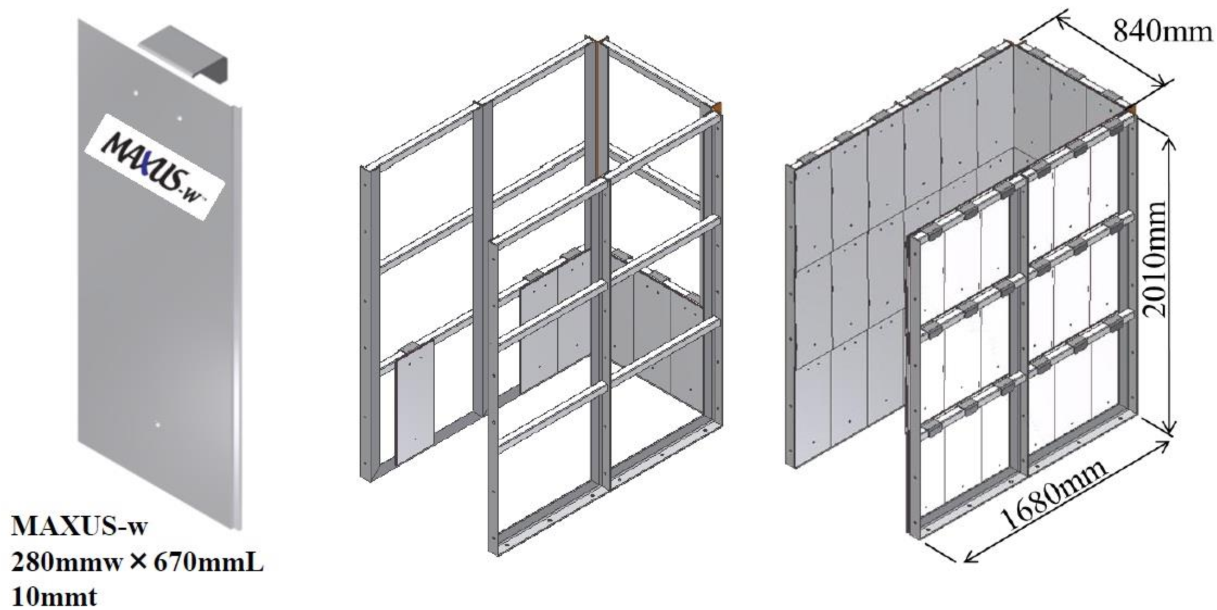
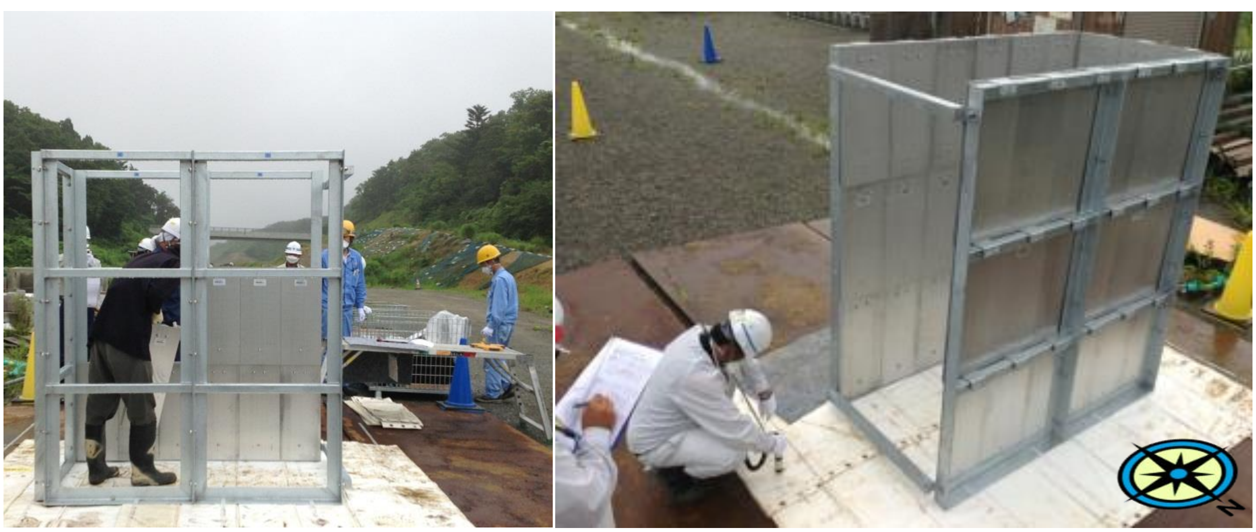


Figure 5. Schematic Image of the γ-Ray Shielding Booth made of MAXUS-w™.



(a) Aσσembling (b) Tεsting

Figure 6. Appearance of the γ-Ray Shielding Booth at Fukushima.

Table 3. Shield Factor of MAXUS-w™(Al-50vol%W, 10mm) as a Single Plate with a Collimator at Fukushima.

Radiation Dose Rate without MAXUS-w™	Radiation Dose Rate with MAXUS-w™	Shield Factor
3.3 μSv/h	1.1 μSv/h	67 %

Table 4. Shield Factor of the γ-Ray Shielding Booth Made of MAXUS-w™ (Al-50vol%W, 10mm) at Fukushima.

Radiation Dose Rate of the Surrounding Area	Radiation Dose Rate inside the Shielding Booth	Shield Factor(**)
4.6 μSv/h (North Sidε)	1.8 μSv/h	60-74 %
6.5 μSv/h (Wεst Side)		
4.5 μSv/h (South Side)		

(**)It shows the ratio of the radiation dose rate inside the shielding room to those of the surrounding area.

Figure 7 shows a summary of the shielding performance of MAXUS-w™ (Al-50vol%W, 10mm). The shielding factor measured at Fukushima is about 20% larger than that measured at our laboratory. It is suspected that the results measured at Fukushima differed from that of measured using monochromatic light (^{137}Cs) at the laboratory because there are several kinds of radioactive elements in the environment of Fukushima.

In this testing at Fukushima, it was confirmed that the shielding booth made of MAXUS-w™ could reduce the radiation dose rate by 60-74%. Considering that this booth used for the testing consists of only three faces (walls), it is expected that the shield factor of the actual products, that has four faces, is much higher (better) than these values.

Figure 8 shows another example of the use of MAXUS-w™ to decrease the radiation exposure of workers. From now on it is expected that MAXUS-w™ contributes to the recovery efforts of Fukushima.

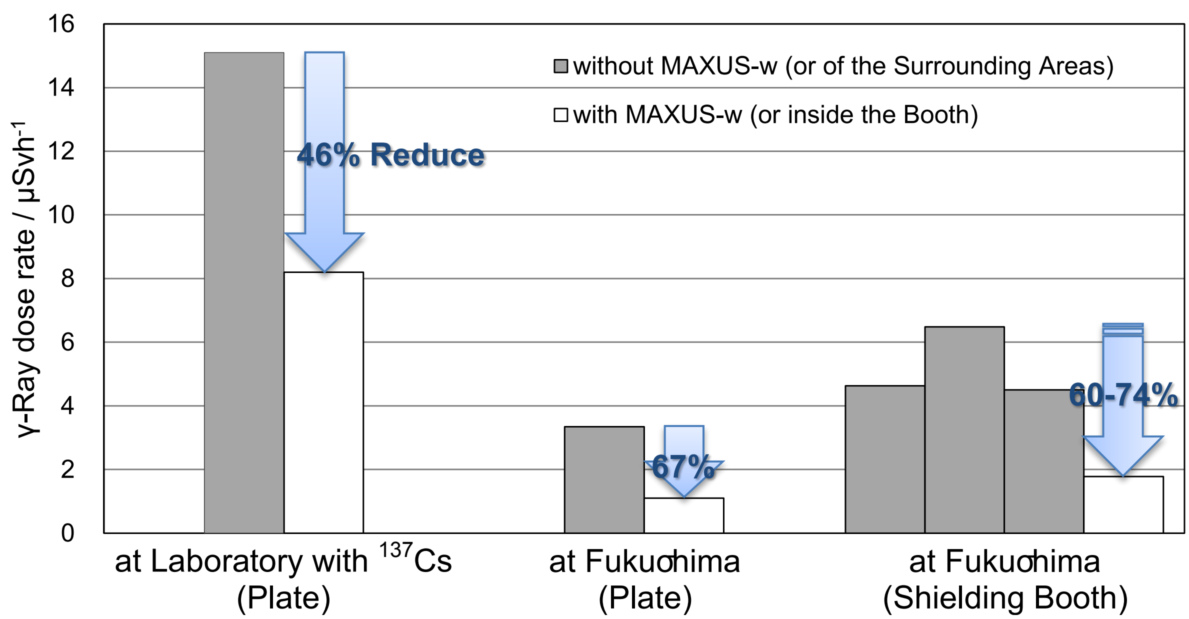


Figure 7. Summary of the Shielding Performance of MAXUS-w™ (Al-50vol%W, 10mm).

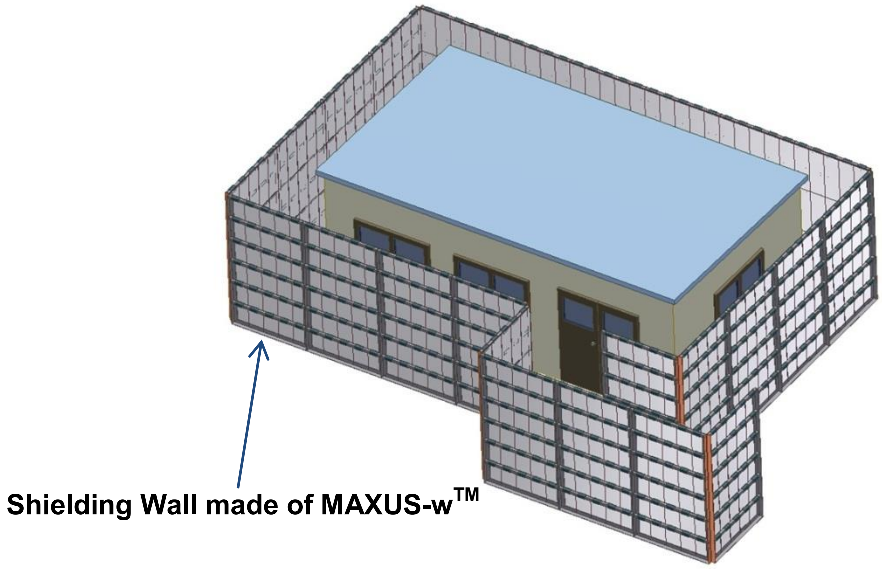


Figure 8. Example Image of the Use of MAXUS-w^{TM}.

CONCLUSIONS

In order to reduce the radiation exposure of the personnel engaged in the decontamination of the high-dose regions of Fukushima, "a new γ-ray shielding material, made from aluminum and tungsten (MAXUS-w^{TM})" has been developed. It is fabricated through the same powder metallurgy process than for the neutron absorber MAXUS®.

This γ-ray shielding material (MAXUS-w^{TM}) possesses favorable material properties (uniform dispersibility of tungsten, mechanical and thermal characteristics, γ-ray shielding performance). The C-shaped γ-ray shielding booth made of MAXUS-w^{TM} (Al-50vol%W, 10mm) was brought inside the decontamination zone of Joban Expressway in Fukushima to verify its γ-ray shielding performance. As a result, it was confirmed that the radiation dose rate in the air was reduced by 60-74% inside the shielding booth compared to the surrounding area. Considering that this C-shaped shielding booth consists of three faces (walls), it is expected that the shield factor of the actual products, that has four faces, is much higher (better) than these values.

Decreasing the radiation exposure of workers is not only making a contribution to the recovery of Fukushima's environment but also removing the obstacle of the land transportation for carrying out the spent fuel from the common pool of Fukushima Daiichi Nuclear Power Plant. From now on it is expected that MAXUS-w^{TM} contributes to the recovery efforts of Fukushima.

ACKNOWLEDGMENTS

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And the authors would like to send many thanks to Mr. M. Tsubota, Mr. K. Yamamoto, and Mr. H. Hommo for the dedication to this development.

REFERENCES

[1] Ministry of the Environment, "Decontamination Roadmap" for the Special Decontamination Areas.

[2] T. Yamazaki, K. Sanada, T. Nishiyama, H. Ishii: Proceedings of the 15th International Symposium on the Packaging and Transportation of Radioactive Materials (PATRAM 2007) (2007), Abstract #228.

[3] ASM International: *Metals Handbook*, 10th edition, Vol. 2 Properties and Selection: Nonferrous Alloys and Special-Purpose Materials (1990), 550.

[4] ASM International: *Metals Handbook*, 10th edition, Vol. 2 Properties and Selection: Nonferrous Alloys and Special-Purpose Materials (1990), 580, 1170.