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Design Improvements of the Protection Tube of a Fuel Capsule for the Development of a Capsule Assembly Process

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1. Introduction

New capsule assembling technology and re-instrumentation technology has been developed to meet the demands for the high burnup test at HANARO since 2003. In 2003, a mockup of the capsule assembly machine was designed and fabricated [1, 2]. The performance test which started in 2004 was undertaken to determine and present the main performance characteristics of the capsule assembly machine (CAM) including the special tools. In 2005, the need to develop new techniques that can assembly the capsule's components such as a capsule's main body and a protection tube was recognized for the re-irradiation test techniques in the HANARO reactor. A series of analyses using a finite element analysis program, ANSYS [3] and full scale tests were performed to improve the design of the capsule's components for an effective utilization of the CAM.

This paper presents a summary of the latest results of the design improvements and the performance tests.

2. Methods and Results

Since a capsule's main body including the irradiated specimens would be directly connected, instead of a welding, to a protection tube for a capsule manufacturing to be used for a re-irradiated test [2], the structural integrity of an assembled capsule under the HANARO operational conditions must be assured before an application in the reactor. Two options for the connecting process were considered [4]; one is a bolting with four bolts and the other is a joining with a specially designed joint. However, the position of the capsule's stopper could be changed due to the flexible feature of the joint, and so this concept was tentatively canceled. As a stopper of the HANARO fuel capsule, which is located at a position of 300 mm from the bottom of a protection tube, the accessibility of a remote tool for a bolting from the main bridge of the HANARO reactor is extremely restricted due to the highly curved outer walls of the stopper as shown in Fig. 1. The critical issue in the present design is therefore to confirm the accessibility of a tool fabricated for a bolting. A series of tests and stress analysis of the proposed structures were performed.

2.1 Description of Instrumented Capsule

The typical HANARO fuel capsule consists of a capsule's main body, a bottom guide assembly, a guide tube, and a protection tube made of SUS 304 tube as shown in Fig.1. The protection tube is 42.7mm in outer diameter, 2.8mm in thickness and 3700mm in length, which has a role to protect the instrumented cables and gas tubes from the reactor coolant and to link a capsule's main body to an I&C system.

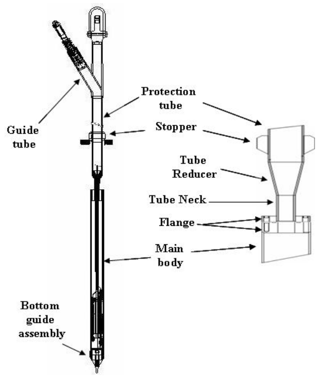


Fig. 1. Schematic view of the HANARO fuel capsule

For an effective assembling process by bolting, each of the flanges was designed to be welded on both sides of the bottom of a protection tube and the top of a capsule's main body, and the two flanges are connected with four stainless steel bolts by using a remote working tool. Sufficient access to the top of a capsule's main body and space for an in-situ bolting by a remote tool must be considered for the assembling process. For the design improvements of a protection tube, three different kinds of protection tubes were proposed as in Table 1 and tested.

Table 1. Tube Lengths of New Proposed Structures

Case	Tube Reducer(mm)	Tube Neck(mm)
1	20	50
2	80	50
3	20	110

2.2 FE Analysis and Experiment Model

The structural integrity of a capsule depends on the shape and size of the protection tube of a capsule. In order to generate the FE model for considering the actual geometry, the central region area of a capsule joined with special bolts was modeled by an elastic shell element (Shell63) with six degrees of freedom per node. When a fuel capsule is inserted into the test hole, supporting structures such as the clamp arm, the stopper, and the rod tip, support the capsules. Thus, as the boundary conditions considered in the analysis, the bottom of the capsule's main body and the top of the protection tube are treated as a simple support, and a dead weight is applied for the analysis.

2.3 Results of the Analysis and Test

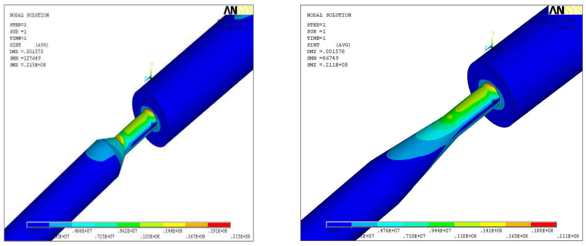
The displacement and stress intensity results for the three cases considered in this study are summarized in Table 2. As shown in Table 2, the calculated values of the displacement and the stress intensity did not differ considerably for the concerned region of a capsule. As the yield stress of the stainless steel 304 is about 205 MPa, it was found to be considerably lower than the allowable stress for the material used. Figure 2 shows the stress distribution at the tube reducer region of a capsule.

The first and second case had similar values for the stress intensity and displacement. Third case had the highest value of the displacement but the lowest value of the stress intensity. The distribution of the stress intensity is a very important for the structural integrity of a capsule during an irradiation in the reactor and it corresponds well to the safety criteria. As the second case showed wide-ranges of the stress distribution and a better access for a remote tool for a bolting, KAERI designed and fabricated mock-ups based on the second concept to carry out an integral test in air.

The test has been successfully performed under the simulated conditions, which correspond to the working condition of the reactor service pool. No abnormality of the performance of the mock-up has been observed in the tests. From the analysis and test results, it showed that the second option is the most promising design concept for an assembly of the capsule's components.

Table 2. Max. Displacement and Stress of the Capsule

Case	1	2	3
Max. Displacement (mm)	1.575	1.578	1.61
Max. Stress Intensity (MPa)	21.5	21.1	17.3



(a) Nominal design (b) Improved design

Fig. 2. Stress intensity of the central region area of the capsule

3. Conclusion

From the performance tests and the stress analyses of the three proposed structures by using the finite element analysis program ANSYS, the major findings from this study are delineated as below.

1. The newly designed protection tube with the introduction of a long tube reducer (dimensions: tube diameter 42.7mm, tube reducer length 80mm) was found to be the most promising design concept for an assembly of the capsule's components.
2. The maximum displacement and stress intensity for the improved structure were 1.57mm and 21MPa, respectively.
3. Test data prepared by this study is to be used for the design and fabrication of the HANARO capsule.

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