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Development of Inspection and Maintenance Program for Reactor and Reactivity Control Units in HANARO

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ABSTRACT

This paper summarizes the overall program for inspection and maintenance of reactor structure and Reactivity Control Units (RCU) of HANARO during lifetime.

The long-term plan for in-service inspection is introduced in the viewpoint of the structural integrity of reactor and RCU, and the operability of RCU mechanism. This program includes the list of components to be inspected, the schedule of inspection and maintenance, and the development of special tools and test rig that are required for the remote inspection and maintenance of reactor and RCU components.

Preliminary results of the evaluation on the lifetime of RCU components are summarized based on the operation history since the installation of reactor. A test rig will be designed and constructed for the purposes of verifying the prolonged lifetime of RCU components being used, the performance of special tools, and the rehearsal of maintenance work as well.

1. Introduction

The HANARO reactor has been operated for four years including one year of non-nuclear system commissioning test. As the reactor is aged by operation the integrity of structure and the performance of components should be periodically inspected and monitored. This paper summarizes the overall program for the inspection and maintenance of reactor and RCU (Reactivity Control Units composed of 4 shutoff units and 4 control absorber units). Most of the components for reactor and RCU are located near the core region so that they require inspection, measurement and replacement under water with the various remotely operated tools specially designed.

The lifetime of RCU components will be evaluated with operation history since the installation of reactor. A test rig is to be designed and constructed as one of main activities to verify the prolongation of the lifetime of the RCU components being used in reactor. The domestic products of RCU with design improvement will also be fabricated and tested in the test rig for the verification of the required performance. In addition to that, the test rig shall be used for the rehearsal of inspection, measurement, and maintenance activities with the verification of tool performance. The overall flow diagram for inspection and maintenance program is shown in the figure 1.

2. Description for Reactor and RCU in HANARO

The reactor is installed vertically in a pool of demineralized light water. Figure 1 shows its main items: the stainless steel Plenum and Grid Plate, the Zircaloy Reflector Tank, the aluminum Chimney, and the Zircaloy flow tubes. Fuel handling, RCU actuation and in-core experiments are accessed from the pool top, while horizontal beam tubes are accessed through the pool wall. The reflector vessel is a toroidal tank whose central channel encloses the array of flow tubes. It is also penetrated vertically by many irradiation sites and experimental sites, including the fuel test loop, and horizontally by the beam tubes. The chimney is a hexagonal duct extending above the core, with two large, angled primary cooling system (PCS) outlets on its sides. The flow tubes are secured to the grid plate. There are twenty-three hexagonal flow tubes and eight cylindrical ones.

On each cylindrical flow tube, a tubular hafnium neutron-absorber "rod" slides up and down, inside the space enclosed by the adjacent hexagonal tubes. A shroud tube extends above the flow tube to enclose and guide the rod. It also shields the absorber rod from the PCS flow exiting the core out the angled duct. Four rods are Control Absorber Rods (CAR), and four are Shutoff Rods (SOR). Each absorber is suspended from an offset, track-guided carriage via a perforated support tube which has a hollow swivel joint called 'Gimbal joint' at each end. The absorber rod is identical for SOR and CAR and surrounds a circular flow tube, which in turn encloses an 18-element fuel bundle. The track is mounted inside the chimney wall. Generous mechanical clearances of 0.5 mm were set on all sliding surfaces to preclude jamming due to floating particles, or absorber and flow tube warpage due to irradiation.

Each SOR is actuated by a directly linked hydraulic cylinder on the chimney, which is pressurized by a pump operating on pool water. Elastomers are avoided by using labyrinth seals, where the high leakage flow generates the back-pressure holding up the piston. The rod is released to drop by gravity, when triplicate solenoid valves ("dump valves") are opened to vent the cylinder. Needle valves adjust the flow and pressure to obtain fast insertion times for shutdown, but moderate withdrawal times for controlled start-up. Pressure switches connected to cylinder body tappings indicate up and down positions. The valves, switches and electric motor-powered pump are mounted at the pool top.

CARs are actuated by electric stepping motor-powered ball-screw drives at the pool top; see Figure 4. The rod's lower carriage is linked to a middle carriage at the chimney top (i.e., in place of the SOR's cylinder), which is linked in turn to the drive through a long, angled tie-rod. For emergencies, an electro-magnet coupling can release the rod and carriages from the ball nut and they drop into the core. The ball screw and electro-magnet are enclosed in a dry well which travels with the carriage.

3. Estimation for Life Time of RCU Components

The design life of the HANARO reactor is 20 years with the reactor assumed to operate at an average of 80% of full capacity. The current SO unit and CA unit had been verified for the endurance for 1500's drop for SOR and 1400's drop for CAR as the design inputs.

For the estimation of lifetime of SO and CA units, the numbers of SOR and CAR drop in future are assumed based on the operation history counted since the installation to the end of 1997 as summarized in table 1 and 2. The results show that the actual numbers of SOR/CAR drop are much higher than expected. According to the drop history and the expected operation for SO/CA units as shown in table 3, the number of SOR drop may reach to its tested number in the year of 2005. And the CAR drop may be saturated in the year of 2012.

Table 1. Number of SOR Drop

Operation	Period	Drop by RPS Trip	Total Drop (SOR #1)	Total Drop (SOR #2-4)
Commissioning Test	1994.7. – 1995.1.		218	128
Periodic Test (5 times)	1995.8. – 1997.12.		50	50
Reactor Operation	1995	4	181	181
Reactor Operation	1996	7	126	126
Reactor Operation	1997	5	92	92
Total	**1994.7. – 1997.12.**	**16**	**667**	**577**

Table 2. Number of CAR Drop

Operation	Period	Drop by Operator	RPS Trip	RRS Trip	Total Drop (CAR#1-4)
Commissioning Test	1994.4. – 1995.6.	17			17
Periodic Test (5 times)	1995.8. – 1997.12.	5			5
Reactor Operation	1995	140	4	9	153
Reactor Operation	1996	104	7	14	125
Reactor Operation	1997	46	5	18	69
Total	**1994.4. – 1997.12.**	**312**	**16**	**41**	**369**

4. Inspection and Maintenance Program

4.1 Preventive Maintenance

Following are the items as the preventive maintenance actions that are being taken periodically.

- Torque measurement of flow tube torque: 18 months
- Torque measurement of bolts having no wire-locking for SO/CA units: 6-12 months
- Calibration of system monitoring gauges for SO/CA units: 12 months
- Change of filter: 6 months

4.2 Periodic Testing & Performance Monitoring

The system performance of SO/CA units are being periodically tested and the test results are evaluated to confirm system availability and to detect deterioration or change in system characteristics. Additionally, the deceleration performance of damping cylinder of CA unit is going to be periodically (each year) measured during CAR drop after 500's drop cycles. Following are the items of periodic test being performed.

- Measurement of SOR drop time: 6 months
- Measurement of SOR withdrawal time with valve setting history for SO hydraulic system: 6 months
- Measurement of CAR drop time: 6 months

4.3 In-service Inspection

The visual inspection is to be performed each 5 years to inspect the surface condition of components for corrosion, erosion, wear, crack, and fastening status of wire-locking on large sized bolts. A remotely operated underwater-camera with lighting equipment should be developed for visual in-service inspections. For the wear point of view, one assembly of carriage/track, which has the largest operation cycle among all SO/CA units, will be removed from reactor for inspection within the period of 10 years. Regarding the effect of irradiation on the material, some components located near the core center are measured in the viewpoints of dimensional change that affects the system performance of SO/CA units. Followings are the list of the periodic in-service inspection to be performed for reactor structure and RCU components.

- Visual inspection of outer surface of reactor structure, beam tubes and expansion joints, shutoff units, control absorber units and neutron detector housings
- Visual inspection of wire-locking for reactor bolts
- Visual inspection of components inside chimney
- Inspection of wear of upper carriage/track
- Measurement of straightness for inner shell
- Measurement of diameters for absorber rods(SOR/CAR), shrouds and cylindrical flow tubes
- Check of fastening torque for the mounting bolts of neutron detector housings

5. Program and Schedule

5.1 Development of Special Tools

Since most of the components for reactor and RCU are located near the core region, they require lots of remote tools specially designed for the components to be inspected and handled. Various tools have been developing for the preventive maintenance, in-service inspection, maintenance and replacement as shown in the table 4. Some of them are being well used but further more tools should be prepared as the reactor accumulates its age.

5.2 Design and Construction of Test Rig

A test rig for HANARO RCU is required for the main purpose of additional endurance test of SO/CA units and performance test of actuating mechanisms if they are required to be replaced with new ones. The rig will also be used for training of tool operators for inspection and maintenance, performance verification of tools, inspection and maintenance rehearsal, and other things such as rehearsal of refueling or vibration test of irradiation facility to be loaded in the core. For the purpose of the tests following conceptual specifications are applicable to the design of the test rig facility. See the figure 3 for the configuration of the test rig.

- Full scale 4 flow-channels, 1 for shutoff unit 1 for control absorber unit, 2 for 2 hexagonal flow tubes for rehearsal of refueling or other tests
- Real height for core and chimney
- Real height(13m) for hydraulic system of shutoff unit
- Reduced height(9m) for control absorber unit (Reduced but equivalent mass of tie rod)
- Reduced and simplified configuration for reactor structure and pool
- Windows on chimney and core region for inspection & measurement
- 7.8m depth, reduced size(1m in diameter) of pool filled with demineralized water.
- For shutoff unit test, pool top will be closed with a sealed cover and pressurized by a water tank at the elevation of 13m to have the equivalent static head as in real depth of pool
- 72 kg/sec system flow including 10% bypass flow to simulate reactor channel flow
- To be constructed in engineering laboratory or HANARO building

5.3 Prolonged Endurance Test of RCU

As mentioned in section 3, the numbers of SOR/CAR drop cycles are predicted to reach to the endurance test number before the end of lifetime of reactor. Therefore the endurance of RCU should be verified for the increased number of operation.

The spare set of RCU, which had been tested for 1500's drop cycles during design verification test, will be installed in the test rig. Additional number of drop for the test program may be about 3500-4000 cycles.

5.4 Design Improvement and Domestic Fabrication of RCU

Domestic fabrication of the RCU components will be carried out including the absorber rods, SO unit hydraulic cylinder, CA unit drive assembly, carriage, instruments and gauges. Design improvements, if recommended based on operation experience, are also implemented to the new products. The performance of all newly made actuating mechanisms will be verified in the test rig.

5.5 Schedule

The overall schedule for the program of inspection and maintenance is shown in table 3. The schedule was preliminarily composed with the target of completion of the verification for the prolonged lifetime of current RCU and domestic products. The schedule shows the prediction of SOR/CAR drop cycles, in-service inspection, RCU test program in test rig, and the development of special tools.

6. Conclusions and Recommendations

(1) Overall program was prepared for the inspection and maintenance of reactor and RCU based on lifetime evaluation with operation history.

(2) Various remotely operated tools are being developed for preventive maintenance, in-service inspection and necessary maintenance.

(3) A multipurpose test rig will be constructed for verification for lifetime prolongation of RCU in core, performance test of new RCU products, training of tool operators, performance verification of tools, inspection and maintenance rehearsal, and others.

(4) Domestic production & verification of RCU will be carried out.

(5) Further studies for program and technology are necessary to proceed detail implementation of in-service inspection.

(6) The metallurgical studies including examinations and testing for the irradiated materials of reactor and RCU should be proceeded.

Table 3. Schedule for Inspection and Maintenance of Reactor and RCU

ITEM \ YEAR	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Accumulated drop cycle for CA units	369	440	511	582	653	724	795	866	937	1008	1079	1150
Accumulated drop cycle for SO units	667	779	891	1003	1115	1227	1339	1451	1563	1675	1787	1899
Preparation of detail work procedure	━━	━━	━━	━━								
Development of tools	━━	━━	━━	━━								
Design & contruction of test rig		━━	━━	━━								
Training of tool operators		━━	━━	━━	━━							
In-service inspection			━━				━━					
Inspection/maintenance rehearsal				━━	━━							
Installation of spare RCU at rig					━━							
Prolonged endurance test of RCU						━━						
Design Improvement, domestic fabrication of RCU					━━	━━	━━					
Test of domestic products of RCU							━━	━━				

Design Life of CA Units : 1400

Design Life of SO Units : 1500

Table 4. List of Special Tools

NO	TOOL NAME	USAGE	STATUS
1	CA Drive Mounting Bracket Jig	CA Drive Inspection & Resetting	Completed in 93. 6
2	Shroud Target and Holder	Shroud Removal/Installation	Completed in 93. 7
3	CA Drive Lower Bracket Tool	CA Drive Lower Bracket Bolt Tightening / Loosening	Completed in95. 11
4	Absorber Torque Tool	Absorber/Shroud Bolt Loosening/Tightening	Completed in 95. 8
5	Cylinder Torque Tool	SO Cylinder Bolt Loosening/Tightening	Completed in 95. 8
6	Middle Carriage Torque Tool	Middle Carriage Loosening/Tightening	Completed in 95. 8
7	Flow Tube Torque Tool	Flow Tube Torque/Orientation Inspection	Completed in 95. 8
8	Spring Balancer #1	Weight Balancer for In-pool Work(30-60kg)	Completed in 96. 6
9	Spring Balancer #2	Weight Balancer for In-pool Work(5-40kg)	Completed in 97. 1
10	OR Site Locknut Tool	OR Site Locknut Torque Inspection	Completed in 97. 2
11	Flow Tube Storage Rack	Storage of Irradiated Flow Tube, Orifice and Lock Washer	Completed in 97. 2
12	In-pool-work Platform	In-pool Working for Reactor and RCU Maintenance	Completed in 97. 2
13	Absorber Element Gripper	Absorber Removal/Installation	To be modified
14	Hexagonal Flow Tube Tool	Hexagonal Flow Tube Removal/Installation	To be modified
15	Remote Underwater Camera	Visual Inspection and Maintenance of In-pool/In-core Work	To be modified
16	Flow Tube Orifice Tool	Flow Tube Orifice Removal/Installation	To be modified
17	Cylindrical Flow Tube Tool	Cylindrical Flow Tube Removal/Installation	To be modified
18	CA Lower Carriage Tie Rod Manipulator	Carriage Removal/Installation	
19	SO Carriage Manipulator	Carriage Removal/Installation	
20	Absorber Height Gauge	Check of Absorber Elevation	
21	SO Cylinder Manipulator	SO Cylinder Removal/Installation	
22	NDH Torque Tool	Neutron Detector Housing Bolt Torque	
23	Remote Dial Gauge	Measurement of Inner Shell Radial Deformation	
24	Remote Cylinder Gauge	Ovality Check of Flow Tube, Shroud and Absorber	
25	Remote Calipers	Absorber Outer Diameter Measurement	
26	RCU Component Storage Rack	Storage and Inspection of Irradiated RCU Components	
27	CA Drive Test Rig	Test of CA Drive Stepping and Damping Performance	
28	SO Test Rig	Endurance Test to prolong life time of SOR drop cycle, Removal/Installation Rehearsal	
29	Ultrasonic Tool for Dimensional Measurement	Dimensional Measurement of In-core Components	
30	Ultrasonic Tool for NDE	Non-Destructive Examination for Welded Area	

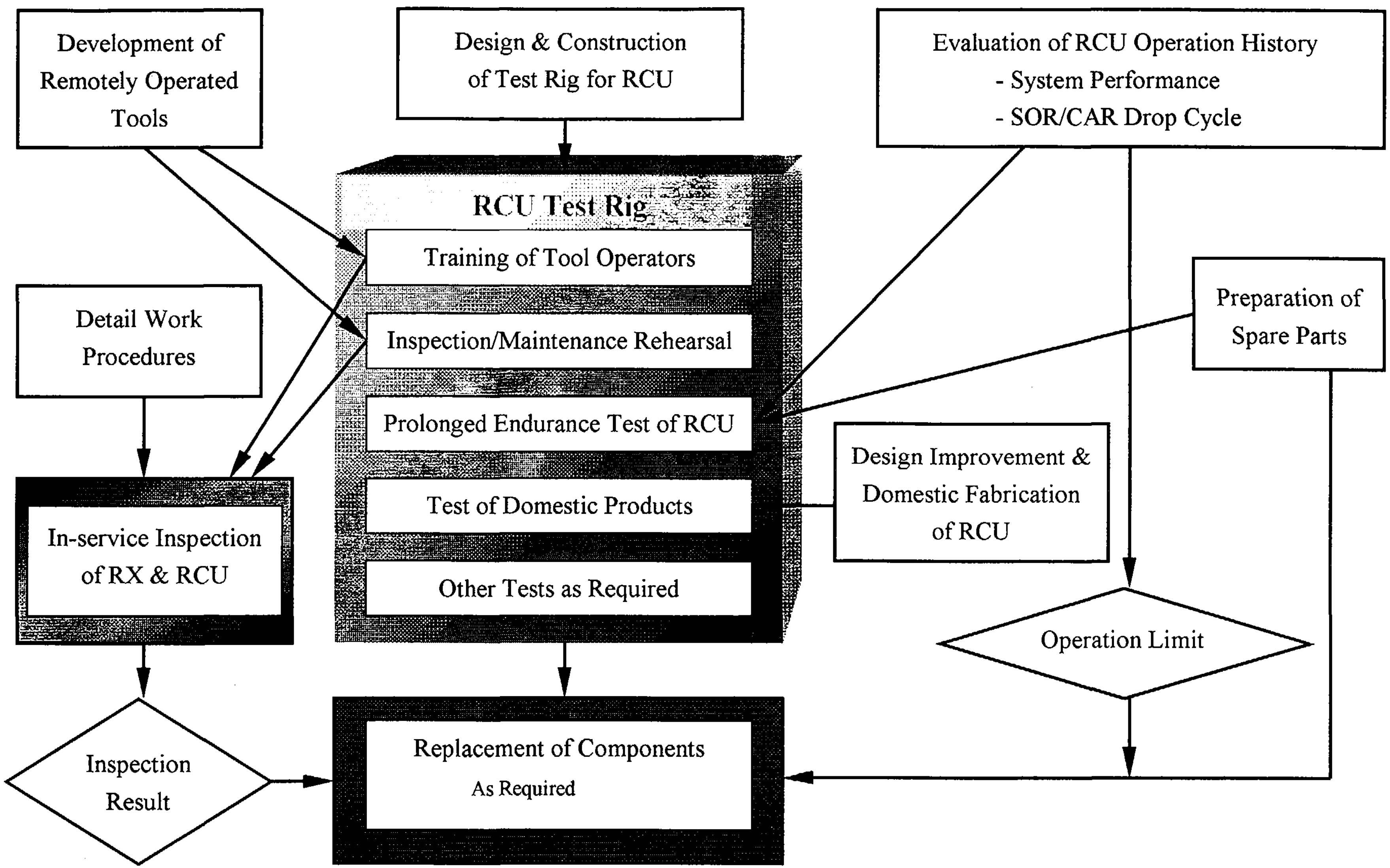

Figure 1. Flow Diagram for Inspection and Maintenance of Reactor and RCU

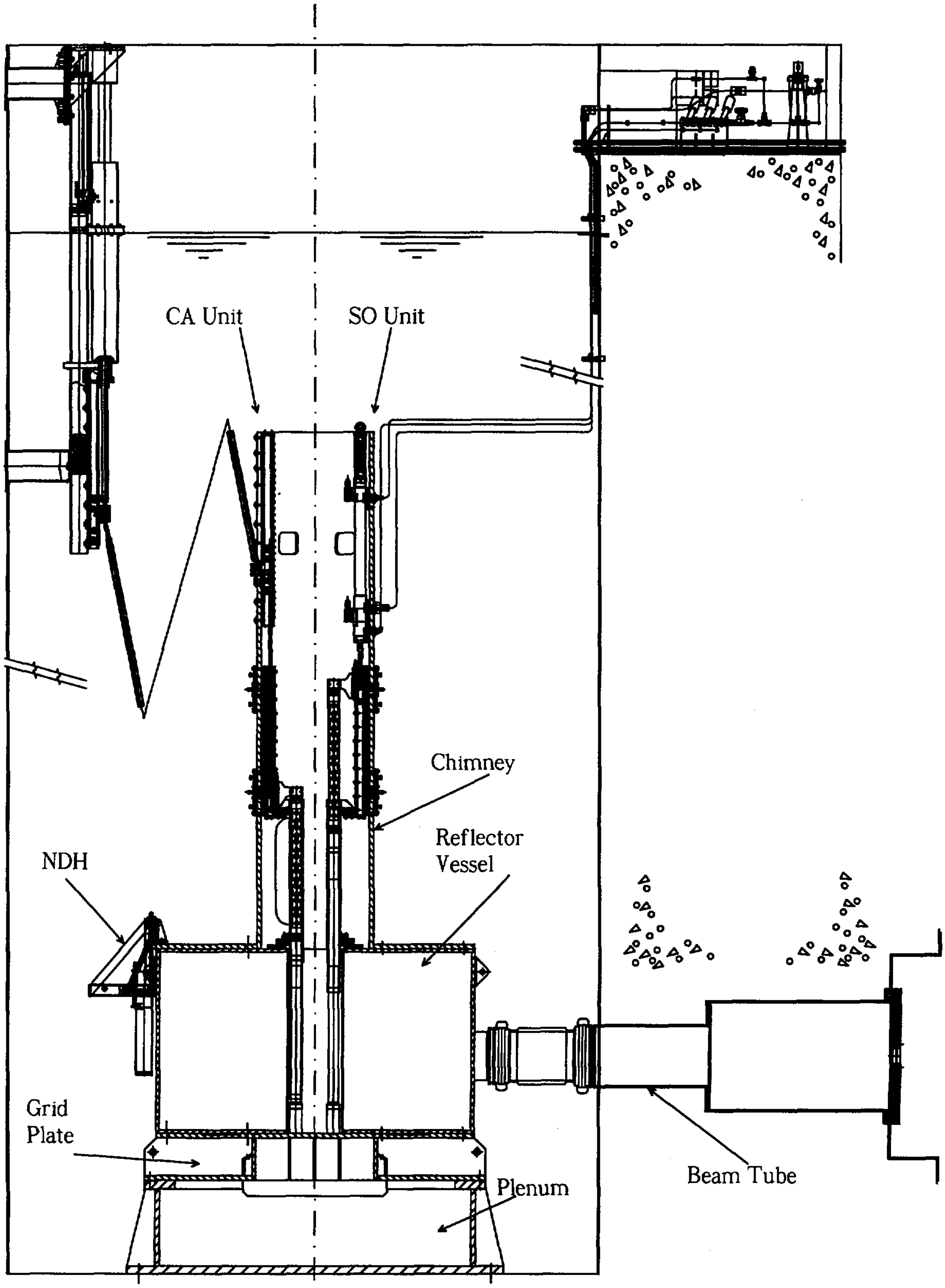

Figure 2. Reactor Structure and RCU

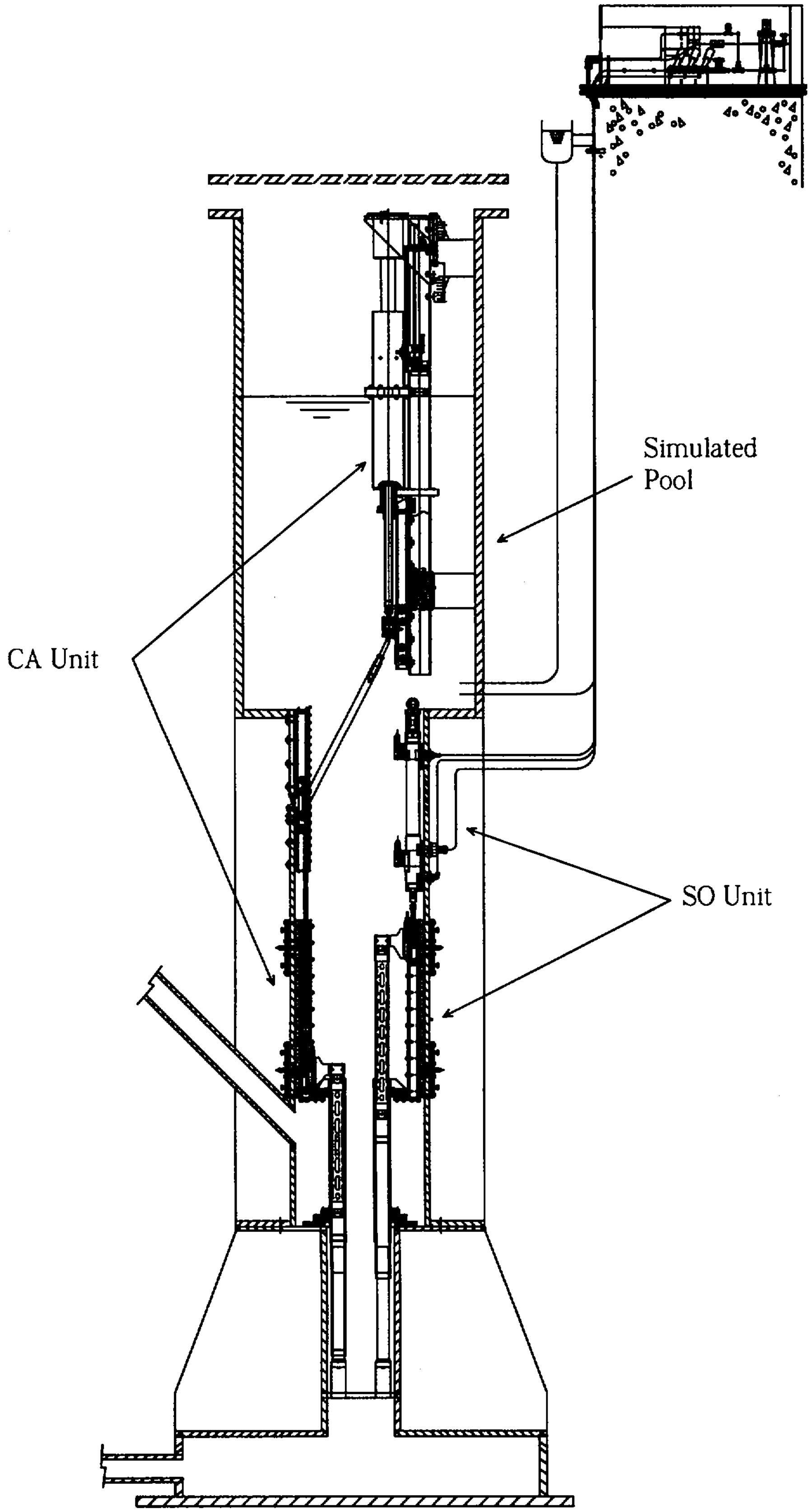

Figure 3. Concept of RCU Test Rig