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REMOTELY CONTROLLED MACHINE FOR BIOLOGICAL SHIELD CONCRETE DISMANTLEMENT

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ABSTRACT

The Japan Atomic Energy Research Institute(JAERI) has been developing necessary dismantling techniques to decommission the Japan Power Demonstration Reactor(JPDR) in the JPDR Decommissioning Program since 1981.

A cylindrical geometric machine equipped with diamond sawing and coring units has been developed for activated biological shield dismantlement. This machine is suspended from a crane and moves within the inner cylindrical shaped wall and fixes its position with built-in outriggers. Cutting process control and point-to-point control are used for automatic cutting.

The paper summmarizes current status of the biological shield, diamond sawing and coring technique and dismantling sequence, design of the machine, and a dismantling system.

1. INTRODUCTION

The JPDR decommissioning program* was begun in 1981 in order to develop reactor decommissioning techniques to decommission the Japan Power Demonstration Reactor(JPDR) and demonstrate these techniques on the site. This small BWR power plant, was the first power generation plant in Japan, was shut down in 1976 after 13 years of operation.

Various dismantling techniques have been developed according to the material and portion to be dismantled: underwater arc-saw cutting for the reactor pressure vessel dismantling; underwater plasma-arc cutting for the dismantlement of the reactor pressure vessel internals; rotary disk knife and shaped explosive cutting technique for the primary piping cutting; diamond sawing and coring, abrasive-water jet, and controlled blasting for the dismantlement of the biological shield concrete. These techniques, except controlled blasting, are executed by remote control devices because the operations are done in highly radiated areas.

The diamond sawing and coring described herein is a cutting method commonly used for reinforced concrete. After the feasibility study in 1981, a prototype remote control cutting machine equipped with a sawing/coring unit was made and used for cutting tests from 1982 to 1984. Based on the test results, a dismantling system including the cutting robot was designed and constructed. After the 1987 - 1988 mock-up test, the removal operation of the activated reinforced concrete by the cutting robot will be carried out in 1990.

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* This project has been performed under contract with the Science and Technology Agency in Japan.

2. BIOLOGICAL SHIELD CONCRETE WALL

The biological shield is where the machine works and what the machine dismantles. A cross section and estimated activated area of the JPDR biological shield is shown in Fig. 1. The structure has an inner cylindrical shape with a diameter of 2.7 m to 3.5 m, and is about 21 m in height with a maximum thickness of 3.0 m.

The portion of the biological shield to be removed by using the sawing and coring technique extends from an elevation of 12.15 m to an elevation of 10.57 m within a diameter of 3.5 m. This part of the structure is composed of 300 kgf/cm^2 of ordinary concrete and is reinforced with 29 mm diameter bars in a grid pattern of 15 cm by 15 cm. The inside surface of the biological shield is lined with 13 mm and 10 mm thick carbon steel plate. Shield cooling pipes 34 mm in diameter and neutron detector guide tubes 150 mm in diameter also lie inside the structure.

3. DIAMOND SAWING AND CORING

Diamond sawing and coring are generally performed by the machines illustrated in Fig. 2.

The diamond blade is driven by a motor mounted on a rack and pinion carriage which travels along a guide track. The carriage is also equipped with a feed screw for plunge cutting. The diamond sawing process is typically done as follows: (1) attach the guide track to the concrete surface with anchor bolts; (2) force the feed screw into the concrete by plunge cutting until desired depth is reached; (3) feed cutting along the guide track.

The coring equipment similarly consists of a drill stand on which the motor travels via a rack and pinion carriage. With the drill stand attached to the concrete surface, core drilling is performed by plunging the core bit into the concrete along the the drill stand.

The motor which drives the blade and core bit can be either hydraulic, electric, or 400 cycle electric (hi-cycle). Water is generally used to cool the diamond segments and wash away the cut concrete particles.

The diamond segments on the diamond blade and the core bit are designed to wear away and expose new diamonds at the same rate as old diamonds are being consumed.

The concrete cutting process with diamond tipped segments is one of impacting and fracturing, while the steel cutting process is one of penetrating and forming metal chips (see Figs. 3 and 4).

The cutting rate depends on the horse power of the motor, the cutting conditions, such as RPM, diamond segment design, and operator experience.

During the sawing or coring operation, as the operator senses the cutting force via the carriage handle and watches the ammeter, the operator adjusts the feed speed of the carriage and maintains a constant cutting load on the motor. For example, the operator slows down when cutting through reinforcing bars and speeds up when finishing the cutting of the rebar.

4. DISMANTLING PROCESS AND DIMENSION OF CONCRETE BLOCK/CORE

Figure 5 shows the conceptual concrete removal sequence used in sawing and coring the JPDR biological shield.

Stitch drilling, a process of drilling a series of intersecting holes side-by-side, is applied to the circumferential cut 3.5 m in diameter in the biological shield.

Cut concrete blocks and cores are placed in a $1 m^3$ rectangular steel container and carried out from the reactor enclosure after radiation monitoring. The dimensions of the concrete block and core are limited by this container.

5. DESIGN CONDITIONS AND CONCEPT OF THE MACHINE

The essential requirement for the remote control machine is the ability to position the diamond tools on the biological shield concrete and make vertical and horizontal cuttings and core drillings to the structure by remote control. For the design the following specifications are important:

- Workspace requirement(see Fig. 6)
- At least 40 cm deep sawing to cut through from an inside surface 2.7 m in diameter to 3.5 m in diameter
- Requirement of 1 m deep drilling and 1 m long vertical sawing
- Machine width is less than 2.7 m in diameter to be able to go through the biological shield
- Machine weight is less than the payload of the polar crane of the JPDR
- Machine height is under 5 m to be able to suspend the machine from the crane
- Sealed mechanisms to avoid contamination

In addition, as there is an analogy between the process of steel cutting process with diamond tools and grinding wheel applications, using a diamond blade and core drill for cutting steel-lined and/or reinforced concrete requires stability, a large transmission force and high precision of the machine.

The design concept of the machine is as follows:

- A cylindrical geometric manipulator because of its easy implantation in the inner cylindrical shaped wall
- Installation of a roll axis between the sawing unit and the end of the arm to change the blade direction for vertical and horizontal cuts
- Being suspended from a crane, the machine fixes its position by mean of actuating built-in outriggers toward the wall
- To reduce occupational radiation exposure when workers exchange the sawing and coring units, the machine is equipped with these units concurrently.

The geometry of the manipulator is shown in Fig. 7.

6. CUTTING MACHINE

Based on the results of the cutting tests using the prototype cutting machine, the Diamond Sawing/Coring Robot(DSCR) was designed and constructed. The DSCR consists of five main parts: sawing and coring units, a manipulator, a platform, blade/core bit sharpeners, and a control system. Figure 8 and Table 1 show the overview and specifications of the DSCR.

6.1 Sawing and Coring Units

A diamond blade 107 cm in diameter having a capability of 40 cm cutting depth, and a diamond core bit 15 cm in diameter were selected. The core bit is mounted with a 1 m long core tube in order to drill 1 m deep.

Since a hi-cycle motor has the advantages of its power to weight ratio and capability of being automatically controlled, a 15 HP water-cooled motor for sawing and a 7.5 HP motor for coring were selected.

The cooling water is supplied through the drive shaft to the diamond segments.

To reduce mist generation, blade guards cover the blade circumference according to the cutting depth. There is also core bit guard to reduce mist generation and limit the swing of the core bit.

6.2 Manipulator

The sawing unit and the coring unit are attached to the opposite arms of the cylindrical geometric manipulator.

Ball-screws as height and reach axis transmissions are employed. The rotation axis is driven by a Harmonic Drive gear box(HD) via spur gears whose gap is adjusted by a gap adjustment mechanism in order to decrease backlash during the cutting operation. Each axis is actuated by a rotary servo actuator(RSA) which is coupled to a step motor and provides digital open loop servo control. The position and velocity of each axis is measured by an optical shaft encoder.

The roll axis, actuated by a hydraulic vane motor and fixed by mechanical stops at positions 0° and 90°, changes the blade direction for vertical and horizontal cuts.

Sawing and coring forces are continuously monitored by means of load cells installed between the sawing/coring unit and the arm.

The sawing process of this manipulator is done as follows: (1) position the blade at the datum point of the biological shield by the manipulator using an ITV camera mounted on the sawing arm; (2) transfer the blade at desired position; (3) measure the distance between the blade and the wall by actuating the reach axis toward the wall until the plunge force of the blade varies; (4) specify parameters of the sawing program; (5) execution of the program.

6.3 Platform

The base plate of the manipulator is mounted on a platform equipped with outriggers and a horizontal level adjuster.

Three outriggers with an angle at intervals of 120° are actuated by hydraulic cylinders. The stroke of each outrigger is measured with a potentiometer.

The X-axis and the Y-axis of the horizontal level are adjusted by screw jacks. The backlash of each axis is minimized by a hydraulic cylinder. Each axis gradient is measured with a level gauge attached to the platform. The schematic view of the horizontal level adjuster is shown in Fig. 9.

When positioning the platform on the biological shield wall, the platform is rotated to the portion where each outrigger can be fixed firmly. Then the outriggers are actuated toward the wall on condition that the stroke of each outrigger is adjusted equally. Finally, the level of the manipulator is adjusted by the horizontal level adjuster.

6.4 Blade/Core Bit Sharpeners

Since the cutting rate is lowered by damage to the diamond abrasive of the diamond segments, remotely operated blade/core bit sharpeners which remove the damaged diamond abrasive from the surface of the diamond segments are attached to the sawing and coring units.

Figures 10 and 11 are diagrams of the sharpneners. The blade sharpener, an application of a cylindrical grinding machine, consists of a grinding wheel, its motor, a traverse mechanism, and a feed mechanism. The core bit sharpener is an application of a surface grinding system and has a grinding wheel, its motor, and a feed mechanism. The rotational speed of the blade and core bit is lowered by the variable hi-cycle electricity of the inverter. Programmable Controllers provide sequential motion for grinding operation.

6.5 Control System

The control system has a manual operation and a programmed action of the DSCR by remote control.

Each part of the DSCR can be controlled by the operator with push buttons and selector switches while viewing indicators and a display. For example, the operator can move one preselected axis at a time at variable speed and adjust the position of the arm manually.

The main functions of the programmed action are the cutting process control and the point-to-point control.

During the cutting operation, the computer system senses the current being used to cut the concrete and adjusts the forward speed of RSA to maintain a constant cutting load on the motor. Figure 12 shows a schematic diagram of this control system.

Cuts are generally made in a step cut produced by repeating plunge cut and feed cut until the full depth is reached(see Fig. 13). To execute this motion, the following parameters are specified before the motion is to commence.

- Cutting type (sawing/coring, vertical/horizontal, plunge/feed)
- Starting/stopping point
- Control type (cutting process control/feed with constant verocity)

The computer system directs the blade position along a predetermined path.

7. DISMANTLING SYSTEM CONFIGURATION

The dismantling system consists of the DSCR and its peripherals, concrete block/core handling machines, container handling machines, a dust collector, a drainage disposal system, and a monitoring system.

Figure 14 shows the arrangement of the machines and devices for the actual dismantlement. The function of the components is described below:

Since the activated concrete block must be removed safely, the cut concrete handling technique is as important as the cutting technique. The concrete blocks and cores are held by special grippers suspended from a circular crane and drawn away from the cavity and put into a container. They are operated from the on-site console installed on the operating floor and ITV cameras help the operation. This console also provides a very basic control of the DSCR.

After radiation monitoring, the container is carried out from the JPDR by a crane and a lorry.

An inverter supplies 400Hz (hi-cycle) electricity to the sawing and coring motors.

Hydraulic power units drive each axis of the manipulator and outriggers.

A cable and hose lift adjusts the pay-out and pay-in length and tension of the DSCR-connected hydraulic hoses and cables according to the DSCR position.

Mist and dust produced during the cutting operation is sucked from the hood and the air intake opening near the funnel under the cavity and sent to the existing ventilation system through the dust collector equipped with a HEPA filter.

A cooling water supply unit feeds water which is required during sawing/coring operations.

A drainage disposal system separates the used coolant which contains cut small particles into water and slurry.

The control console is installed in the emergency ventilation building of the JPDR.

8. CONCLUDING COMMENTS

Major design features of a biological shield dismantling machine using sawing and coring have been reviewed.

At present, a mock-up test using the DSCR has been executed prior to the actual dismantlement operation in order to confirm the operability of the machines and train workers for the dismantling work.

The technique developed in the JPDR decommissioning program is expected to be applied to future commercial power plant decommissioning.

REFERENCES

1. Ishikawa, M., and Kikuyama, T. 1985, "Decommissioning Plan and Present Status of Technical Development in JPDR," Proceeding of the International Nuclear Reactor Decommissioning Planning Conference, pp.450-468, 1985

2. Yanagihara, S., et al., "Diamond Sawing and Coring Technique for Biological Shield Concrete Dismantlement," Proceeding of the 1987 International Decommissioning Symposium

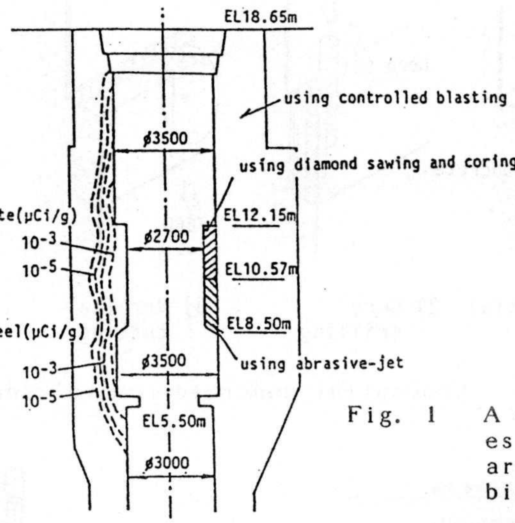

Fig. 1 A cross section and estimated activated area of the JPDR biological shield

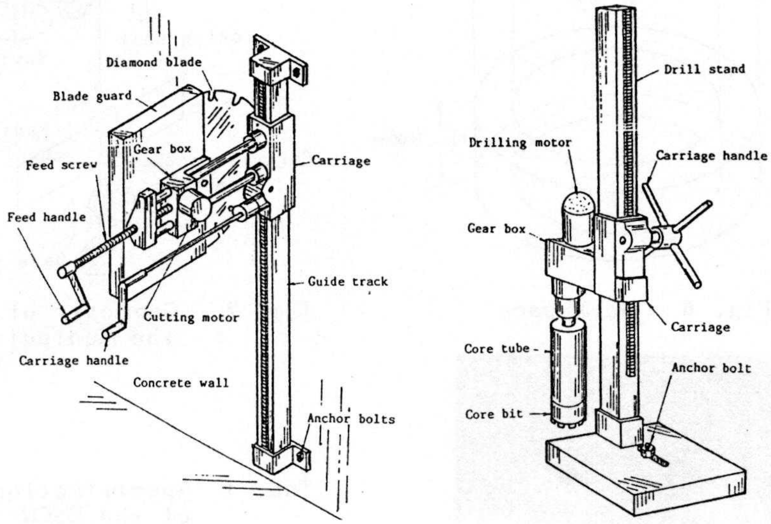

Fig. 2 Diamond sawing and coring in general use

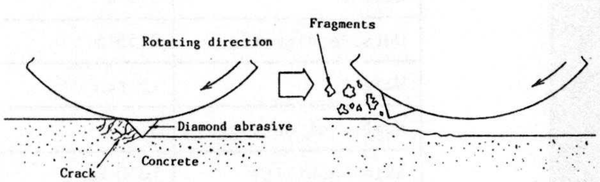

Fig. 3 Cutting process of concrete

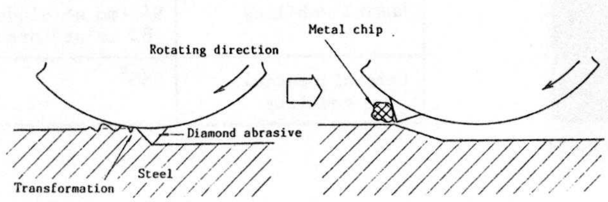

Fig. 4 Cutting process of steel

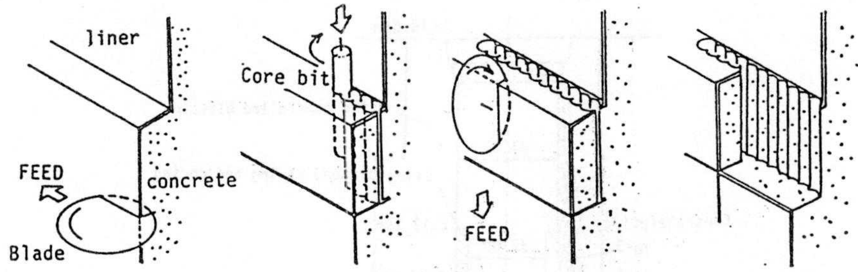

Fig. 5 Conceptial concrete removal sequence

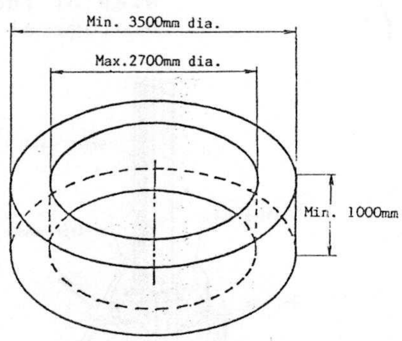

Fig. 6 Workspace

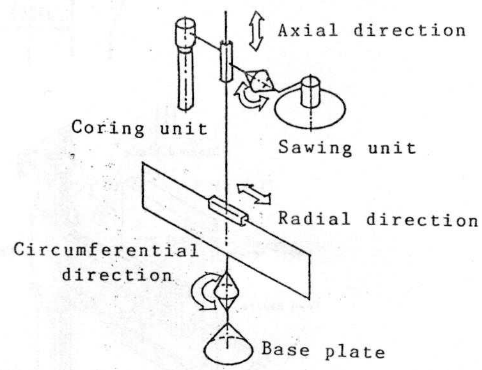

Fig. 7 Geometry of the manipulator

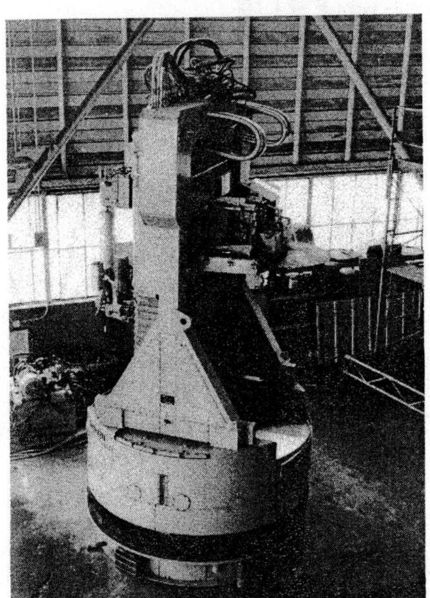

Fig. 8 Overview of the DSCR

Tab. 1 Specifications of the DSCR

Item	Performance
Height	5.0 m
Outside diameter	2.55 m
Weight	15 ton
Number of outriggers	3
Axial mobility	1050 mm
Radial mobility	945 mm at blade side 485 mm at core side
Circumferential mobility	380°

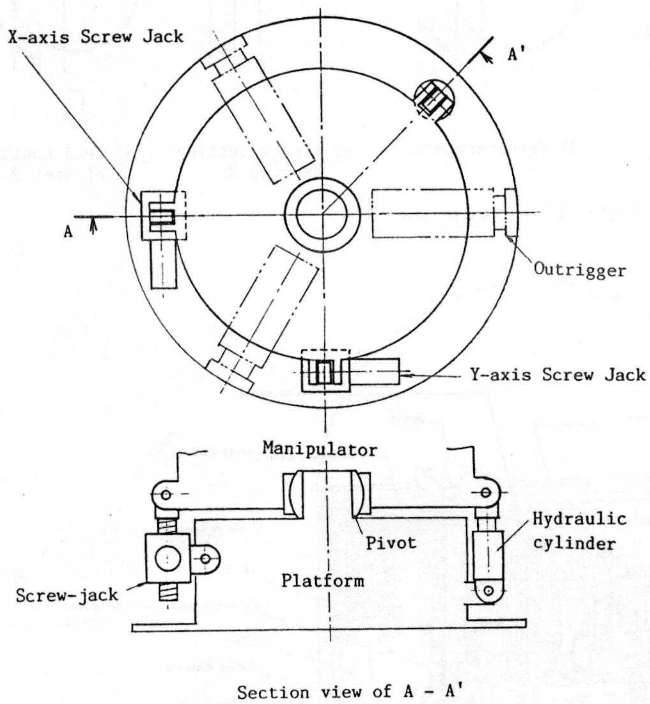

Fig. 9 Configuration of the horizontal level adjuster

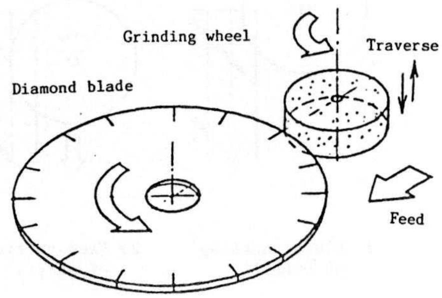

Fig. 10 Blade surface grinding

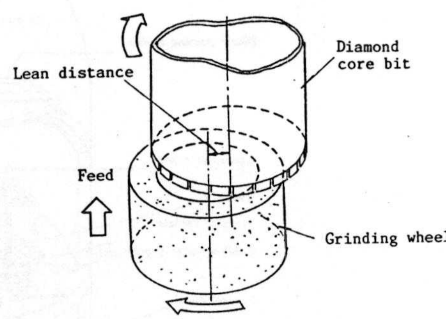

Fig. 11 Core bit surface grinding

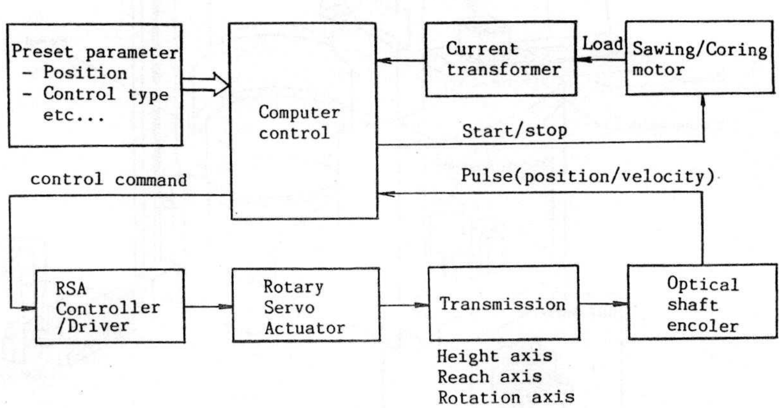

Fig. 12 Cutting process control

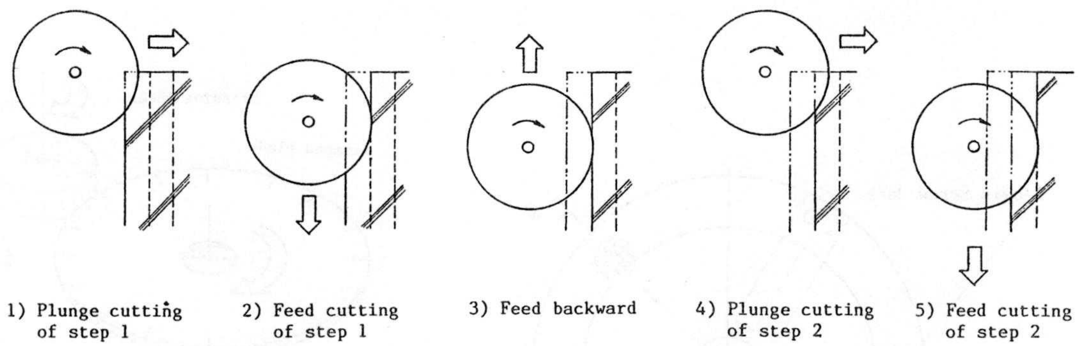

Fig. 13 Step cut

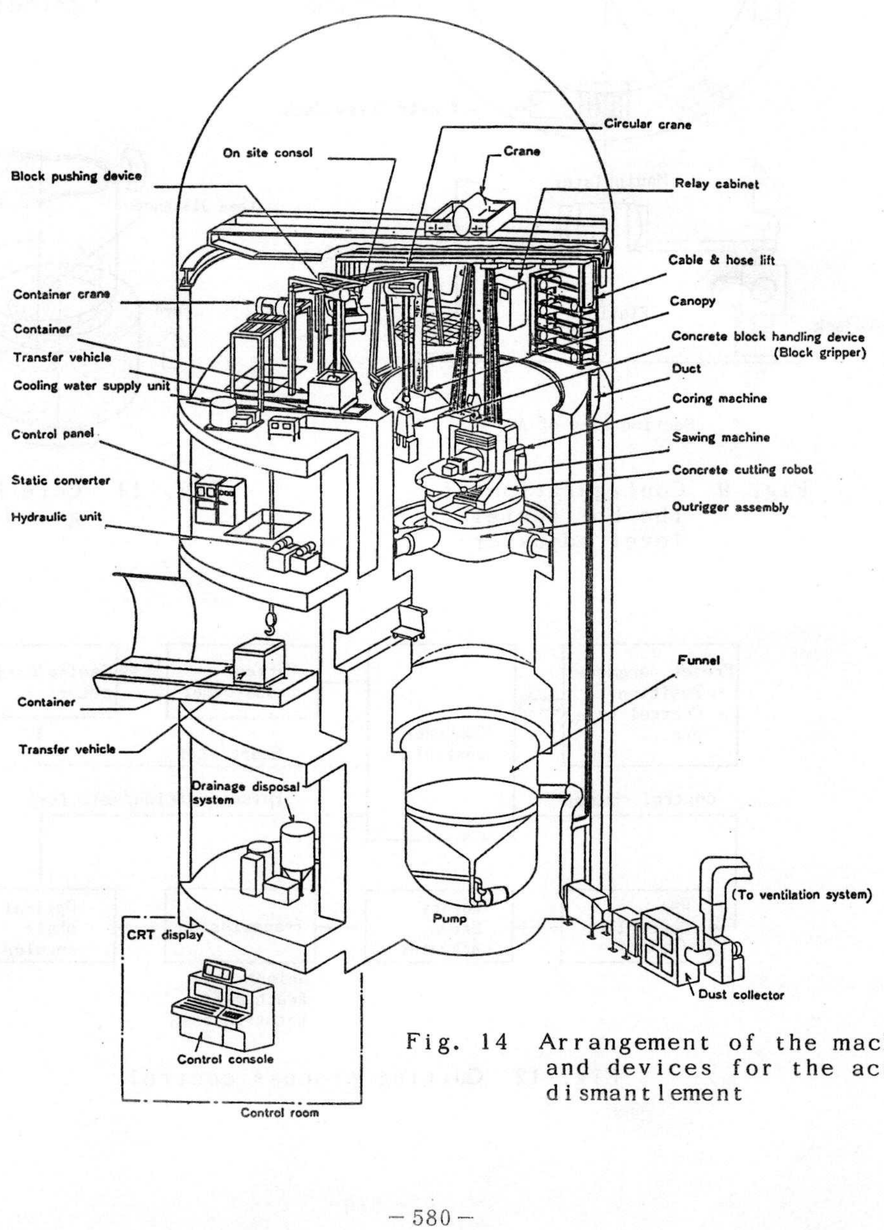

Fig. 14 Arrangement of the machines and devices for the actual dismantlement