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TMI-2 CORE BORING MACHINE[1,2]

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ABSTRACT

An important and essential aspect of the TMI-2 defueling effort is to determine what occurred in the core region during the accident. Remote cameras and probes only portray a portion of the overall picture. What lies beneath the rubble bed and solidified sublayer is, as yet, unknown. This paper discusses the TMI-2 Core Boring Machine, which has been developed to drill into the damaged core of the TMI-2 reactor and extract stratified samples of the core. This machine, its unique support structure, positioning and leveling systems, and specially designed drill bits, combine to provide a unique mechanical system. In addition, the machine is controlled by a microprocessor, which actually controls the drilling operation, allowing relatively inexperienced operators to drill the core samples. A data acquisition system is integral with the controlling system and collects data relative to system conditions and monitored parameters during drilling. Data obtained during the actual drilling operations are collected in a data base which will be used for actual mapping of the core region, identifying materials and stratification levels that are present. Ultimately, this information will be used during the overall defueling of the reactor.

INTRODUCTION

Early examination of the damaged core of the TMI-2 reactor revealed that the central portion of the core had collapsed approximately 5 ft (1.5 m) below its original level, into a bed of loose rubble. Subsequent probing of the rubble bed revealed a solid sublayer some 2 to 3 ft (0.6 to 0.9 m) below the surface of the rubble. This discovery led to a decision that stratified vertical core samples would be required to provide data on what actually occurred during the accident and to aid in subsequent defueling of the reactor.

As a result of this decision, the following set of general requirements were developed for a core stratification sampling system (called the TMI-2 Core Boring Machine):

- The system will be capable of removing a sample approximately 2.5 in. (6.35 cm) in diameter and up to 8 ft (2.4 m) long
- The system will be capable of accessing any position within the central 8-ft (2.4-m) diameter of the core
- The system will utilize the General Public Utilities Nuclear Corp. (GPU Nuclear--owner/operator of TMI) shielded work platform for support over the reactor
- The system will utilize the GPU Nuclear defueling canisters for removing the samples from the reactor
- The system must be made up of modules sized to pass through the containment airlock [3.3 ft (1.0 m) wide x 6.2 ft (1.9 m) high]
- The system will provide data during drilling operations to characterize the material being drilled into four general categories:
  - Standing fuel arrays
  - Loose rubble
  - Solid material
  - Void
- The system design will minimize the number of operating personnel and the required sample acquisition time.

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[2] The official title for this project is the "TMI-2 Core Stratification Sampling System."

BIT DEVELOPMENT

The first order of business was to find a cutting tool which could bore through the anticipated core materials. Best-guess estimates were that the core materials ranged from loose, gravel-like rubble to solid stainless steel to resolidified fuel which could be ceramic-like with very high hardness values.

A series of tests were performed to evaluate various types of cutting tools. Composite samples were devised consisting of simulated partial fuel assemblies including lower endfittings, concrete blocks, gravel of various sizes, and hard-fired alumina plates.

Information obtained from these tests was combined and evaluated, and a version of the Norton-Christensen Chrisdril bit with the configuration of the cutting teeth modified was selected as the cutter most appropriate for the work at TMI-2. Subsequent proof testing showed the bit to be successful in cutting all of the anticipated material configurations. This bit is shown in Fig. 1. The bit has a rounded, cast-matrix crown set with industrial diamonds on the outer and inner surfaces and has cutter inserts made of "Stratapax" material set into the crown with silver solder. "Stratapax" is a tungsten carbide material with synthetic diamond bonded to it and is manufactured by the General Electric Corp.

DRILL UNIT

Once a usable bit had been obtained, efforts were then directed toward selecting a drill unit to drive it. Results of testing the bit had defined the required rotational speed, torque, and weight on bit capacities; the overall system requirements dictated other general requirements such as configuration, spindle size, and load.

A survey was conducted of commercially available drill units meeting all or most of these requirements. Then, based on a thorough tradeoff study, a unit manufactured by the Longyear Corp. was selected. The Longyear 38-EHS drill unit is a compact, self-contained machine. It consists basically of a hydrostatically driven spindle (which applies torque to the drill string) and hydraulic feed cylinders (which apply downward force on the bit during drilling operations). The cylinders also function to move the drill string into and out of the hole. Torque is transmitted to the drill string through a hydraulically actuated chuck which is mounted on the spindle.

The drill unit is equipped with a nonstandard spindle assembly called the Megalo head, which is manufactured by the Japanese subsidiary of the Longyear Corp. The Megalo head spindle and chuck are large enough to permit installation, removal, and

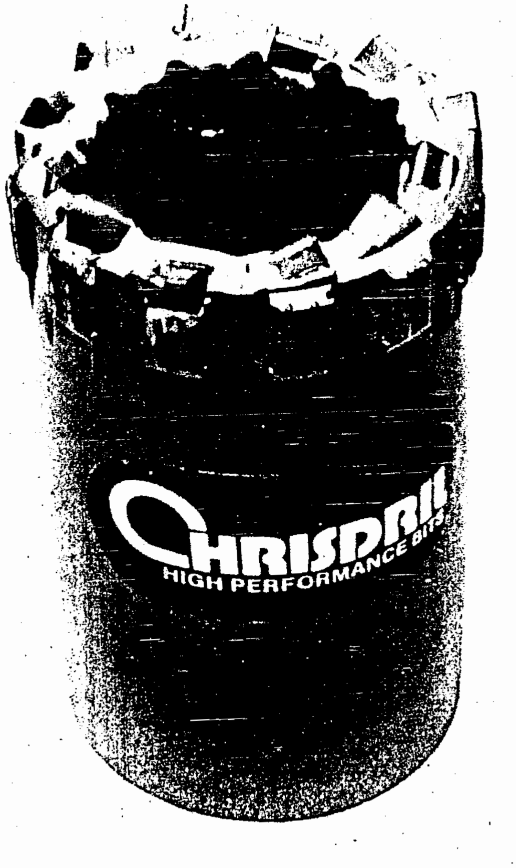

FIG. 1 PHOTOGRAPH OF A NORTON-CHRISTENSEN CHRISDRIL

operation of the large diameter drill string and casing. Different sizes of pipe are accommodated by changing the clamping jaws in the chuck to the required size.

The hydrostatic spindle drive system is powered by a 50-hp (37.3 kW) electric motor through a multi-speed gear system to provide a wide variation in available rotational speed and torque. A separate hydraulic pump, driven by the same electric motor, provides power to the feed cylinders, the spindle chuck, and two separately mounted clamps used in handling the drill and casing strings.

Manual controls for all drilling operations are located within easy reach of an operator standing alongside the drill unit, as is instrumentation to provide visual indication of rotational speed and torque on the drill string and the weight being applied to the drill bit. The machine contains two types of readout instrumentation. The first is the original instrumentation, which comes with every standard drill unit. These consist of gauges indicating weight on bit, rotational pressure, amperage, and rpm. The second is the instrumentation added for this task. These consist of digital displays (LED displays) on the operator's control panel (rpm, torque, weight on bit, depth, coolant flow) and are activated by the system control computer. The LED displays have been accurately calibrated.

The drill unit has a rotational speed range of from 0 to 500 rpm and a torque range of from 0 to 3000 ft-lb (0 to 4067 J). Downward and upward force capabilities are limited to 10,000 lb (4535 kg) each, due to design load considerations for the GPU Nuclear shielded work platform.

The drill unit is also used to make and break the threaded joints of the drill string and casing, using the chuck clamp on the spindle in conjunction with the "A," "B," and underwater clamps (discussed later).

DRILL UNIT SUPPORTING EQUIPMENT

The drill unit assembly is a complex combination of subassemblies and supporting structures. The following discussion describes these pieces of equipment, as well as their individual and collective functions. Fig. 2 provides an elevation view of the drill unit with its supporting structures and equipment.

Drill and Casing Strings

The drill and casing strings consist of a core barrel assembly, the drill string necessary to reach the desired sample depth, and casing to provide stability to the drill string during drilling operations. The casing also maintains a clear hole for video camera inspection of the lower reactor area once the core barrel and sample have been removed.

The core barrel, which is a standard commercial design, functions to contain and protect the core sample, support the drill bit, transmit drilling forces, and channel flush water through the bit. A double-tube core barrel is used, permitting the inner tube to remain stationary around the core sample while the outside tube rotates the bit. This requires a swivel mechanism built into the top of the core barrel. A vent with a check valve allows water to escape as it is displaced by the core sample. The overall length of the core barrel including the bit is 132 in. (3.35 m) to ensure the assembly will fit inside the defueling canister.

Drilling will be done with an essentially standard commercial drill string and casing, 3.5- and 4.5-in. (8.9- and 11.4-cm) outside diameter, respectively. However, some nonstandard lengths of drill string and casing are required, and the casing threads have been slightly modified to facilitate the breaking of joints in the proper locations. Since the casing inside diameter is 4 in. (10.2 cm) and the drill string outside diameter is 3.5 in. (8.9 cm), spacing bars are welded to the outer surface of two sections of drill string. These act as guides or bushings to keep the casing and drill string concentric during drilling operations.

During drilling operations, borated water at flow rates up to 6 gpm (3.78×10^{-4} m^3/s) are required to provide cooling to the bit and flushing of drill fines. Clean borated water will be used to rinse the drill string and casing during their removal from the reactor for decontamination purposes. Coolant water will be provided by a standard, positive displacement pump. The suction for the pump will be taken directly from the reactor vessel for drilling purposes and from flush water supply tanks for rinsing of the drill string and casing. These tanks are stainless steel 55-gal drums, modified to provide inlet and outlet fittings and level control switches. These switches control high- and low-level indicator lamps on the drill unit control panel. Borated water for the supply tanks will be provided by the TMI borated water make-up system.

Drill Unit Support Structures

The drill unit support system, consisting of the interface platform, drill indexing platform, indexing roller platform, tilt platform, and underwater stabilizing structure, is mounted on the GPU Nuclear shielded work platform as shown in Fig. 2. This shielded platform is a structure mounted on the reactor vessel flange for use in defueling operations. It has a circular platform which can be rotated in a horizontal plane about the vertical reactor centerline. A radial slot 18 in. (46 cm) wide is provided in the rotating platform to allow access to the reactor internals for defueling.

Secured to the defueling platform is an interface platform which was designed to ensure compatibility between the drilling equipment and the shielded work platform.

The interface platform supports the drill indexing platform through slide bearings which permit approximately 2 in. (5 cm) of side-to-side and front-to-back movement between the two structures. This is accomplished through the use of jacking bolts and provides for fine adjustment of the drill unit over the designated sampling locations. In addition to supporting other structures, the drill indexing platform provides a work platform for the drill operating personnel.

The drill indexing platform supports the indexing roller platform which enables the drill unit to be moved radially some 4 ft (1.22 m) outward from the reactor centerline. This radial movement, plus the rotational capability of the shielded work platform, permits access to the required sampling locations in the reactor core. The roller platform is

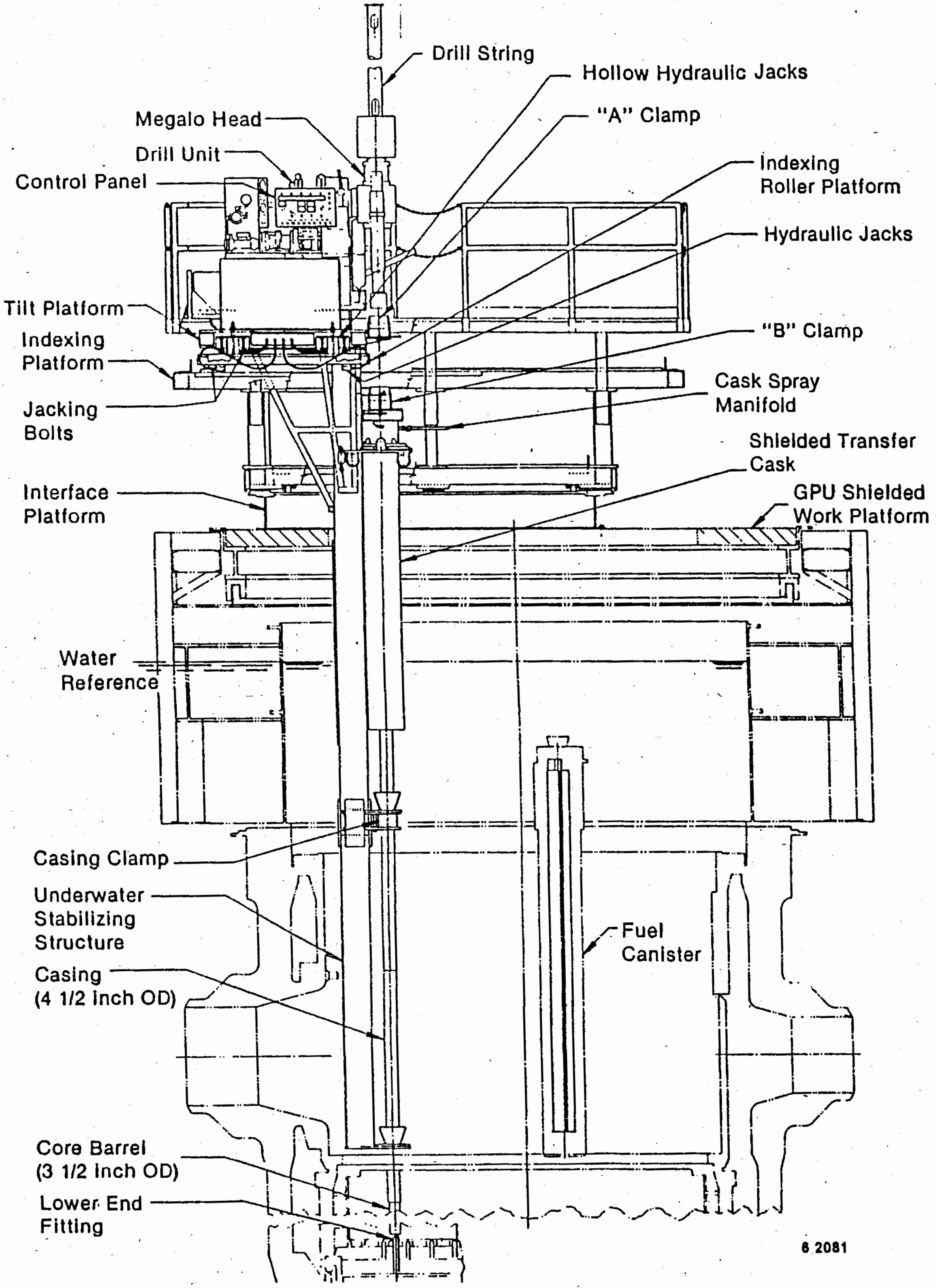

FIG. 2 ELEVATION VIEW OF THE DRILL UNIT WITH ITS SUPPORTING STRUCTURES AND EQUIPMENT

Prior to this effort, use of this type of drilling unit and cutting tools were confined primarily to acquisition of stratified earth samples, drilling of water wells, and use in the mining industry. In these applications, high precision is not normally required and manual controls are adequate. However, characterizing the stratified layers of core debris at TMI-2 requires that the drilling unit be equipped with a microprocessor for process control. The process control instrumentation provides automatic control for rotational speed, torque, weight on bit, and adjustable torque setpoint for the making and breaking of the drill string and casing joints. Fig. 3 is a plot showing some of the parameters monitored during an actual drilling operation.

During operations, the microprocessor provides for the safety of operating personnel and the drilling equipment itself in the following areas:

- Water pressure to the drill bit is monitored, and an automatic shutdown is provided if the pressure exceeds 490 psi (3.38 MPa). This safety feature provides protection against overpressurization of the coolant hose. To further ensure safety, a mechanical relief valve has been provided as a backup.

- Water flow to the drill bit is monitored and an automatic shutdown is provided if the coolant flow to the bit drops below 2 gpm (1.26×10^{-4} m^3/s). This ensures both adequate cooling and removal of drill fines from the cutting area.

- Opening and closing of the foot clamps ("A" and "B" clamps) and the chuck clamp are monitored and controlled to prevent inadvertent dropping of the drill string and/or casing into the reactor vessel or twisting of the drill string during operations.

- The volume of fluid in the hydraulic system reservoir is monitored by the computer. The computer automatically shuts down the drill unit if a leak develops or a hose bursts and if it detects a loss equivalent to one-half gallon of fluid. The system is thus protected against loss of fluid due to a leak or hose burst.

- The temperature of the hydraulic fluid is monitored, and an automatic shutdown occurs if the temperature exceeds 150°F (65°C).

The data acquisition system provides information for postdrilling determination of stratification of the core region, the relative "drillability" of materials located there, the elevation of the layers (relative to reactor vessel internals), and the thickness of the layers. This information is obtained from a data base developed during thorough testing of the drilling system prior to delivery to TMI. During operations, nearly every function provided by the drill unit is monitored and the data are stored on a hard disk within the computer cabinet. The data are transferred to a tape, and the information on the tape is reduced and plotted for later analysis. The parameters monitored by the data acquisition system include the following:

- Real time (clock)
- Rotational speed of the bit (RPM)
- Weight on bit (WOB)
- Torque applied to the bit
- Drilling location (hole number)
- Gear selected
- Elevation monitoring of the bit within 0.002 in (5×10^{-2} mm).
- Bit coolant water pressure
- Bit coolant water flow rate
- Status of 16 functions, including foot clamp and chuck clamp position, and all switch positions during the course of operations.

These monitored parameters are updated once per second, providing an accurate accounting of any situation concerning the drill unit at any particular time.

SAMPLING OPERATIONS

A typical sampling operation proceeds as follows:

1. The drill unit is positioned (using a computer-linked theodolite system) over the desired sampling location.

2. Casing is installed with the casing bit just above the drill target surface, and the upper end is supported in the "B" clamp. Casing sections above the "B" clamp are removed.

3. The core barrel and associated drill string are installed, and drilling is begun.

4. Drilling is stopped when the lower fuel assembly endfitting has been penetrated.

5. The drill string is allowed to rest on the lower grid distributor plate, and the upper end is temporarily plugged.

6. The upper casing sections are installed, and the casing string is drilled down around the drill string to the upper surface of the endfitting.

7. The casing string is clamped in the casing (underwater) clamp, and the sections above the clamp are removed.

8. The drill string is raised until the core barrel is inside the shielded transfer cask with the upper end clamped in the "B" clamp. The upper sections of drill tube are removed.

9. The cask is moved to a position over the fuel canister, and the core barrel is lowered into the canister using a crane.

10. If required at this sample location, a video camera is lowered into the casing to inspect the area below the fuel assembly endfitting.

11. If required at this sample location, a smaller core barrel is installed, and a sample is obtained below the endfitting and transferred to the canister in a similar manner.

12. If required, a plug is installed in the hole drilled in the endfitting.

13. The casing string is recovered from the reactor, and the lower 11-ft (3.35-m) section transferred to the canister for disposal.

SUMMARY

The TMI-2 Core Boring Machine is a complex assembly of mechanical, electrical, and electronic hardware. By using this machine and the operating procedures developed especially for TMI Unit 2, it is intended to discover, for the first time since the TMI accident, the extent of damage to the core of the reactor. And more important, it will be possible to determine the process of damage by acquiring data and examining samples.