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ROBOTICS AND REMOTE HANDLING CONCEPTS FOR DISPOSAL OF HIGH-LEVEL NUCLEAR WASTE

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ABSTRACT

This paper summarizes preliminary remote handling and robotic concepts being developed as part of the US Department of Energy's (DOE) Yucca Mountain Project. The DOE is currently evaluating the Yucca Mountain Nevada site for suitability as a possible underground geologic repository for the disposal of high level nuclear waste. The current advanced conceptual design calls for the disposal of more than 12,000 high level nuclear waste packages within a 225 km underground network of tunnels and emplacement drifts. Many of the waste packages may weigh as much as 66 tonnes and measure 1.8 m in diameter and 5.6 m long. The waste packages will emit significant levels of radiation and heat. Therefore, remote handling is a cornerstone of the repository design and operating concepts.

This paper discusses potential applications areas for robotics and remote handling technologies within the subsurface repository. It also summarizes the findings of a preliminary technology survey which reviewed available robotic and remote handling technologies developed within the nuclear, mining, rail and industrial robotics and automation industries, and at national laboratories, universities, and related research institutions and government agencies.

I. INTRODUCTION

In 1982, with the passage of the Nuclear Waste Policy Act, the US Congress designated that the Department of Energy (DOE) investigate and design a mined geologic disposal system (MGDS) to dispose of the nation's spent nuclear fuel (SNF) and high level nuclear waste (HLW). With subsequent passage of the Nuclear Waste Policy Amendments Act in 1987, Congress ordered that the investigation and site characterization activities should focus exclusively on Yucca Mountain, Nevada, as a potential site for constructing the repository. In parallel with the site characterization efforts now underway, engineers are developing conceptual and preliminary designs of what the repository might look like should the Yucca Mountain site be found suitable for construction[1]. These preliminary design efforts are required to obtain the necessary construction and operating licenses from the Nuclear Regulatory Commission (NRC).

Current Yucca Mountain Repository concepts are based on an extensive underground network of access tunnels and emplacement drifts beneath Yucca Mountain (Figure 1). A waste handling and packaging facility, located near the repository's north ramp entrance, would process casks of SNF and HLW that would arrive by rail or truck from nuclear power plants and DOE facilities around the country. The SNF and HLW would be unloaded and placed in high integrity waste packages that will provide long-term waste containment.

The waste package design for long term disposal continues to evolve. Depending on the type of waste to be disposed, the waste packages will range in diameter, length and weight. At present, concepts for the largest waste packages provide for 21 assemblies of SNF from Pressurized Water Reactors (PWR) to be contained in a disposal container measuring approximately 1.8 meters in diameter and 5.6 meters in length and weighing about 66 tonnes. After emplacement the waste packages would lay horizontally within the drifts and would be spaced about 17 meters center to center.

This paper reviews robotic and remote system design concepts developed for consideration during two main phases of the project, namely, Emplacement and Performance Confirmation[2]. The Emplacement Phase encompasses about 24 years of activities related to moving waste packages from the surface waste handling facility into the subsurface emplacement drifts. Performance Confirmation is a program of baseline data acquisition and ongoing monitoring that ensures assumptions made during the repository licensing process are correct and confirms that the repository system is

performing as it was intended at the time of licensing. The Performance Confirmation period will last for 100 years after the start of Emplacement.

II. REPOSITORY ENVIRONMENT

One of the most important reasons for using robotic and remote systems technology in the underground repository is to minimize radiation exposure and safety risks to operating personnel. Radiation dose rates near emplaced waste packages may reach 28 REM/hour[1]. At these rates, workers would quickly exceed annual occupational dose limits. For this reason, the emplacement drifts, as they become filled with waste packages, will become highly restricted areas that are off-limits to humans. Emplacements drifts will comprise approximately 95% of the overall subsurface area.

Elevated temperatures are another harsh condition to be dealt with in the subsurface repository. Of primary concern are the ambient operating temperatures that will be encountered near the waste packages. Thermal models indicate that waste package surface temperatures during emplacement activities will be approximately 70 °C. During the emplacement process, ambient conditions for the emplacement drifts would be maintained by actively ventilating the drifts so that air temperatures would be kept below 50 °C.

After an emplacement drift is loaded with waste packages, the drift isolation doors will be closed and the drift will remain essentially unventilated during the 100 year Performance Confirmation period. Design assumptions call for drift temperatures not to exceed 200 °C. Thermal models indicate that during the Performance Confirmation phase the drift wall (i.e. host-rock) temperatures would peak in the range of 153 to 183 °C. The elevated drift temperatures could be cooled by active ventilation; however, due to concerns over the affects of thermal cycling, this will be avoided except in off-normal situations.

The fact that the proposed repository would be built underground imposes certain physical constraints on remote handling and robotic systems developed for use on this project because these systems would need to operate within relatively confined spaces. The network of horizontal emplacement drifts will be excavated by Tunnel Boring Machines (TBM). The drifts will primarily have a circular cross-section. The emplacement drifts will be approximately 5 meters in diameter and average about 600 meters in length. At the entrance to each emplacement drift there will be a radial bend that will obstruct a direct line of sight into the drift. In total, there are to be over 180 kilometers of emplacement drifts excavated within the mountain.

III. TECHNOLOGY SURVEY

A preliminary technology survey was conducted as part of the conceptual design effort. The survey reviewed state-of-the-art remote handling and robotics technologies in the nuclear, aerospace, mining, railroad, and industrial automation industries. The survey examined robotics research programs at the DOE, NASA, leading universities and various research institutions.

The technology survey focused on areas such as: automated rail-based transportation systems; robotics, remote systems and remotely operated vehicles for hazardous environments; and design of electronics, sensors and components for use in high radiation and elevated thermal environments.

Several mobile vehicle control and communication technologies were reviewed including: direct radio control[3], leaky feeder, microwave[4], slotted microwave waveguides, laser/optical systems, infrared transmission systems, slip-contact conductor bar systems and motorized tether systems. Likewise several mobile power source technologies were also investigated including: battery systems, conductor bars, trolley cables, energized third-rail systems, and tethered power delivery systems.

IV. WASTE EMPLACEMENT CONCEPT

A preliminary concept-of-operations has been developed for the nuclear waste package emplacement process (Figure 2). Central to the emplacement concept is the use of remote systems and remotely operated equipment. By focusing on existing, well understood and relatively mature technologies, a fairly simple monitoring and control system will be devised that will enable remote control of the emplacement equipment (Figure 3). Critical emplacement operations will be remotely monitored, supervised, and controlled by operators located at a central operator control station. This will be accomplished via a local area network and fiber optic backbone connected to a subsurface network of computer workstations, programmable logic controllers, and wireless communications links to mobile equipment.

In current design concepts, remotely operated mechanisms would be used in the Waste Handling Building to load the highly radioactive, thermally hot waste packages into a shielded railcar called the Waste Package Transporter. As shown in Figure 2, trolley powered locomotives would be used to haul the Transporter and waste package into the subsurface repository. Transporter shielding will allow for human operators to be in the cab of the locomotive which can be either manually or remotely controlled.

Before the emplacement drift isolation doors and Transporter doors are opened all personnel will be required to evacuate the immediate area. After the doors are opened, the Transporter would be backed into the entrance of the emplacement drift. This docking procedure would be performed by operators at the central control station. The waste package would then be unloaded from the Transporter into the emplacement drift by remotely operated transfer mechanisms. At this point, a remotely operated Emplacement Gantry, previously loaded into the emplacement drift, would pickup the waste package, transport it along the emplacement drift, and set it on a pre-installed pedestal.

V. EMPLACEMENT GANTRY SYSTEM

One of the interesting design challenges will be to develop the remotely operated, mobile, heavy-lift Emplacement Gantry system. Early conceptual designs are underway (Figure 4). The Emplacement Gantry would need to lift waste packages weighing as much as 66 tonnes, reliably operate in a high radiation environment, and in local thermal conditions as high as 50 °C.

Emplacement Gantry subsystems being con-ceptually designed are: controls, communications, power source, locomotion, actuators and sensors. Initial technology evaluations have been performed based on design criteria such as: functionality, reliability, maintainability, life-cycle costs, personnel safety, proven design history and maturity, technology commercial availability, survivability, installation and alignment complexity, and amount of design customization required. The functions such as raising and lowering the waste package will be controlled by on-board redundant programmable logic controllers (PLC's).

Leading candidates being considered for remote mobile communications include: direct radio control, leaky feeder and slotted microwave waveguide technologies. Leaky feeder technology is currently used in mining applications for transmission of video, data, and voice signals to remote control stations. Slotted microwave waveguide technology is used in the mass transit field for communication and control of operatorless trains and trams.

The leading candidates for the mobile power source are: conductor bars, trolley cables and battery systems. One of the advantages of conductor bar and trolley cable technologies is that they can operate at elevated temperatures. Batteries add significant weight to the mobile equipment and are typically not well suited for operation in elevated temperatures.

VI. PERFORMANCE CONFIRMATION

Following emplacement there will be a 100 year period of Performance Confirmation to ensure that the mined geologic disposal system (i.e. the repository, structures and systems) is performing as anticipated and designed. Remotely operated systems and teleoperated vehicles will play key roles in monitoring and inspecting the emplacement drifts and waste packages during Performance Confirmation. In-drift app-lications may include: remote visual inspection, thermal mapping, radiological inspections, light-duty remote manipulation, sample-test-coupon retrieval, environ-mental monitoring, and response to off-normal situations.

Several conceptual designs are being considered for Performance Confirmation. Concepts range from rail-based inspection gantries to mini-rover inspection systems and overhead mono-rail inspection systems. These mobile inspection systems would serve as multi-purpose platforms on to which several different types of instruments, sensors, manipulators, and tools would be mounted.

VII. DESIGN ISSUES

A. Elevated Temperatures

Preliminary calculations indicate that temperatures inside the emplacement drifts during Performance Confirmation may reach almost 200 °C. Developing remote systems that can, at least for limited periods of time, withstand these extreme thermal conditions will be a significant design challenge.

Several design strategies and technologies exist that should enable the development of high temperature remotely operated vehicles (ROV's). There are a number of industries, including the nuclear, aerospace, automotive, and oil and gas industries that have developed electronic components and instrumentation that can operate in elevated thermal environments in excess of 150 °C. In designing thermal control systems for remotely operated systems, the basic design philosophy is to keep external heat out and to minimize and dissipate heat internally generated.

For much of the design, it will not be difficult to select appropriate mechanical components (gears, bearings, etc.) and structural materials that are suitable for limited duty use at elevated temperatures. A key area of concern, however, is the use of on-board electronics and actuators which may be sensitive to the temperature ranges expected. Typically, commercial grade electronics and components have maximum operating temperatures in the range of 50 to 85 °C. If available, military grade (i.e. MIL-SPEC) electronic components are often rated for operating environments in the range of 75 to 110 °C[5]. Electromagnetic actuators typically become less efficient as temperatures increase, requiring more power to do less work, the increased power consumption in-turn increases the internal heat generated.

Beyond selecting the most suitable electronic components, there are several design strategies and technologies that may enable the use of ROV technologies inside the emplacement drifts during Performance Confirmation. These include: limiting time of exposure, thermal insulation (heat rejection) technologies, active and passive cooling systems, using thermally robust power and communication systems, limiting the duty cycle of power intensive systems, using low power electronics and components, using heat tolerant electronics and hardware, and prudent design layout.

B. High Radiation

With maximum radiation dose rates reaching 28 REM/hour, the radiation levels inside in the emplacement drifts will be high enough to make human entry impractical, however, existing design strategies and technologies are currently available, and adequately demonstrated, for minimizing the effects of radiation on remote systems at the levels anticipated. Neutron and Gamma shielding materials and radiation-hardened components and technologies exist that can protect sensitive components from the radiation levels expected.

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REFERENCES

[1] CRWMS M&O, "*Mined Geologic Disposal System Advanced Conceptual Design Report*", DI# B00000000-01717-5705-00027 Rev 00. Volumes I to IV, Dept. of Energy, Civilian Radioactive Waste Management System, Management & Operating Contractor (1996).

[2] CRWMS M&O, "*Subsurface Repository Remote Handling & Robotics Evaluation Report*", DI# BC0000000-01717-5705-00016, Rev. 00, Dept. of Energy, Civilian Radioactive Waste Management System, Management & Operating Contractor (1995).

[3] Crutcher, R.I., Moore, M.R., "*An RF Communi-cations System for the West Valley Transfer Cart*", Proceedings of the ANS Fifth Topical Meeting on Robotics and Remote Systems, Vol II, pg 569-576, ANS, La Grange Park, Ill. (1995).

[4] Smith, S.F., Bible, D.W., Crutcher, R.I., et.al., "*Radiation-Hardened Microwave Communications System*", Proceedings of the ANS Fifth Topical Meeting on Robotics and Remote Systems, Vol II, pg 577-584, ANS, La Grange Park, Ill. (1995).

[5] Dorf, R.C, "*The Electrical Engineering Handbook*", CRC Press, ISBN 0-8493-0185-8 (1993).

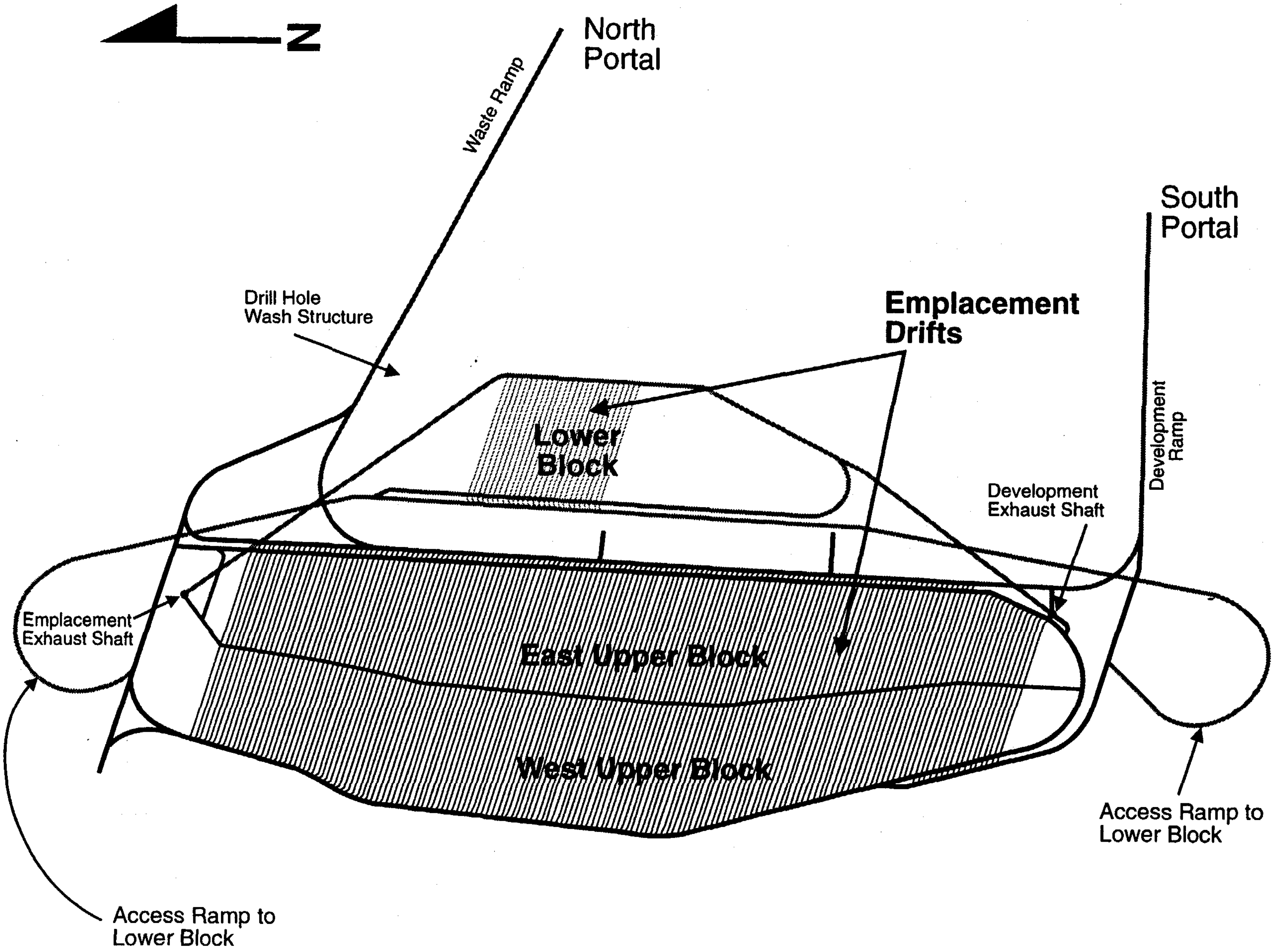

Figure 1. Subsurface Repository Drift Layout

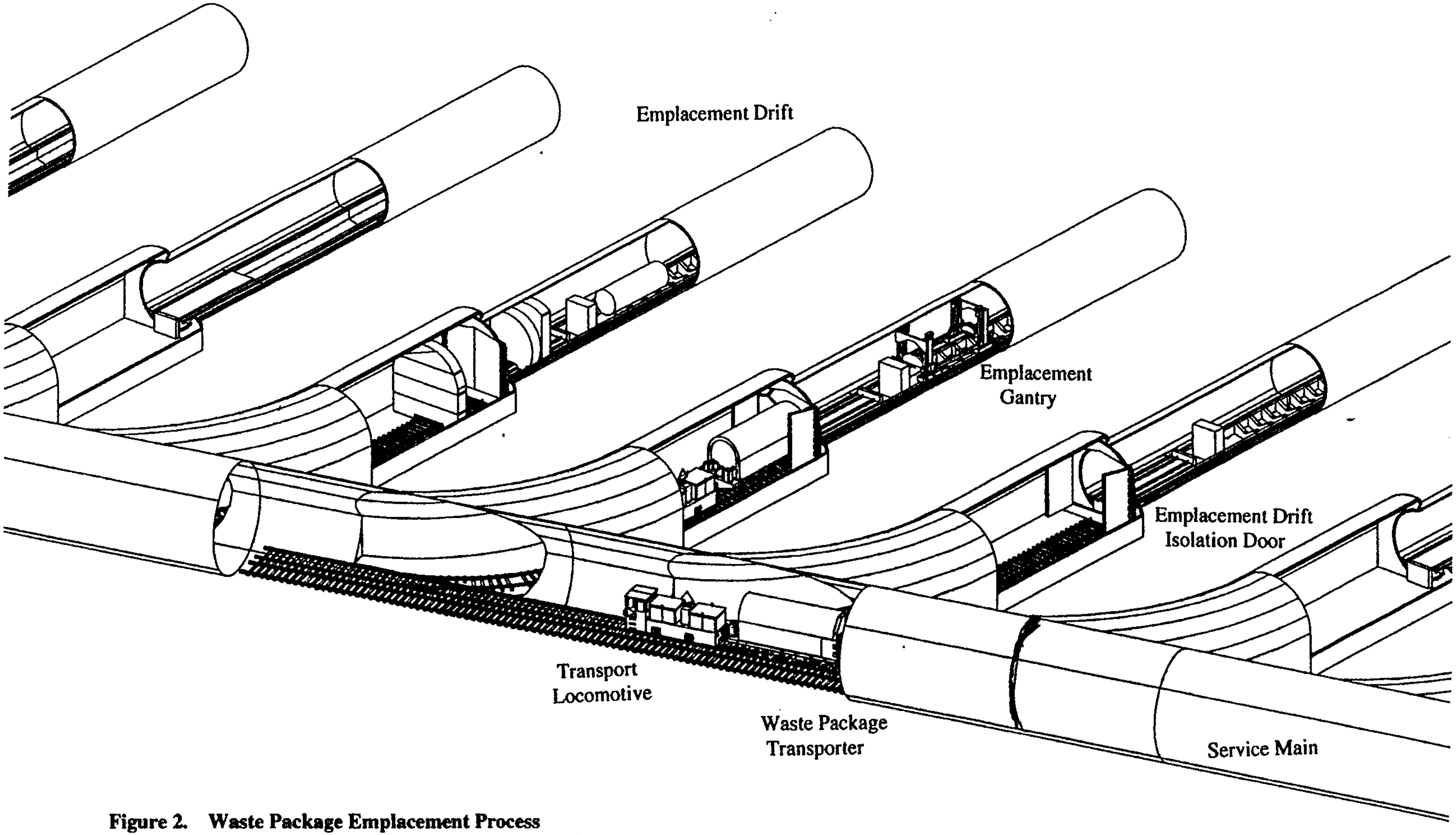

Figure 2. Waste Package Emplacement Process

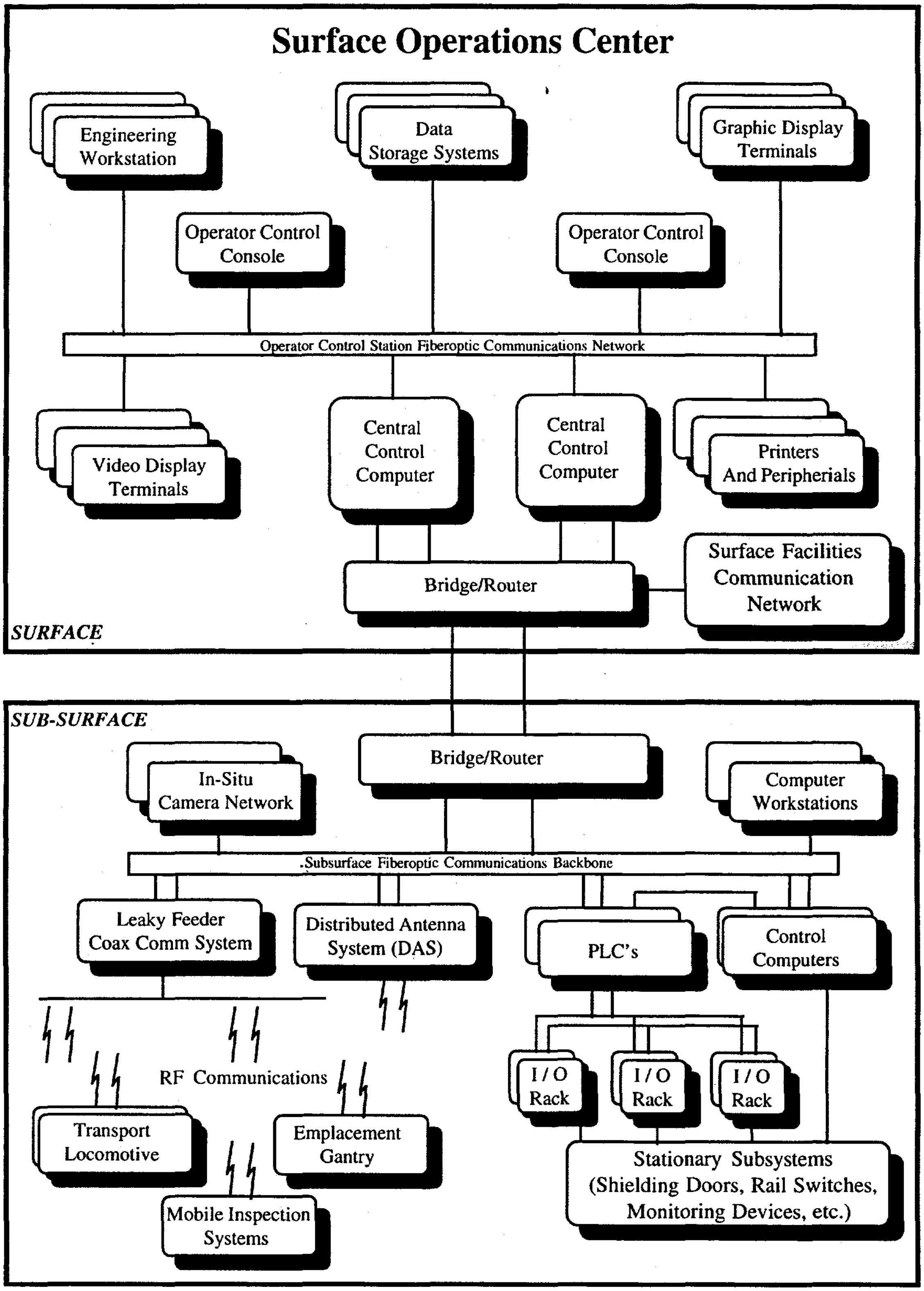

Figure 3. Subsurface Repository Control Systems

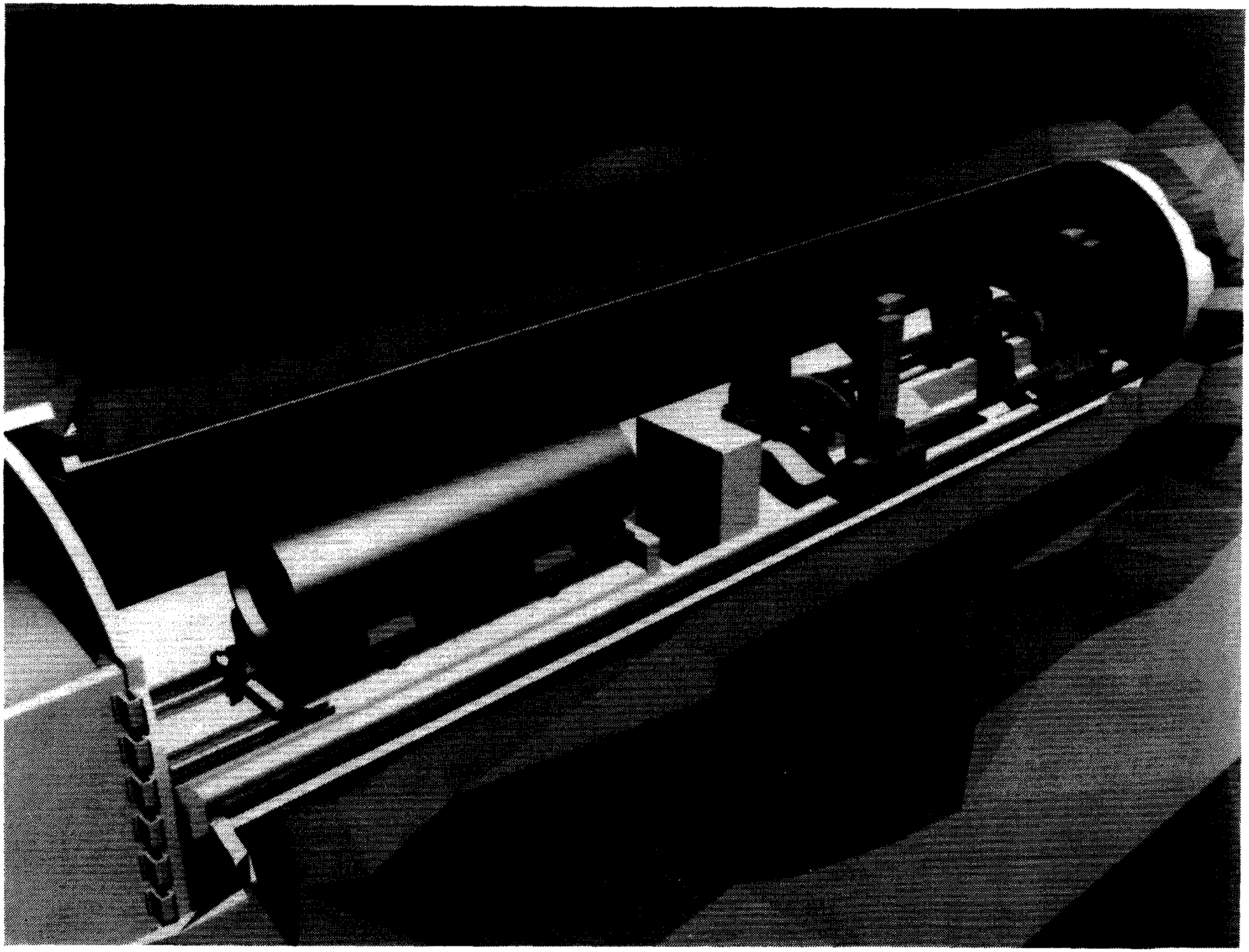

Figure 4. Emplacement Gantry