MANNED GROUND SUPPORT EQUIPMENT

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I shall describe a new remote-handling tool, the shielded cab vehicle with manipulators, known as the "Beetle," outline the need for such a tool, and list its planned uses.

The shielded cab vehicle with manipulators is a completely self-contained, manned, mobile, remote-handling station. It is a mobile mount for two manipulators and environmental protection for their operator. It consists of a shielded cab mounted on a track-laying chassis. The cab has two manipulators mounted on it. The cab is capable of rotating 420° with respect to the chassis and may be elevated fifteen feet from its lowest position.

ENVIRONMENTAL CONDITIONS

The shielded cab vehicle with manipulators has been designed and built for use in all kinds of weather including a temperature range of -30°F to 120°F, a humidity range of near zero to 100%, as well as conditions of dust, rain, and ice. Materials, components, lubricants, and design were selected and tested to meet these requirements.

CAB

The cab is large enough for one man and is shielded all over with the equivalent of twelve inches of lead. It contains five windows, each twenty-two inches thick, of high-leaded glass. The shielding of the cab permits the operator to approach a "hot" power plant with safety. The outside cover glass on each window is equipped with an electrical conductive coating that warms the glass to prevent ice, snow, and water from adhering. The cab contains all of the controls for the vehicle, the manipulators, and the rotation and elevation of the cab.

Air conditioning is supplied to the cab by a unit which provides cool or warm air and controlled humidity. All air to the cab is filtered through a high-efficiency filter. Emergency air is stored in the cab.

Two means of communication are provided: a two-way radio and a public address system unit, which is also used as a warning siren.

Mounted on the rear of the cab is a pod containing a 110-horsepower gasoline engine, 40 KW generator, hydraulic pump, valves, tank, battery, controls, fire control system, air conditioner, gamma-radiation recording equipment, and manipulator controls.

Mounted in the cab is a radiation-level monitor system with visual indication and audible alarms and chart recorder, with intensity range from zero to 1000 Mr/Hr. There is also mounted outside the cab a radiation-level monitor, with intensity range from zero to 100,000 R/Hr. This monitor system may be read inside the cab.

An air-sampling system for monitoring the entering air is provided in the cab.

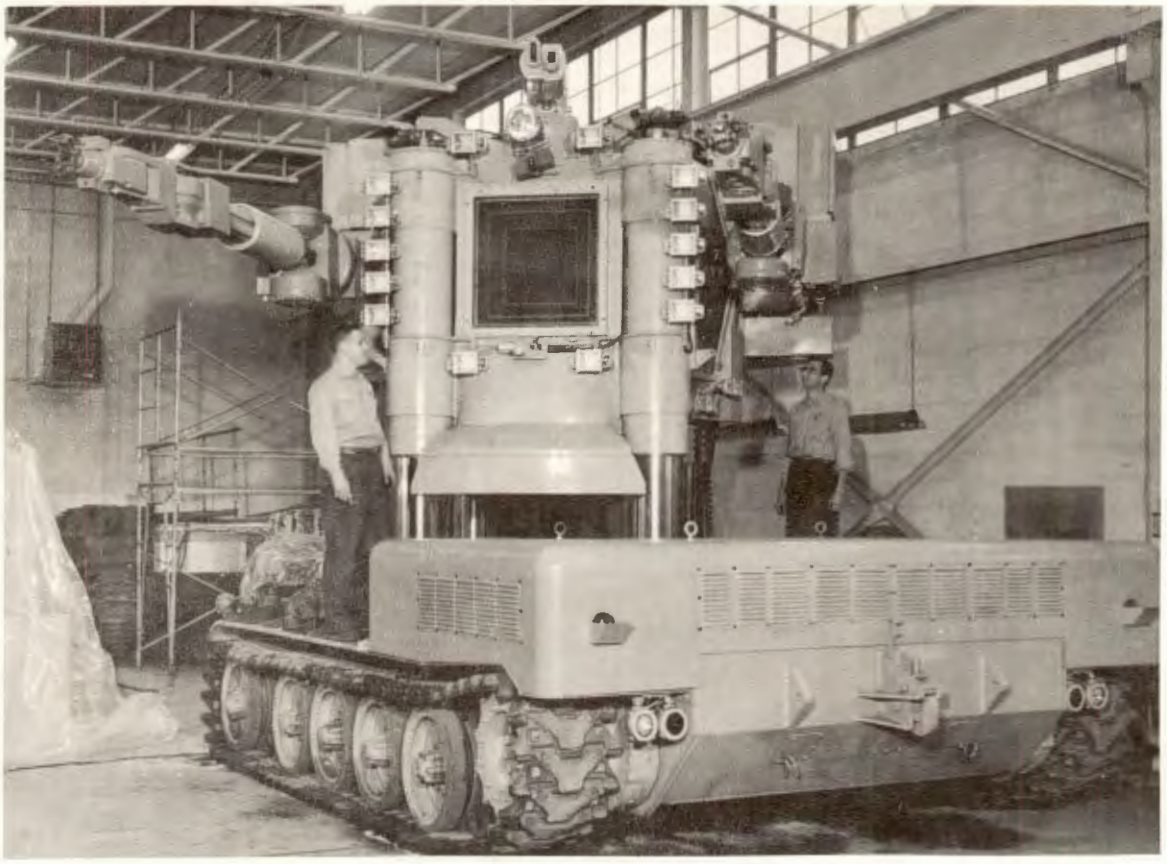


Figure 1. Beetle, Cab Slightly Raised (Front End View)

VIEWING

Excellent viewing has been provided, utilizing shielded windows for close-up direct viewing, a periscope for color differentiation and observation of fine detail magnified, and closed-circuit TV for inspection inside small openings and for observation of otherwise inaccessible areas.

The shielded windows provide practically as good overall viewing as a modern automobile with the exception of rear vision. They were designed and built by Corning Glass Works.

The periscope has 1.5 and 6 magnification with range of vertical scan almost straight up and straight down ($\pm 80^{\circ}$). The azimuth range is 230°. All periscope motions, including azimuth, elevation, magnification, focus, etc., are remotely operated from controls inside the cab. The periscope is provided with thermostatically controlled heated head windows to insure clear vision under unfavorable climatic conditions such as sub-zero temperatures or desert sun. Provision has been made to mount a camera on the periscope inside the cab to allow for excellent photography of "hot" nuclear power plant parts, components, and assemblies. The periscope was designed and built by the Kollmorgen Optical Corporation.

Three camera locations are provided for the closed-circuit TV. One camera is mounted on each aft corner of the cab, facing aft, and the third camera is flexible and may be held by either manipulator hand and moved to any point within range of the hand. The TV monitor and controls for the cameras are inside the cab.

MANIPULATORS

Two highly versatile, heavy-duty, electro-mechanical manipulators and supporting booms are mounted on the cab (one on either side). These manipulators and booms were designed and manufactured by General Mills to General Electric specifications. We believe that this is the first time that manipulators have been designed with the capability of reaching in any direction. They can reach up as well as down. It is believed that all prior manipulators have been hung from a boom or crane and can reach in only one direction, namely, down. These manipulators and their controls are a definite advancement in the state of the art.

Nine motions are provided (in each manipulator system) to permit operations to be performed over a large working volume. The manipulator hand will extend sixteen feet and support one hundred pounds in any position with an allowable deflection of eight inches. Under test the deflection with the loaded hand in any position is less than one inch. The manipulator size is small to provide maximum accessibility in restricted working area and to permit maximum viewing.

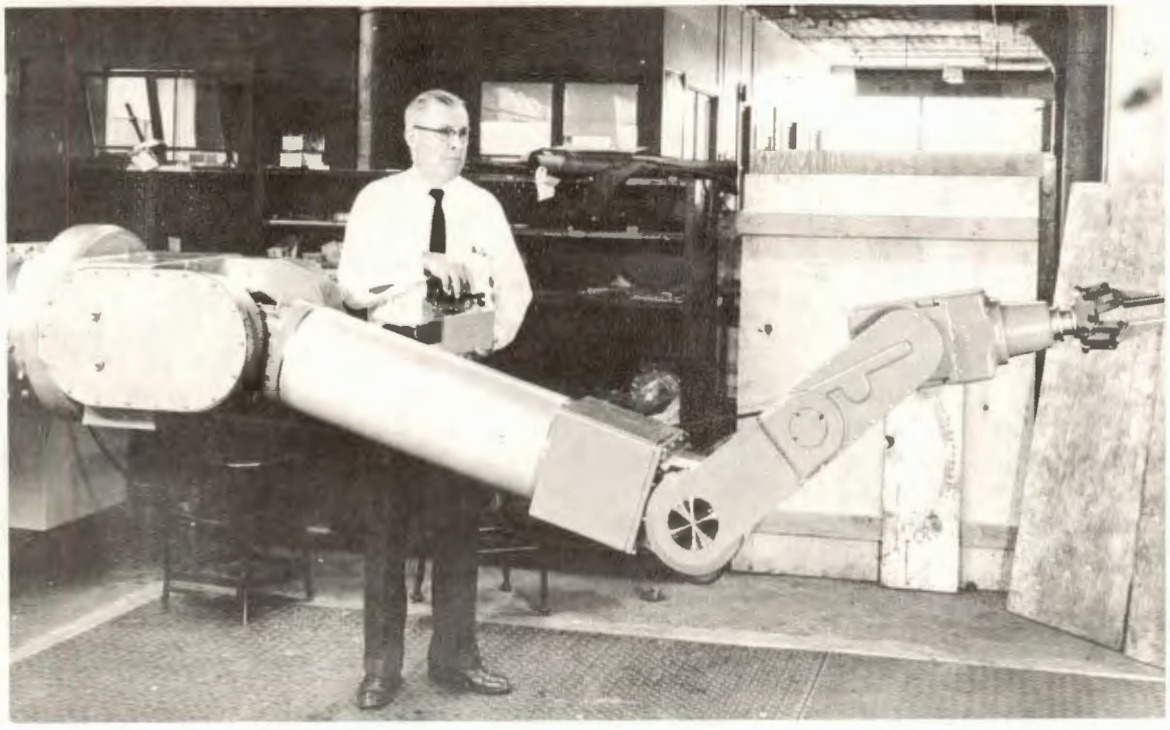


Figure 2. Beetle Manipulator

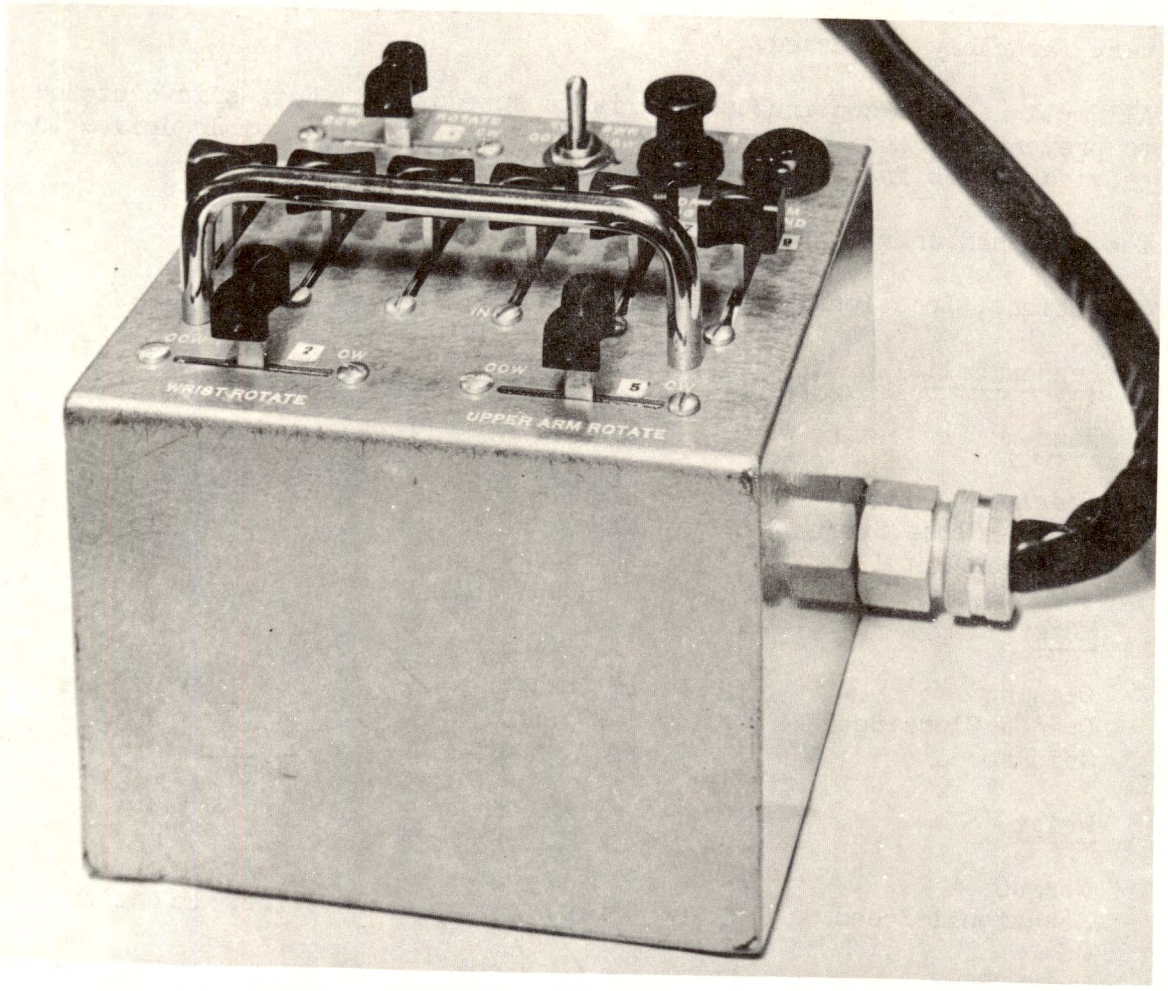


Figure 3. Beetle Manipulator Control Console

One of my requirements was that a control console for each manipulator system be roughly the size of your hand. This was accomplished. All motions are controlled by lever action switches each with forward and reverse motion. Those who have seen and used the small controls were very favorably impressed.

All motions have continuously variable speeds. All have slip clutches to prevent overloading. All have brakes and/or irreversible drives to provide "creep free" operation.

The attached chart shows general manipulator specifications.

Motions, Locations, Travels, and Rates follow:

Mechanical:

Hand

Opening	5 inches
Open - Close Speed	20 i.p.m.
Grip Force	200 pounds

Hook

Opening	$2\frac{1}{2}$ inches
Open - Close Speed	8 i.p.m.
Grip Force	1200 pounds

Wrist

Torque	50 ft. lbs.
Rotational Speed	8 r.p.m. continuous either direction

Wrist Bend

Torque	185 ft. lbs.
Pivot Arc	230 degrees
Speed	2 r.p.m.

Elbow Rotate and Bend

Bend and Rotate Torque	385 ft. lbs.
Bend Speed	1.5 r.p.m.
Rotational Speed	2.0 r.p.m. continuous, either direction
Bend Arc	220 degrees

Upper Arm Extension

Upper Arm Thrust	660 pounds
Extension-Retraction Speed	120 i.p.m.
Travel Range	18 inches

Shoulder

Bend and Rotate Torque	950 ft. lbs.
Bend and Rotate Speed	1 r.p.m.
Bend Arc	180 degrees

Rotation, continuous, either direction

Electrical:

Power Source for Manipulators

Voltage	208 to 240 volt
Frequency	60 c.p.s.
Phase	1

Power Required for Two Manipulators - 12.0 KVA

CHASSIS

The chassis for transporting the cab is a track-laying vehicle. It has torsion bar suspension. Standard ordnance parts were used in the following areas: Track laying, suspension, power plant, transmission, and turret ring. Maximum speed of the vehicle is ten miles per hour. An electric creep drive powered by nickel-cadmium batteries has been provided for safety in case of power failure. The vehicle can be driven a distance of eight hundred feet with battery power.

The cab is supported on four hydraulic cylinders, mounted on a standard ordnance ball bearing gun turret ring. It is elevated by hydraulics.

The attached chart shows a picture of the vehicle with principle dimensions.

GENERAL

The mobile cab vehicle with manipulators is a completely new remote-handling tool. It enables an operator to get within a very few feet of a "hot" nuclear power plant for the purpose of thorough inspection and for miscellaneous minor maintenance. The manipulators have hand-grip force and wrist-torque indicators inside the cab which will enable the operator to perform extremely delicate work. During the test and check-out period the manipulators picked up an egg, a glass of water, and an electric lamp bulb without damage. The manipulators can remotely pick up torque wrenches, impact wrenches, and a host of other power tools, remotely apply power, and control torque on numerous sizes of bolts.

The shielded cab vehicle with manipulators can be used for towing heavy loads. It has a draw bar pull of 80,000 pounds.

Provision has been made for driving other self-propelled vehicles by means of a cable from the shielded cab vehicle with manipulators. Examples of such self-propelled vehicles are a power plant mating vehicle, fire fighting vehicle, salvage vehicle, rescue vehicle, crane, jacking equipment, auxiliary power source, etc.

Driving, warning, signal, clearance, and working lights have been provided. The original specifications called for the equivalent of bright sunlight within the working area of the manipulator arms. Apparently this is impossible, so the requirement was relaxed. The shielded cab vehicle with manipulators was designed and built by Jered Industries, Inc., to General Electric specifications.

The shielded cab vehicle with manipulators is capable of transversing all kinds of terrain including unpaved surfaces.

NEED FOR SHIELDED CAB VEHICLE WITH MANIPULATORS

The shielding of flight versions of nuclear power plants for aircraft is such that the gamma-radiation levels after operation will not allow unshielded personnel to approach with safety to within something like one hundred feet of the power plant. Yet, in order to remotely mate a nuclear power plant with an airframe or remotely remove a nuclear power plant from an airframe, it becomes necessary for an operator to approach to within a few feet in order to direct such operations successfully. Radio control of mating equipment, together with TV vision, has been considered. It is our opinion and the opinion of others that the state of development of such equipment is not advanced enough to completely eliminate all the hazards involved in such operations at this time. Therefore, it appears that the directing of such operations by an operator, or operators, with direct viewing is the best solution.

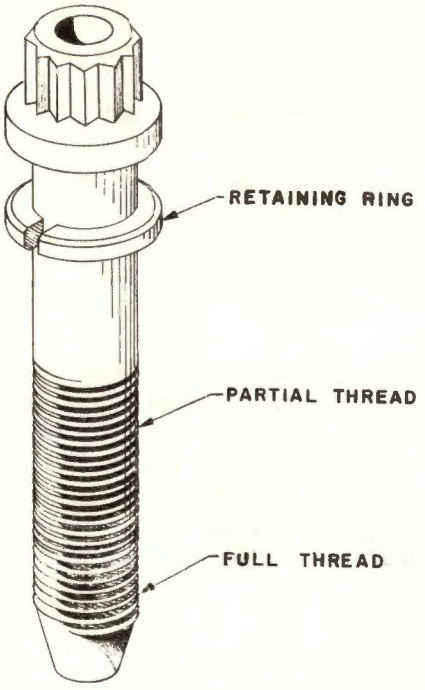
PLANNED USE OF MOBILE SHIELDED CAB WITH MANIPULATORS

INSPECTION

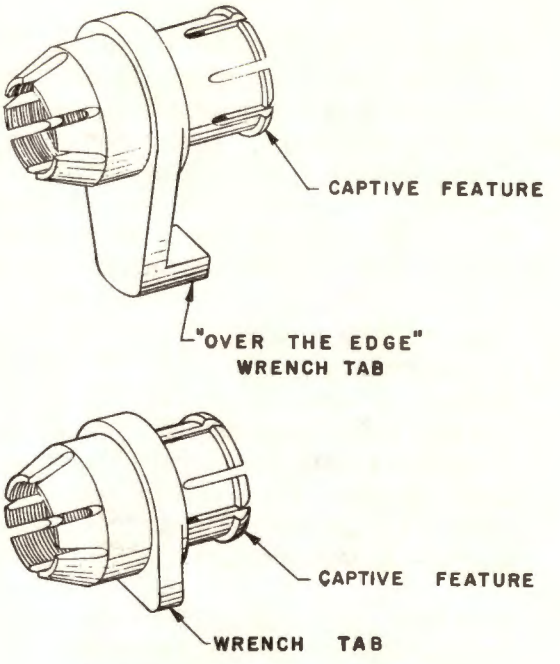
Planned use for the shielded cab vehicle with manipulators is the inspection of aircraft nuclear power plants in test cells during the development phases of such power plants. This inspection is to include the search for items such as oil leaks, chemical fuel leaks, loose fittings, inoperative actuators, cracks in power plant components, loose bolts, loose electrical connections, insufficient aftercooling, etc.

MAINTENANCE

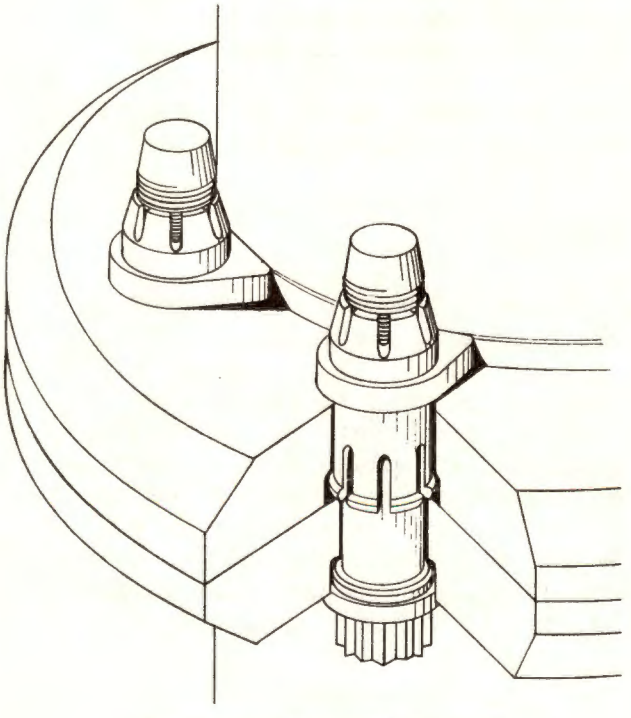
Planned use of the shielded cab vehicle with manipulators would also include minor maintenance operations of the power plant in the test cell. These consist of the tightening of various lines, ducts, electrical connections, bolts, etc., as well as the removal and replacement of various sensors, actuators, filters, electrical harness, etc.



a. Double Hex Head-Captive Bolt



b. Remote-Handling Self-Locking Nuts



c. Typical Captive Nut and Bolt Application

Figure 4. Captive Nuts and Bolts

I would like to show you some of the provisions we make for remote maintenance. In order to service and maintain a nuclear power plant remotely all components and assemblies have designed into them lift points, support points, register points, locating dowels, proper rabbets, fits, wrench clearances, visibility requirements, remotely handled fastening devices such as captive nuts and bolts, remotely operable quick disconnect fluid couplings, remotely operable electrical quick disconnects, captive Marmom-type clamps.

Some of the tools (including manipulator tools used for nuclear power plant maintenance) are: Nut-handling tool, nut-removal tool, bolt-retaining ring tool, torque-controlled flat angle wrenches, high-torque disassembly wrench, tool-holding fixture with remote air disconnect coupling, remotely operable tube cutter, bolt-handling tool, tool stand, bolt shears, standard nut and bolt machine, slings, stands, compressor removal fixture, upending machine, fuel-loading machine, fuel-storage and rollover machine.

The same general philosophy of power plant design and the same type of remote-handling equipment could be used on nuclear missiles and nuclear rockets.

REPAIR ACCIDENTS

In the planning and operation of a complex system such as a nuclear power plant, unexpected developments and situations occur. The shielded cab vehicle with manipulators provides a versatile equipment to perform inspection and remote-handling tasks in such situations. In emergency situations such as the breakdown of a transport vehicle carrying a "hot" power plant, the shielded cab vehicle with manipulators is invaluable.

The shielded cab vehicle with manipulators provides a means of inspection, radiation monitoring, and cleanup and repair of accidents involving radioactive products.

GROUND SUPPORT ACTIVITIES

The shielded cab vehicle with manipulators may be used for the directing of all ground support activities of nuclear-powered airplanes.

The shielded cab vehicle with manipulators may be used for the directing of the mating of a nuclear power plant with an airframe. It may be used for the directing of the removal of a nuclear power plant from an airframe. It can serve the same functions for the power plant cowling. It may be used for close-up inspection of power plant and cowling mating. It may be used to drive other self-propelled vehicles connected by cable. Other self-propelled vehicles could be power plant mating vehicle, fire fighting vehicle, salvage vehicle, rescue vehicle, crane, jacking equipment, auxiliary power source, etc.

Figure 5. Remotely Operable, Electric, Quick-Disconnect Coupling

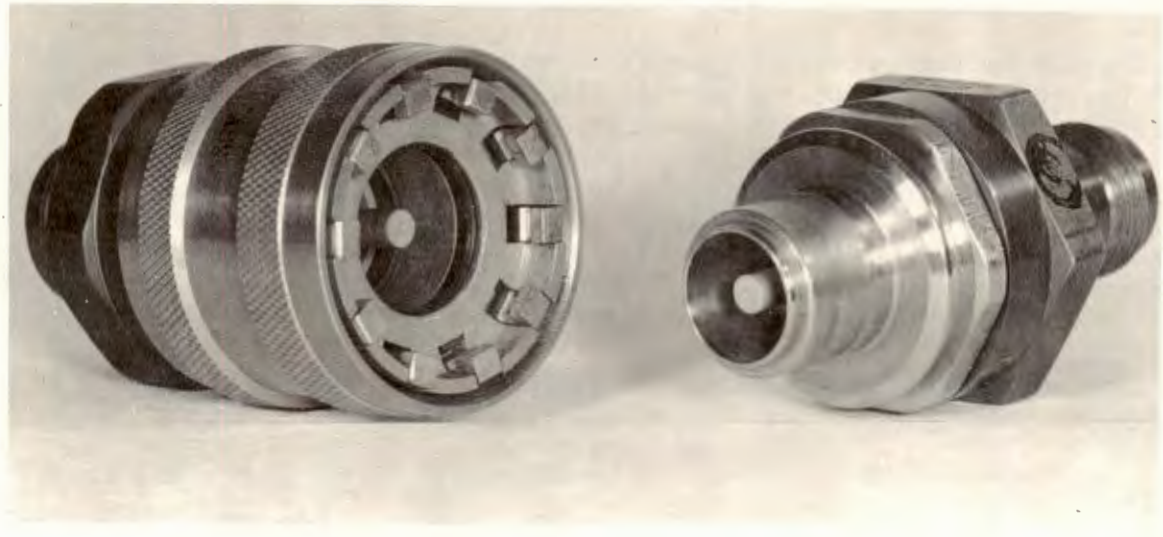


Figure 6. Remotely Operable, Fluid, Quick-Disconnect Coupling

The shielded cab vehicle with manipulators could be used for the remote inspection, the remote maintenance, and the transportation of nuclear power plants for missiles, both during ground test developments and after recovery from flight.

The shielded cab vehicle with manipulators could be used for the remote inspection and the remote maintenance of nuclear rockets for outer space, both during ground test developments and after recovery from flight.

Another planned use of the shielded cab vehicle with manulators is to connect and disconnect aftercooling ducts.

WHY A MANNED VEHICLE

The establishment of specifications for the shielded cab vehicle with manipulators presented many problems, the primary one being: was a manned vehicle really necessary?

An unmanned, radio-controlled vehicle with manipulators and television viewing was considered. Twelve major manufacturers of such equipment were consulted. Of these, six refused to have any part of it. The opinion of the majority of the other six was that the system would be too complicated at this stage of development to be practical for our use. Therefore, from these opinions, and because of the difficulty of precision control of both vehicle and manipulator motions by radio, together with lack of depth perception with television viewing, it was felt that the use of this type of equipment in connection with aircraft nuclear power plants was too hazardous.

SL-1 INCIDENT

The Aircraft Reactors Branch of the Atomic Energy Commision inquired about the status of the Beetle shortly after the SL-1 incident, our first fatal reactor accident which happened in January 1961 at the National Reactor Training Station in Idaho.* It is my understanding that the Beetle has been offered to Combustion Engineering, Inc., which operated the SL-1 reactor for the AEC and the Army. It would be used to disassemble the wrecked, radioactive SL-1 for any additional clues to its failure, This incident made it clear that a device such as the "Beetle" is very much needed.

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*Armagnac, Alden P., "The Atomic Accident That Couldn't Happen," Popular Science, Vol 179, No. 3, p52, September 1961.