# TELEROBOTICS MADE EASY

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## ABSTRACT

AEA Technology has developed, and now supplies, products that can reduce the cost and improve the reliability of decommissioning and radwaste operations. This paper describes some of the features of these products, which include NEATER, a telerobot based on a commercial industrial robot, and $TV^3$ - an engineered 3-D TV System. The products are designed for the radiation and environmental conditions of a range of nuclear plant. The operator-robot interface has been improved by the provision of a telerobotic controller, and of a new multi-degree-of-freedom force reflecting input device, that can also be used to control many different types of slave manipulator. Human factors experiments and field trials have proved that the $TV^3$ system gives useful performance benefits and is comfortable to view. NEATER and $TV^3$ are affordable, robust systems which make telerobotics a realistic option for the nuclear industry.

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## INTRODUCTION

The Remote Handling and Robotics Department of AEA Technology has recently evolved a special approach to solving remote handling problems. Although in the past, its in-house development programme has produced sophisticated manipulators for use in decommissioning and fuel cycle operations, in general its experience has been that its traditional approach to development led to long timescales.

In 1984, a new approach was devised, that had the potential to reduce the development timescale, and bring remote handling products into operation much more quickly [1]. The new approach is made up of five key principles:

- use techniques proven in previous projects
- use off-the-shelf solutions wherever possible
- if not, adapt and modify existing equipment
- develop special equipment only when necessary
- anticipate evolution.

By 1987 some of these principles had been applied in building telerobotic controllers for industrial robots, and in producing robust black and white and colour 3-D TV systems [2,3]. The next goal was to build fully-engineered robotic and viewing hardware that could be used in radioactive environments. Instead of building totally novel hardware, solutions were proposed that incorporated a blend of existing equipment design, special material selection [to survive in an active environment], and re-engineering to meet particular size or maintenance constraints. Equipment suppliers were involved in re-engineering to the necessary target specifications.

The result has been the rapid prototyping and subsequent production engineering of NEATER (the Nuclear Engineered Advanced Telerobot), and $TV^3$ (the engineered 3-D TV system). This paper describes the development of NEATER and $TV^3$, and the associated work on a telerobotic input device.

As a result of the programme of design, testing, and development described here, simple hardware is now available to make telerobotics easy, for operators, designers and manufacturers.

## TELEROBOTICS

Telerobotics is a blanket term relating to systems which can support both remote manipulation with a human operator in the loop and programmed manipulator operations. In consequence telerobotics combines all that is best in industrial robotics with all the skills of a human operator to respond to ill defined and unpredictable tasks.

From this definition it is clear that the operator requires both a means of exercising control and feedback information about how the remote manipulator is performing. Most experience in the nuclear industry is of mechanically-linked master-slave manipulators [MSMs] with direct viewing through a shielding window. The hydraulic manipulator developed at Harwell[4] has a greatly increased payload compared to MSMs, but still relies on visual feedback except when executing a pre-programmed task. Without the benefit of force feedback, tasks have to be carefully controlled by the operator.

NEATER can operate as a telerobotic manipulator because a Telerobotic Controller [TRC] has been built and attached to the standard controller [5]. The TRC conditions demands from the input devices - joysticks or force balls - so that the end effector moves smoothly throughout NEATER's considerable operating volume. A touch-screen interface sets up the different operating modes of the telerobot.

In their basic forms, both the hydraulic manipulator and NEATER are unilateral manipulators. However bilateral (force feedback) control of both manipulators will become possible using the kinematically dissimilar Cartesian mini-Master Arm. $TV^3$, the engineered stereoscopic TV system enhances the ability of an operator to perceive and control complex tasks in a nuclear environment. These two developments are described in the following paragraphs.

**INPUT DEVICES**

Simple input devices such as three-degree-of-freedom joysticks can be used to control NEATER through the TRC. A new development is the Cartesian mini Master Arm which provides end point bilateral control of remote manipulative operations. The system is designed to be easily maintained, to produce useful force feedback from within a generous operational volume and to be simple to interface with the TRC and auxiliary processors.

Figure 1 shows a outline of the prototype Cartesian mini Master Arm, which will be operational at the end of 1990. It is an optimised structure, consisting of a parallel-serial linkage in a gravitationally balanced package. The mechanism is symmetrical and has homogeneous mechanical properties. Low force/torque friction thresholds produce a comfortable responsive control without fatigue or mis-cued information.

**$TV^3$**

$TV^3$, the engineered stereoscopic TV systems developed by AEA Technology, give operators or observers a 3-D view of a remote scene which may be part of an inspection, repair, maintenance or decomissioning task. There are many tangible benefits of $TV^3$, which have been achieved by a thorough understanding of how three dimensional images should be re-constructed and presented for remote viewing. Unlike time interlaced systems, $TV^3$ produces no flicker, and simple polarized spectacles are all that are needed to view the display. The viewer can use the $TV^3$ display for long periods of time without eyestrain or other forms of fatigue, which are common in most other forms of 3-D TV system. Auxiliary tasks and use of VDUs are in no way inhibited by the use of the polarised spectacles. Among the benefits of good stereo TV over 2-D viewing systems for manipulation tasks are:

- there are significant time savings in performing manipulation tasks
- the number of cameras required may be smaller
- positioning of cameras and lights is easier
- complex tasks are completed with fewer manipulative movements
- the risk of collision damage to manipulators and their environment is reduced.

Figure 2 shows the radiation tolerant camera built for in-reactor inspection. Cameras and displays have been built for both colour and black-and-white systems. Applications include 3-D computer graphics, 3-D flow visulization, and systems for decommissioning operations.

**NEATER**

NEATER, the Nuclear Engineered Advanced Telerobot is based on the mechanism design of Staubli-Unimation's clean room PUMA 762 robot. The radiation tolerance objective was achieved in a two-stage programme, with a tolerance of $10^4$Gy achieved initially, followed later by upgrading to $10^6$Gy by back-fitting improved components.

Working with Staubli-Unimation, AEA Technology examined every component and subsystem for radiation tolerance. An initial assessment of the robot identified a number of areas with obvious radiation tolerance problems, for example, cable and wire insulation, lubricants, motors, optical shaft encoders. Substitution of equivalent materials which were radiation tolerant was carried out wherever possible, but some components needed to be completely re-engineered.

The optical shaft encoders fell into this category. After considering the alternative of replacing the encoders with resolvers, it was decided to re-engineer the encoders. This involved a new circuit design, using components that were stable when irradiated, or at least varied in a predictable way. Using the RHRD radiation effects database, supplemented by extra testing, a computer simulation of a range of possible circuit designs was undertaken. On the basis of this simulation, an optimal design for a radiation tolerant encoder was selected and built. Prototypes were successfully tested in the Harwell fuel ponds, and then exercised on NEATER itself.

A maintenance review indicated that extra seals were required at the joints, so that NEATER could withstand contamination, and also be decontaminated easily. The manipulator is designed to be split into three components. A split base offers a weight reduction of 100kg. A removeable forearm eases in-cell maintenance procedures, and extensive use of quick release connectors and special tapering bolt heads facilitates active maintenance of the machine [Figure 3].

The resulting manipulator [Figure 4] has all the mechanical design features of an ordinary industrial robot, and benefits from the knowledge gained during millions of operational hours in non-nuclear applications.

**EXPERIENCE WITH NEATER**

NEATER was officially launched at the IBC Conference on the Applications of Robotics in the Maintenance, Inspection and Refurbishment of Nuclear Installations, in December 1989. Inactive trials at Staubli-Unimation's Telford works and at Harwell Laboratory have been carried out over the last year. More than 1200 operational hours of experience have accumulated without a failure of any of the special components in the manipulator or standard controller. In the interests of economy, the telerobotic controller has now been rebuilt using a single 486PC. Work on glovebox cutting and decommissioning trials have continued, with robotic deployment of many of the tools that are currently being used in manual decommissioning.

Tools such as nibblers, bandsaws [Figure 5], hacksaws, jigsaws and drills have been tried, to establish which give the best performance in cutting up to 6mm steel plate. Most of the tools require compliant mountings to isolate the telerobot from parasitic vibrations and to prevent tool jams. The tools have a common interface with the robot which allows them to be exchanged either manually at a gloved change station or robotically at a tool change station. A jaw change mechanism developed for the hydraulic manipulator is being adapted for use with NEATER.

NEATER comes in three basic forms [6]:

1) A basic radiation tolerant version of the clean room PUMA without modularity or improved sealing, for high radiation, low contamination applications [for example in waste drum handling or swabbing] - designated PUMA 762N [N for nuclear].

2) A modular version, with improved seals but not highly radiation tolerant, for applications where the decontamination is necessary but radiation levels are low [for example in replacement or assistance to pressurised-suit operations] - designated PUMA 762M [M for modular].

3) A radiation tolerant decontaminable version, which can be used in the most extreme environments, with modularity to help maintenance-designated PUMA 762NM [nuclear and modular].

The prototype NEATER at Harwell began as Version 2, with modularity, improved seals and some radiation tolerant components. It is now being brought up to the target tolerance of $10^6$ Gy, [Version 3] by the addition of the radiation tolerant encoders.

Two NEATER robots have been supplied to the nuclear industry, to swab the outsides of high level vitrified waste containers. The specification called for 50°C operation, with a contact dose of up to $5.10^3$ Gy per hour. 750 cycles per year were demanded from the manipulators, so that over a two year period an integrated dose of $10^6$ Gy could be expected. Because there was unlikely to be a contamination hazard to the machine, PUMA 761N versions [radiation tolerant, no modularity or extra sealing] were supplied.

Inactive demonstrations of the system were performed following a simulation using GRASP. The robots had to perform complete surface swabbing, providing a fixed contact pressure, and then exchange the swab at a transfer station. The first robot was produced and delivered after customer acceptance trials, and was shortly followed by a second machine. Radiation tolerant encoders have been fitted, and it is anticipated that the first manipulator will be installed in an active area in late 1990.

## CONCLUSIONS

The development programmes to produce NEATER and $TV^3$ in radiation tolerant form have been successful. The time taken from the prototype stage to a fully-engineered production piece of equipment has been short, and this is a direct result of working closely with manufacturers to set design specifications that are achievable and are based on existing knowledge of systems used in a wider field than nuclear engineering. New developments such as the Cartesian mini Master Arm will enhance the capabilities of NEATER and the hydraulic manipulator, and radiation effects research, testing and design will continue to provide new solutions by adapting existing equipment. Telerobotics made easy is now a justified claim.

## ACKNOWLEDGMENTS

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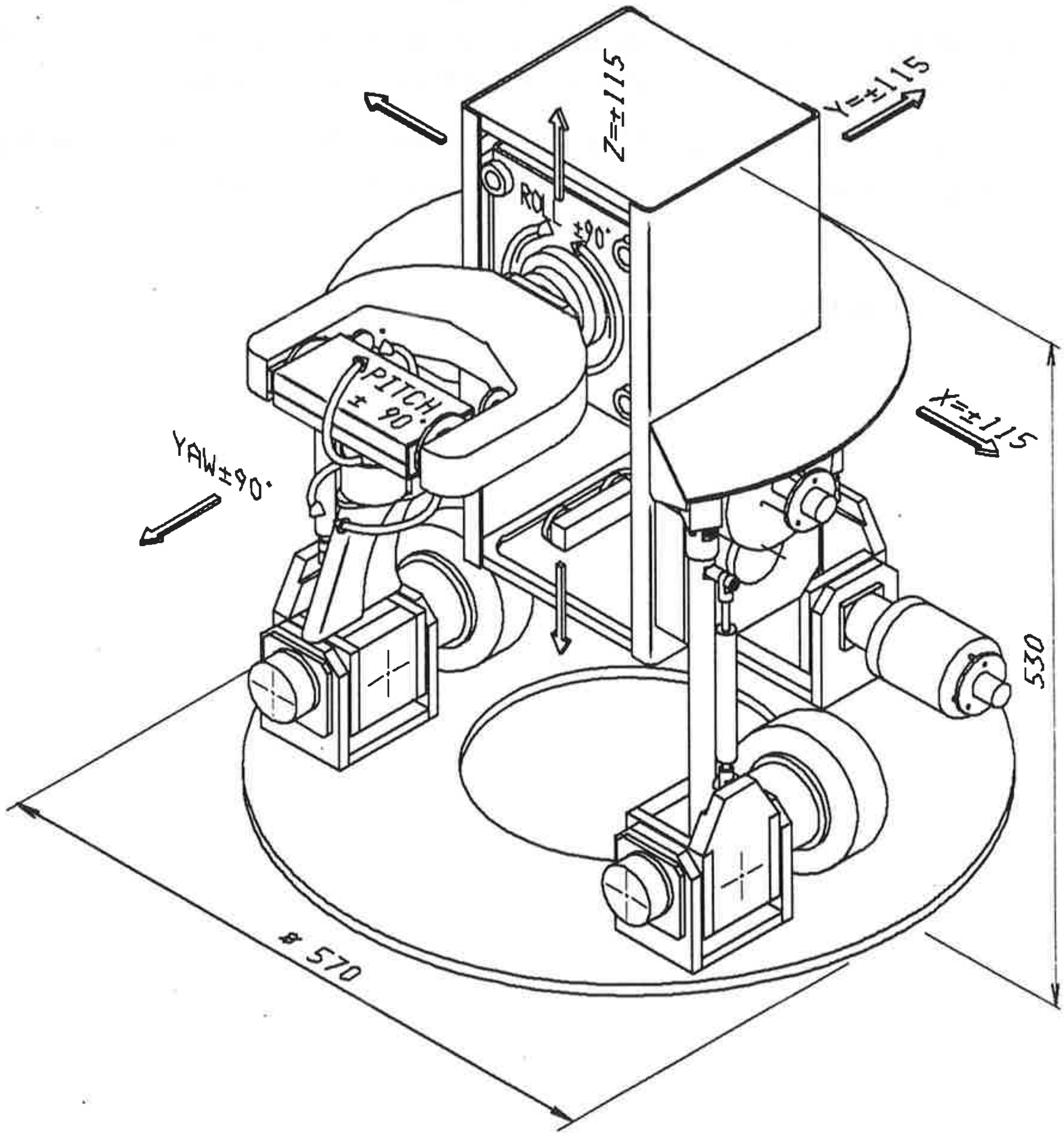


**Figure 1: Kinematic Arrangement of the Cartesian Mini Master Arm**

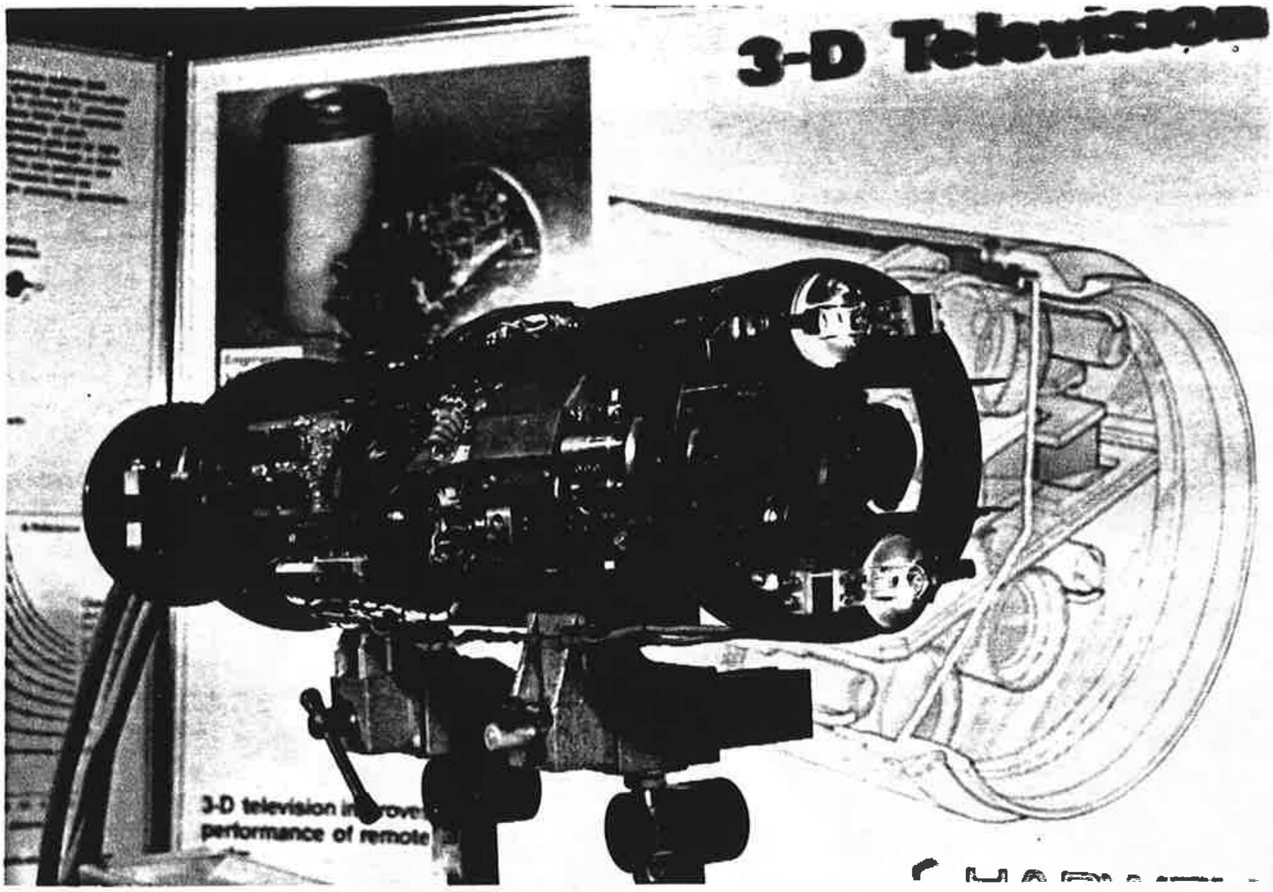


Figure 2: Radiation Tolerant Camera - Nuclear TV[3]

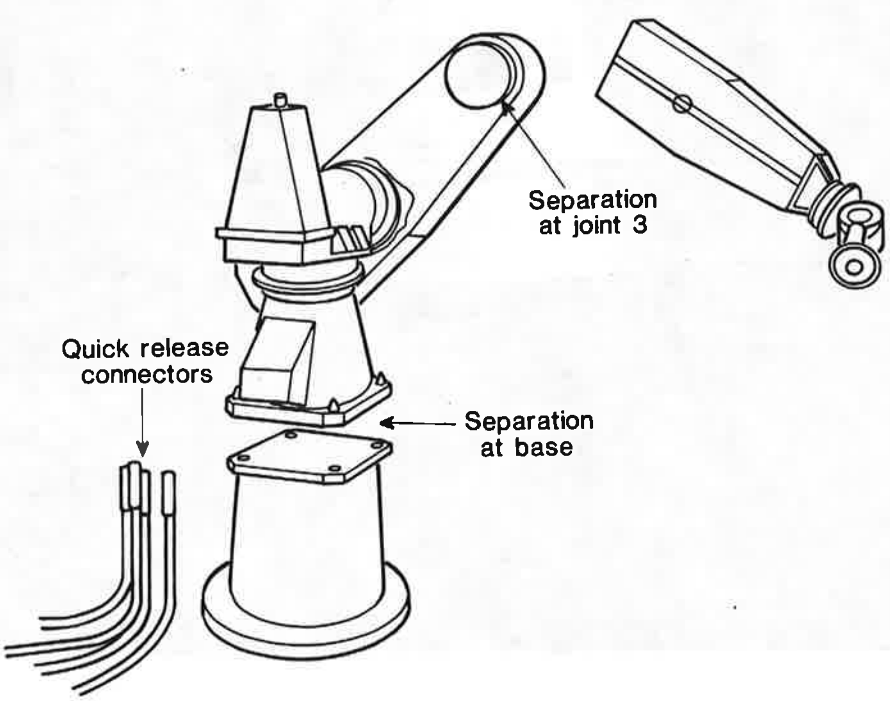


Figure 3: Modular Design of NEATER

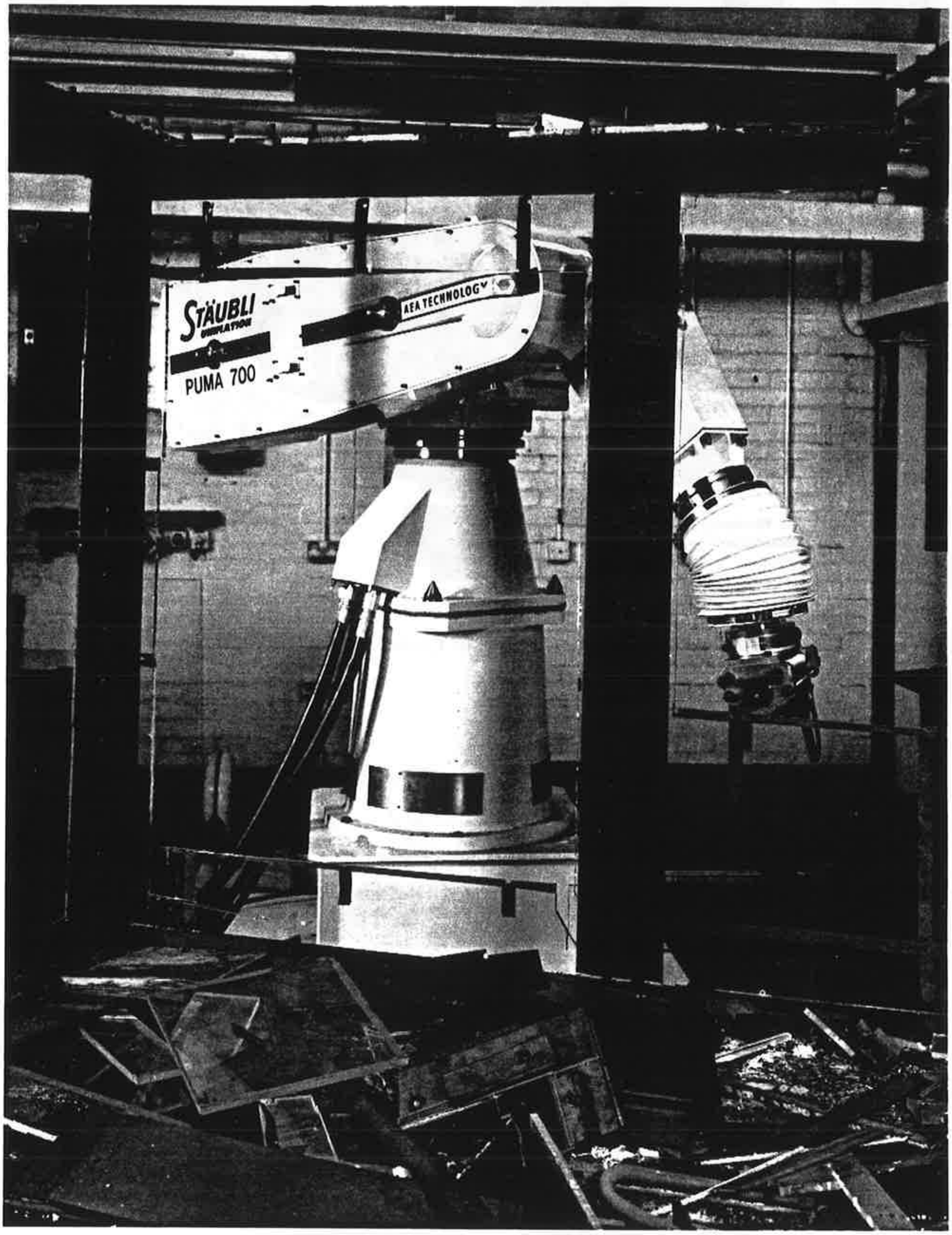


**Figure 4: NEATER carrying out a Decommissioning Trial**

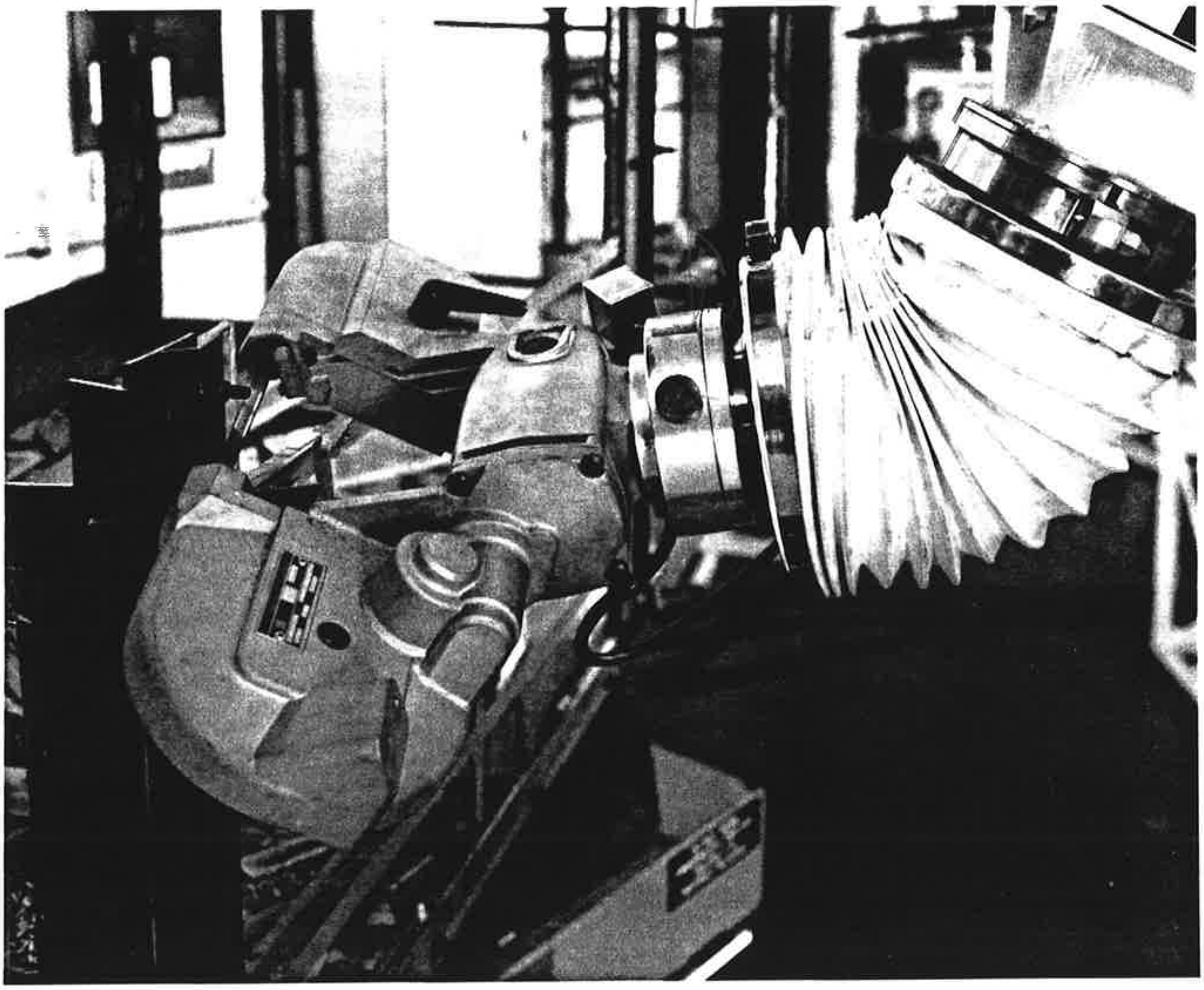

**Figure 5: NEATER Deploying a Bandsaw**