Enhancing ALARA[1] and Reducing Costs: The Future of Robotics*

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by

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Introduction

In the early 1980s, one of us (TAK) was working as a health physicist at Ontario Hydro's Bruce-A plant. This CANDU nuclear power station has four reactor units all of which are fueled on-line through the same two computer-controlled fueling machines. A fault in the computer's refueling program caused an irradiated fuel bundle to be badly crunched. Some fuel pencils broke, and the pellets spilled on to the floor of the fueling machine duct. The area radiation fields were in excess of 10 Gy/h (1,000 Rad/h), and the utility was facing a very serious problem. At that time, robots rarely were used in nuclear power plants. However, a simple, tethered, robot named 'STANLEY', which was used in explosives ordinance disposal, was hurriedly procured from the Canadian army. STANLEY was modified and the recovery and cleanup process was started. Soon, the maintenance crew of the fueling machine developed an affection for STANLEY. The entire operation was a success; the cleanup and recovery task was carried out at a cost of just 60 person-mSv (6 person-rem), and the reactor was back on line 6 weeks ahead of schedule. Thus, the cost for this simple robot was recovered many times over.

Robots were used with mixed results after the two major nuclear accidents. At Three Mile Island-2 (TMI-2), robots were used successfully for surveillance, underwater inspections, and for cleaning the concrete structures in the basement of the TMI-2 building. A stair-climbing robot was equipped with instrumentation for radiation surveys. Unfortunately, a robot specially designed to carry a variety of tools was not extensively used because it was too large, too complex, and too unwieldy for the tasks required. At Chernobyl, robots also were not fully satisfactory: some devices failed in high-radiation areas when their batteries ran out, and also, there were problems with movement over the terrain. Some microprocessor-based control systems proved faulty.

These incidents showed that robots of simple design performed more effectively than complex ones, especially in critical situations. However, since then, robotics have come a long way. Instead of using robots as basic manipulators and simple tools, manufacturers are making greater use of microprocessors to control the robots and the new microprocessors are more advanced. They are investigating 'radiation hardening' to develop more rugged, more sophisticated, and more durable devices that may be used in harsh environments. Moreover, there has been a revolution in developing sophisticated remotely controlled or automatic devices which carry out tasks requiring precision, such as inspecting control rod drive penetrations[2], handling fuel[3],

[1] ALARA implies keeping radiation exposures <u>A</u>s <u>L</u>ow <u>A</u>s <u>R</u>easonably <u>A</u>chievable.

[2] G. Baro, F. D'Annucci, "Improving CRDM penetration inspection," Nuc. Eng. Int., January

installing nozzle dams[4], inspecting steam generators and carrying out a host of steam generator maintenance tasks[5]. All these tasks are carried out during normal operations. At the same time, these robots contribute greatly to avoiding radiation exposure.

The trend towards robotics

The use of robotics technology is increasing in nuclear power plants, and the technology eventually may become a key element as electric utilities realize its potential for significant savings in exposures and costs. Robots not only reduce radiation exposures and facilitate work in environments with excess heat, humidity and chemicals, but they also increase the plant's availability. Their utilization for in-service inspections reduces dose while contributing to plant safety. Moreover, the more widespread use of robotics in other industries has hastened maturity of the technology and demonstrated its economic value. Now, using robots is easier to justify not only on the basis of radiation safety but also on the basis of economics and quality of workmanship.

Five factors are motivating the trend to robotics applications:

- The lower radiation-exposure limits and occupational safety standards.
- ALARA.
- The need to reduce operational and maintenance costs.
- The economic pressures to increase plant availability.
- The desirability of extending plant lifetimes.

Plants whose lifetime is extended require more inspections and robots may facilitate these inspections without excessive radiation exposure to the workers.

Figure 1 shows how the robots used by U.S. utilities are employed; the data were compiled by the Utility/Manufacturer Robot Users Group (U/MRUG)[6]. At present, their largest use is in pipe inspections, and general surveillance and inspection. However, increasingly they are being used for remote manipulation and handling, inspecting the reactor vessel, and underwater cleaning and decontamination.

1995, pp. 38-39.

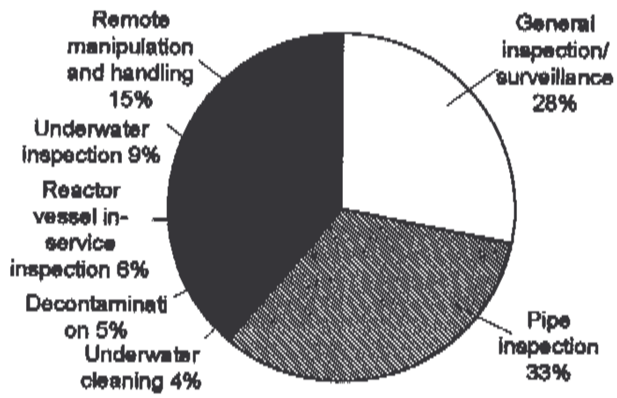
[3] M. Stromberg, "Automatic Fuel Handling Systems," Nuc. Eng. Int., December 1991, pp. 45-46.

[4] "Installing nozzle dams 100% remotely," Nuc. Eng. Int., March 1994, pp. 17-19.

[5] "ROSA III: The Westinghouse workhorse, "Nuc. Eng. Int., December 1991, pp. 42-43.

[6] ALARA Notes #10, October 1994, available from Brookhaven National Laboratory ALARA Center, Building 703M, Upton, NY 11973-5000.

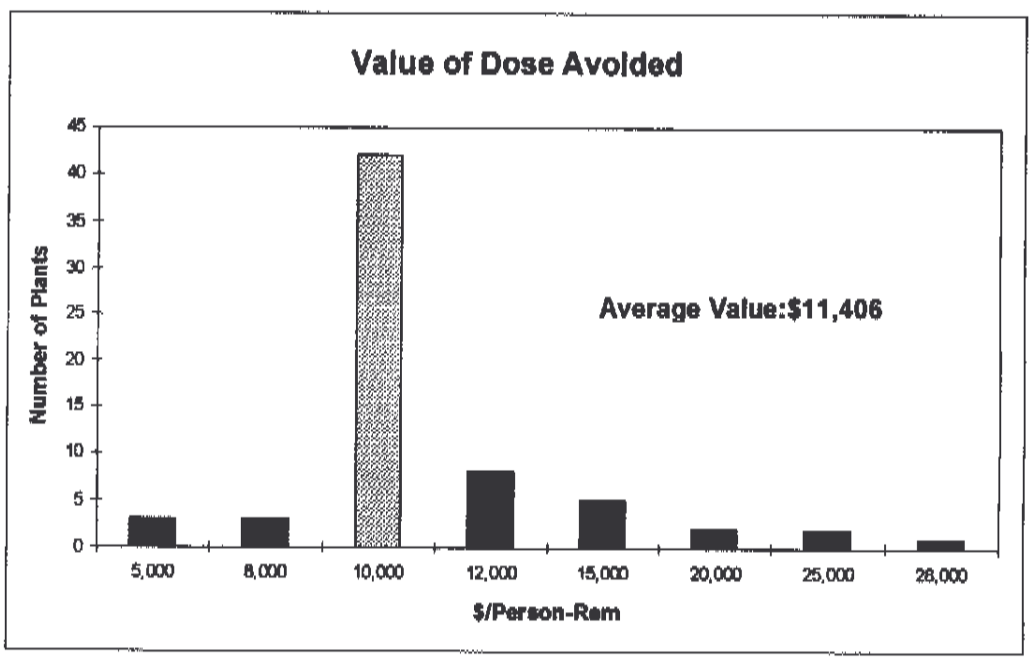
Fig. 1: Robot activities by category



Survey of robot activities by category

The economics of using robots is looking more and more attractive. In the United States, each nuclear power plant determines a monetary value for a unit of radiation dose avoided. Figure 2 shows the values used by 66 plants[7]. The average value of $1.1 million per person-Sv ($11, 406 per person-rem) would suggest that serious investment in robotics technology can be justified to avoid radiation dose. Additionally, often there are savings in critical path time, and in the quality of the product. Furthermore, robots can work under extreme heat, humidity, and toxicity for indefinite periods, and workers cannot.

Fig. 2: Monetary values used for dose avoided by U.S. nuclear power plants



[7] Provided by G.W. Kindred, Perry Nuclear Power Plant, to ALARA Center's ACEFAX system

Utility experience with robotics

We discussed experience with robotics technology with four utilities. For certain tasks, for example those carried out in areas of high radiation fields, in extreme environments, or under water, robots were judged to be very cost-effective. They were not considered to be advantageous for less hostile environments. Some utilities still felt that simpler robots were more reliable and more cost-effective. Sophisticated robots required more maintenance, care and training. The consensus seemed to be that investments in robots must clearly be shown to be cost-effective.

Public Service Electric and Gas (PSE&G) originally concentrated on such applications as underwater inspection and surveillance, surface decontamination, remote operation and maintenance, and inspecting, cleaning, and removing debris from the steam generator's secondary side tube sheet.

As the original goals were met, a second program was started which used robots for such tasks as inspecting and cleaning the steam generator's upper support plate, reducing the dose from the steam generators for health physics tasks, general operation and maintenance, improved monitoring of health physics tasks, preprogrammed inspection of controlled radiation areas, as well as inspecting and repairing the service water piping and other piping in the plant.

PSE&G also looked at the economics of their robots (Table 1)[6]. They invested $1.6 million on purchasing and developing robotics hardware; this included photographic equipment, special radiation probes, recording equipment, special tools and spare parts, and moneys for upgrading and repairing robots. However, the savings were substantial, some $5.3 million. PSE&G used a value of half a million dollars for each person-Sievert of dose avoided ($5,000 per person-rem). Their analysis showed that savings in radiation protection costs alone were enough to justify the robots.

Commonwealth Edison (CommEd) uses miniature remote cameras and component video imaging. Its plants have submersible miniature and vacuuming crawlers, a crawler with an arm, wrist, and manipulating gripper, another with a telescopic head, and an integrated-radiation mapper assistant. They have a miniature robot which can enter pipes 3" in diameter; it cleans the heat exchanger tubes. All these devices are considered reliable and effective.

GPU Nuclear (GPU) uses robots for surveys in hostile environments, and for decontamination in areas of high radiation, high dust content, or where toxic materials are present. They use robots that can climb the wall of the containment structure to measure its thickness ultrasonically. They employ pipe crawlers to clean pipes and measure defects with ultrasonics and radiography. They also utilize robotic welding devices. Some of the tasks routinely carried out by robots are: pipe inspections through a robot carrying a camera attached to a video recorder; underwater reactor vessel inspections for loose parts; visual inspection of welds and components ; semiautomatic tensioning for the head stud-bolts of reactor pressure vessels; underwater cleaning during refueling; and underwater fuel inspections in the fuel pool. The initial driving force towards robotics was to reduce radiation exposure but experience has shown that robots are equally effective for avoiding non-radiological risks of high heat, extreme humidity, and the presence of asbestos and dust.

Table 1: Costs and Savings of One Utility's Robotics Program

Description of Robot	**Investment ($)**	**Operational Savings ($)**
MiniRover MK I	55,000	1,200,000
MiniRover MK II	90,000	150,000
SuperScavenger (2) and related tools and equipment	120,000	300,000
Kelly Vac Decon System and associated special tools	190,000	250,000
SURBOT-T	200,000	200,000
CECIL	750,000	3,200,000
ANDROS MK VI/MISR	120,000	
Hardware to support the program:	75,000	
Total	**$1,600,000**	**$5,300,000**

Tokyo Electric Power Company (TEPCO) extensively uses robotics technology and automation in its power plants. Some of the remote maintenance and inspection devices employed by TEPCO are automatic refueling platforms for refueling and shuffling; automatic control-rod-drive handling machines; reactor cavity cleanup machines; automatic ultrasonic inspection-equipment for the reactor pressure vessel shells and for piping; automatic seat-lapping of the main steam isolation valves and handling equipment; semiautomatic overhaul and inspection equipment for control rod drives. Although the main driving force for the use of robotics is reducing radiation exposures, in Japan, they sometimes reduce the need for skilled manpower.

Role of robotics in plants of the future

Although the current generation of plants was not designed for extensive use of robotics, some tasks already are better handled by such devices. However, in the short term, the utilities, that are trying hard to reduce costs, are likely to continue to view robotics carefully, being very cost-conscious.

H. T. Roman, past President of U/MRUG, proposed the following characteristics for the robot of the future:

- Modular in design and capable of reconfiguration for a variety of applications.
- Easy to decontaminate.
- Highly mobile and able to contend with a variety of plant obstacles and types of terrain.
- Infrequent failure (at least 1,000 hours of use between failures).
- Fail safe and able to be rescued by other robots.
- Ability to interact with, and operate upon, varied types of equipment.

This list appears to encompass a good agenda. Moreover, if future plants are designed to use robotics technology, then some of this agenda may become easier to implement. Robots are likely to play a very important role in the advanced design nuclear power plants of the future.

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