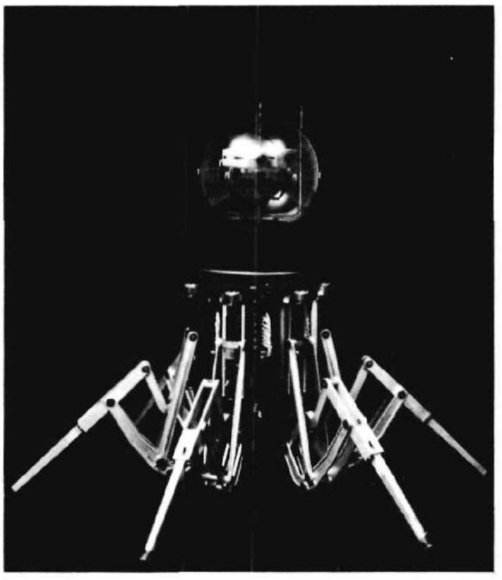

Control-room operators are already benefitting from electronic and computer aids. Tomorrow, robots such as Odex (inset) may help other nuclear-plant workers with maintenance, inspection, and other jobs. (Credits: Atomic Industrial Forum, Inc.; inset, Odetics, Inc.)

Nuclear power and the electronics revolution

From video systems to robots, electronic tools are influencing nuclear plant operations

by Leonard Konstantinov, James Joosten, and Vladimir Neboyan

One dominant aspect of improvement in nuclear power plant operation is now the very high speed in the development and introduction of computer technologies that are bringing continuous changes into the design of plant instrumentation, control, and safety systems. The rapid developments have taken place within about 20 years.

Today, there are growing demands for high reliability and improved cost-performance of measurements and control equipment used to achieve a higher level of availability and economy in nuclear power plants. To meet these demands, extensive efforts are being made to utilize innovations in electronics that are well-suited to reactor purposes, small, draw little power, and can be well-shielded against pernicious plant environments.

One microcomputer, for example, can depend on back-up battery supplies that can see it through plant electrical supply interruptions. It also is extremely reliable, having a mean-time-to-failure of 10 to 100 times better than conventional computers, for an average life comparable to the plant's life.

Increased use of computers also has provided a good tool for supervising and controlling plant operation. Essential progress has been achieved in operator support systems. Plant disturbance analyses and plant diagnostics are presently major objectives in this development. The introduction of microprocessors in protection systems also makes it easier to implement "defense-in-depth" strategies that give better assurance of correct system responses and also prevent unnecessary reactor trips, thus improving plant availability.

Microcomputers and other digital techniques, such as integrated circuits, of course have demanded introduction of a new element – the software – which can fail just as can other system components. This in turn led to the necessity of validation of software – a problem which, of course, will remain with us in a new dimension due to the immense increase in complexity.

In their history, computerized control systems already have passed three stages of development, or so to say, generations. The reliability of previous generations of so-called centralized systems appeared to be lower, in general, than the reliability of reactors themselves and their main technological equipment.

In the early 1980s a new generation of control systems for nuclear power plants came on the scene. These new control systems are distributed systems, and they open a new area of computerization of nuclear power plants since they have important advantages. They unload the central computer for more sophisticated and delicate analysis of current processes, leaving for peripheral microprocessors maintenance of all units. Thus, they distribute responsibility between central and peripheral processors into a hierarchy system that tremendously increases the system's reliability.

Safety systems

Until recently, computers were not used in special safety systems. Advanced control technology had not been accepted by the nuclear industry for a variety of reasons. These include standardization, a long time span from initial design to actual construction, and concern for safety and reliability of advanced systems. Considering the long experience of using direct digital control in the reactor regulating systems, computers that monitor the status of safety systems, make safety decisions with the help of other computers, and fully computerized shutdown systems seem to be natural offsprings.

This development has required considerable effort for developing standards for hardware and software of computerized safety systems to gain full acceptance by licensing authorities. The incorporation of digital computing devices in systems important to safety now is progressing fast in several countries.

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Advantages associated with such developments include:

- Very compact construction
- Easy change of the logic
- Simple realization of different self-testing methods
- High reliability
- Event logging after shutdown
- The ability to implement more complex mathematical calculations than can be performed by hard-wired circuitry
- Introduction of new protective functions into safety systems.

With the introduction of computer devices in systems important to safety, plant availability and safety are improved because disturbances are treated before they lead to safety action, in this way helping the operator to avoid errors.

Noise analysis

Additionally, the fast development of micro-electronics has made it possible to construct systems by which the condition of power plant components can be surveyed on-line. In this connection, the noise analysis technique can be applied to surveillance systems of nuclear power plants. The technique allows detection of damages at an early stage, thereby increasing safety and availability of the plant. A large number of experiments with neutron, temperature, pressure, and acoustic noise signals carried out at different laboratories – as well as good performance of experimental devices for noise analysis – illustrate the fact that some countries already have started, and many others are very close to, practical application of surveillance systems based on the noise analysis technique.

Simulators

The advantages of low-cost powerful computer systems and rapid development of modelling techniques also have brought nuclear power plant simulators within reach of an increasing number of users.

Since the first IAEA specialists meeting on training simulators in 1976, many new training simulators have been taken into operation and much experience has been gained in their operation and utilization. At present, about 100 full-scope nuclear power plant training simulators are in use or under construction in the world, and the number is still rapidly increasing. Numerous basic principle, part-task and other restricted scope simulators also are in use, and it can be said that simulator courses are essential parts of operator training in most countries having or starting nuclear power programmes.

Man-machine interface

Considering the growing complexity of nuclear power plants in general, and the resulting complexity of the human cognitive process to monitor, control, and diagnose these plants, it is quite understandable why so much attention is now being paid to the problem of man-machine interface, both in normal plant operation and in possible accident situations.

The need to improve the interface between man and machine has come to the fore in recent years, as it has been demonstrated that human error is one of the principal factors contributing to possible accidents. This has been confirmed by risk analyses, as well as by the experience of the Three Mile Island accident and other abnormal events at nuclear power plants.

At the same time, man-machine questions play an ever increasing role because the new instrumentation and control systems can be matched more easily to the needs of the operator. The man-machine interface of the computerized operator support system supplies the operator with the plant status information, diagnoses the plant status, recommends and performs the corrective actions, and confirms the recovery of the plant status.

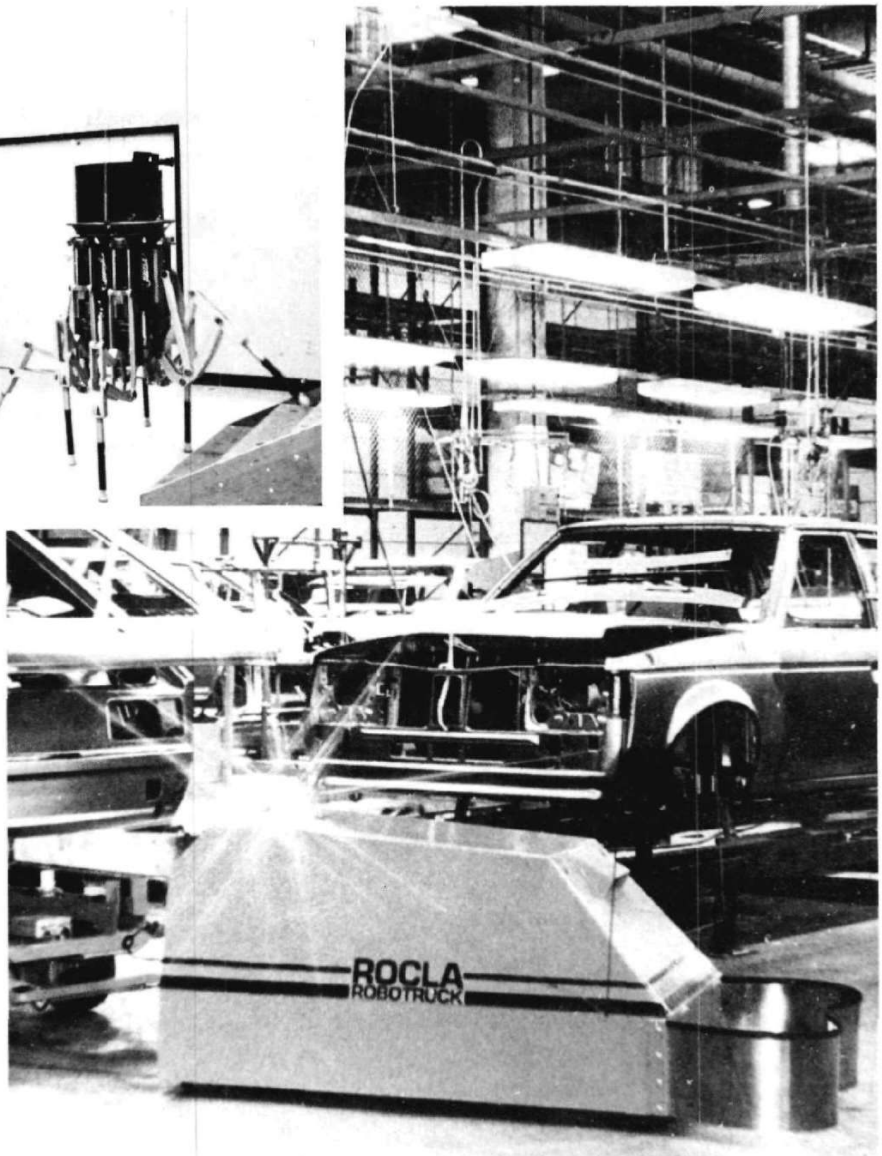
The first results that have been obtained in this field seem to be promising for the introduction of new technology and methods in the very important area of man-machine communication. But we still need more experience to answer the question of how the control room will look in the future.

Robots and remote systems

Associated with the recent advances in electronic controls have been significant developments in the field of robotics. Up until recently, robots were largely confined to science fiction literature. The robotics industry itself grew slowly due to the limited applications and the high costs of development. Now, however, developments are taking place rapidly as electric utilities have begun to consider the potential uses of robotics in nuclear power plants.

One of the most obvious reasons for the shift in attention is the robot's ability to work in hazardous environments such as the high temperature, high humidity, and high radiation areas found in nuclear power plants. In these areas working conditions are difficult, not conducive to high quality work, and human access is restricted, or severely hampered by protective clothing.

In some cases robots offer the potential to do work that simply cannot be matched by humans. In other cases, robots offer the possibility to improve availability by shifting some outage activities off the critical path. For example, some surveillance and maintenance tasks in the reactor containment, which are normally performed only when the reactor is shut down, may be performed by robots while the plant is on-line. Robots also offer the advantage of not tiring out or having a "bad day" and are thus capable of working around the clock during an outage. In nuclear applications where quality assurance measures are essential and often



Typifying growing industrial interest in robotic systems: a robotic fork-lift truck works on an automobile assembly line in Finland, *while in the nuclear industry,* researchers put the Odex robot through its paces at the US Electric Power Research Institute. (Credits: Tech Ops, Inc.; inset, Odetics, Inc.)

costly, they offer the advantage of reliability, precision, and repetition.

Worldwide efforts currently underway to optimize radiation dose commitments and reduce exposures to "as low as reasonably achievable" provide an additional driving force to develop robotics. So far, six robots have been tried or proposed for use in the clean-up efforts at the damaged Three Mile Island reactor (TMI-2). Last November, for example, an inspection robot called RRV was introduced into the basement of the highly contaminated reactor building. Prior to the robot's entry, the area had not been viewed since the accident in 1979 except by glimpses with small optical probes.

Recent nuclear robotic developments tend to focus on three main areas: surveillance, inspection, and maintenance activities. In the areas of surveillance and inspection, a number of prototypes have been developed and are being tested in practical applications. A typical example is a robot that can continuously monitor radiation, temperature, and relative humidity. The robot can climb stairs, go through low, tight passages, listen for steam leaks with its noise sensors, read gauges with its video cameras, and take up to 18 radioactive contamination smear samples.

Small, mobile surveillance robots are also under development for security duties such as patrolling the perimeter of a building. Although robots for reactor vessel weld inspection have been in use for some time now, new robots are being developed for other difficult weld inspection areas, such as those associated with loop pipe cracking at boiling-water reactors.

The application of robotics to nuclear maintenance is perhaps one of the most promising areas of future development. Robots equipped with high-pressure spray nozzles have been in use as early as 1983 to decontaminate walls and floors at TMI-2 and a remote concrete chipping device is under consideration for use in the containment basement. Robots that perform steam generator tube inspections and repairs recently have become available, eliminating the need for humans to "jump" inside the high radiation fields of the plenum area. Studies indicate that robots used for reactor cavity clean-up and maintenance bolting activities will pay back their development costs in less than a year. Robot welding applications are also considered to have a good potential for reducing outage times.

The ultimate goal of robotics developments will most likely be the development of machines containing artificial intelligence that are capable of fully autonomous operation with some form of self-controlled reasoning. Thus, the future of robotics lies in developing the union between artificial intelligence and the machine. Although operator-guided robots can be expected to be in wide use by the turn of the century, the practical application of autonomous robots is not expected by most experts to occur until a decade or two later.

All these innovations are obviously very expensive, and require a lot of manpower, so it is a real challenge even for big industrial countries. In this situation it would be beneficial for all countries, especially for developing ones, to make the best use of the IAEA policy to promote international co-operation and exchange of experience in this field.

From the early 1970s, the IAEA has carried out a series of specialists meetings and symposia in the field of instrumentation and control with the aim of technical information exchange in areas surveyed here. Since innovations of electronic components and programmable processors are rapidly developing and interest in robotics for nuclear applications, as well as for other industries, are growing worldwide, the Agency is planning to hold in 1987 an International Conference on "Man-Machine Interface in the Nuclear Industry; Control and Instrumentation, Robotics, and Artificial Intelligence". Articles featured in this issue of the *IAEA Bulletin* may serve as preview and background to many topics the conference will cover.