INTRODUCTION

Mechanical engineering research and development in AECL is proceeding at the Whiteshell Nuclear Research Establishment in Manitoba, at Power Projects, Sheridan Park, Ontario, and at the Chalk River Nuclear Laboratories.

We normally use the term "development" very loosely; however, to give you a better understanding, nearly all the Whiteshell work is in the basic development category, while the majority of work at Power Projects is prototype testing and equipment proof testing. The mechanical engineering development effort at Chalk River is split equally between longer-range development and shorter-term problem solving of difficulties that occur at the nuclear power plants.

Prototype testing applies to the first unit produced and proof testing applies to units intended for normal service. The basic development program is intended to produce both, basic understanding and specific data, that can be used to progress from the unreliable "state of art" approximations to properly engineered processes and products.

In the time available, it is only possible to introduce you to a typical list of activities for each site and describe one or two of them.

Whiteshell Development

Mechanical engineering development at Whiteshell is proceeding in the Components Development Branch which is made up of five professionals and nine technicians, and in part of the Design and Project Engineering Branch where two professionals and one technician are involved.

A list of typical development work is shown in Table I. Only two of these will be reviewed.

Holography and heat-exchanger development

Holography

Development work is proceeding to establish the applicability of holographic-interferometry to high-temperature displacement measurements. The major advantage of this technique is that no mechanical attachment is required on the hot specimen. The stability of the laser beam at high temperature makes the measurements most reliable. With a helium-neon laser, resolution to 13 micro-inches is possible. The laser used in the following experiments was quite low powered (15 mW). The experimenters believe that with a more powerful laser this method can be used up to the material melting point.

The basic arrangement used in making holograms is shown in Figure 1: the film normally receives two exposures; one for each of the test piece conditions that is to be observed. For a pressure vessel, this could be the unpressurized and the pressurized state. The film is then developed and then illuminated with the laser. The interference patterns that were formed by the incident and reflected laser beams from the vessel in the neutral and displaced condition are then visible.

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Figure 1—Basic arrangement used in making holograms

Figure 2 is a hologram of a pressure vessel. Calculations can be made based on the measured angles in the physical set-up, the wavelength of the laser beam, plus the number of interference fringes observed, which will give the amount of surface displacement.

This technique was used on a graphite cantilever beam heated in a metallurgical furnace equipped with a quartz window. Prior to this test, there was concern about the effect of glow from a high-temperature object. At 700°C, the graphite beam became incandescent but this did not seriously affect the quality of the holograms; however, at 800°C the luminescence was a problem. In this test the graphite beam was deflected 0.0002 inches and the holograms were checked against deflections calculated for various points along the beam using a standard beam formula. The largest error was in the order of 3 micro-inches near the fixed end of the beam and was probably due to slight shifting of the apparatus.

Heat exchangers

In the area of heat-exchanger development, Whiteshell has developed computer programs capable of evaluating complex turbine cycles. To accomplish this, portions of the program calculate the heat-exchanger surface requirements and are based on the best data currently available. Whiteshell's interest is in using the organic-cooled primary heat-transport system in a power reactor, where the heat is transferred from the pressurized-organic-coolant primary to the boiling secondary. The heat-transfer film coefficient for the organic coolant is lower than for water at comparable velocities; therefore, allowance for inaccuracy in this coefficient has a very significant effect on the calculated heat-transfer surface.

At the present time, the Whiteshell engineers are in the early stages of a proposed development program to establish, with more accuracy, the heat-transfer parameters and fouling factors on both the primary and the secondary side of a boiler containing an organic on the primary and boiling H₂O on the secondary.

The proposal is to build a 16-MW boiler for use on one primary coolant loop of the Whiteshell reactor and consideration is being given to including inconel, monel and carbon steel tubing to assess their relative acceptabilities in this service. The program will also provide useful data on the required coolant chemistry control.

The proposed instrumentation will provide the normal primary and secondary temperatures and also a temperature profile in the organic along the length of the heat-exchange tube. In addition to the heat-transfer aspects, the plan is to design for minimum tube and baffle vibration. This will undoubtedly lead to testing various design concepts prior to manufacture of the 16-MW boiler.

Power Projects Development

Power Projects at Sheridan Park have a large development laboratory (Figure 3). Twenty engineers and 75 technicians are employed by the laboratory. A large part of the work here is prototype testing and equipment proof-testing. Table I shows a list of typical jobs in which the project is currently involved. Of these, only the last two will be discussed in any detail.

Approximately 50% of the staff are engaged in fuelling machine and fuel transfer equipment testing. This subject is too large for reasonable coverage in this talk; however, Figure 4 shows a view of one of the three fuelling machines being tested for the RAPP reactor in India. Figure 5 shows one of the 11 fuelling
machines being tested for the four Pickering reactors. The prototype machine is included in the above figure.

Figure 3 — PP development lab

Figure 4 — PP fuelling machine

Automatic tube welder

In a nuclear power plant there is a great deal of relatively small tubing used for instrumentation and sampling. Mechanical tube fittings, which are acceptable for high-pressure and high-temperature heavy-water service, are costly and are considerably more prone to leakage than high-quality welded joints. To ensure high-integrity welds, automatic tube welding was required. Good automatic tube welders were not available for field use.

Development work has continued for nearly ten years and AECL's automatic tube welders for portable field use now have most of the desirable features. These are

- Power supplies (Figure 6) with current stability adequate to provide consistently good welds on one-quarter inch O.D. 0.049-inch-wall tubing, which is one of the most difficult sizes to weld;
Quick opening welding heads for tube insertion (Figure 7) instead of bolted closures;

Adequate clamping jaws for tube alignment and retention (Figure 8);

A tube stop for accurate positioning of the tube end under the electrode;

Low surge current when the electrode is inadvertently shorted on the work piece. This is provided by a high-response control circuit with feedback, to operate silicon-controlled rectifiers;

Elimination of high frequency flashover in the control cabinets, and induced voltage interference in the weld head drive circuit controls (Figure 9);

A constant electrode to weld distance has been provided by the addition of a tube follower to guide the electrode;

Proper inert gas blanketing by completely enclosing the weld area;

Considerably increased mechanism reliability with more tolerance to reasonable amounts of construction dust and dirt.

Compactness was also desirable and automatic welders are available for one-quarter-inch tube that need only 2½ inches radial clearance. To date, seventeen automatic welders have been built and two more are under construction. Approximately 40,000 production welds have been made to date.

It is unnecessary to radiograph these welds, as it is now possible for the engineering and technical personnel to review recorder charts for the current, voltage, and time and accurately predict the weld quality. While the really troublesome problems have been overcome, the engineers recently indicated that there are still several areas where improvement is desirable.

Another area of development testing has arisen because present safety rules require that the 750-MW Bruce reactors be provided with two independent fast shutdown systems. In one of these systems, a neutron-absorbing solution, referred to as poison, is injected into the heavy-water moderator. Within 5 milliseconds of the initiation signal the first poison must reach the reactor, and in 811 milliseconds from time zero approximately 25 cubic feet of poison liquid must be injected. The poison must be sufficiently distributed in the moderator to provide a negative reactivity effect of 15 milli-k in 811 milliseconds and subsequent dispersion must provide 50 milli-k negative after approximately 7 seconds. To accomplish this injection, helium at pressures up to 1400 psig are used (Figure 10). The helium is stored in a 15-cubic-foot tank and passed via three parallel...
Figure 10 - Flow diagram of poison injection valve circuits to each of nine poison tanks approximately three cubic feet each. The poison is forced from each tank to the reactor via a 2½-inch pipe to an injection nozzle 15 feet long containing 926 quarter-inch holes to distribute the poison in the moderator. The poison tanks must empty in not more than 1140 milliseconds. There is a requirement that little or no helium is to follow the poison into the calandria because of the danger of overpressure in the reactor vessel.

To accomplish this, the poison tanks (Figure 11) are approximately 9 inches in diameter and 7 feet long with a ball seal at the bottom. A tank has been tested with a ball floating on the poison liquid. This ball is intended to seal against a seat in the base of the tank to prevent blowthrough of the helium when the tank empties. Initially the incoming helium jet caused enough turbulence and liquid surface break-up that the sphere did not follow the falling liquid surface. Redesign of the helium inlet has overcome this problem in the model tank.

In the full-size test, the simulated reactor vessel contains clear water. This vessel is very well lighted and equipped with viewing windows. Water in the poison tanks has phenolphthalein added to produce a bright red colour. A colour movie camera operating at 600 frames per second is used to check the time lapse between the initiating injection signal and the first show of colour from the injection nozzles.

The photographic record is also used to check the poison distribution along the nozzle length and also its penetration into the moderator. Since the negative reactivity effect is dependent, to a considerable degree, on good dilution of the poison in the moderator and it is not possible to accurately assess this from the movie films, trials are to be made using photocells and conductivity cells as a means of measuring dilution of the red dye.

A series of liquid-level probes on the poison tank are used to provide the data on injection rate versus time. During similar tests at an earlier date, it was found that the best commercial probes available were not clearing quickly enough since accuracies within a few milliseconds were required. Therefore, the engineer responsible for this work developed a fast-response probe.

In addition to the level probes, photocells will be used near the top, mid-height and bottom of the poison tanks to register the passage of the floating ball mentioned previously. This data, in conjunction with that of the probes, will indicate whether the ball leaves the liquid surface at any time.

Phenolphthalein was chosen as the poison dye in these tests because the liquid in the test reactor vessel can be cleared by adding a small amount of acid.

Chalk River Development

The 30 engineers and 21 technicians in the Special Projects Division are engaged in work that provides support for the Canadian nuclear power program.

Table 1 lists typical current activities. Only the activities on valve stem sealing, computerized storage, and reliability analysis will be reviewed.
Valve steam seals

The Nuclear Power Demonstration reactor and the Douglas Point reactor have pressurized-heavy-water primary systems. D₂O leakage and valve maintenance problems showed valve improvement was necessary.

Unrecovered leakage and upgrading of recovered heavy water are both costly. Valve servicing requires shutdown of the plant which is also costly. Valve servicing even in the shutdown radiation fields places too large a man-rem burden on the maintenance staff.

Because of these conditions a valve-stem seal development program was initiated and since 80% of the nuclear power station valves were under 2-inch pipe size and of the packed stem variety, the emphasis was placed on these first (Figure 12).

Literature searches indicated there was very little engineering data on valve stem sealing. Design practises appear to have been evolved rather than developed. A test program was set up using a brand of packing used widely at the power stations. Numerous tests were conducted in packing-leakage-test rigs where temperature, stem finish, packing lengths, packing axial stress and packing area were varied (Figure 13). These indicated that packing axial stress was the most important single variable and that the gland load decreased relatively quickly early in the test period.

Similar rigs using Belleville spring-loaded gland followers to compensate for packing consolidation were used next (Figure 14). At packing stress levels of 3 500 and 9 500 psig, the leakage rates fell within the range of that on previous tests.

This program is now being expanded to stem sizes up to 3-inches diameter.

The previous testing indicates that packing compressions of 8 000 to 10 000 psig are needed to control stem leakage (Figure 15). This results in significant friction forces on the stem. Inadequate allowance for this results in inadequate stem strength, and undersize handwheel or operator. Thus, valve operation is difficult or impossible.

Testing is under way to establish accurate friction loads for various packing.

![Figure 12-Valve stem seal](image)

![Figure 13-Stem packing leakage test rig](image)

![Figure 14-Belleville washer rig](image)
After having been in service for a period of time, leakage occurs on the packed stem valves. The packing is very hard and it is located in a very confined space. Development is proceeding to provide properly engineered removal tools, such as powered multiple drills and removal screws and hydraulic packing removal equipment.

Cartridge packings are also being developed that will remove quickly and easily in one piece (Figure 16).

Packing materials and stem materials must be compatible. We have had instances at reactor sites where severe corrosion has taken place. Therefore, investigations as to the packing formulation, and testing with stem materials under varying conditions are also being done.

This is a very abbreviated review of our valve development work. The results of our work to date have been sufficiently good that significant numbers of valves at Pickering and Gentilly reactors are being modified based on this development data.

Small computer uses

The quantity of information generated during routine operation of a nuclear power station staggers the imagination. Nevertheless, the recent and long-term history of systems and components must be readily available, if the station staff are to cope with the demands of routine maintenance and unforeseen difficulties. To answer these questions would require several days of manual searching through records of past years, which are often distributed among the design, operations and registry files. The implementation of computerized data storage and retrieval has alleviated some of these problems; but for the most part these have relied upon large, costly and somewhat inaccessible computers.

During the last year, programs have been developed to permit a small digital computer to be used for a variety of data storage, retrieval and analysis problems. In each case, the developed technique has been applied to data from the Douglas Point Nuclear Generating Station before being expanded for more general use in the Canadian nuclear power program.

Programs which have been in use for some months are

- fuel-performance studies,
- production and maintenance reviews,
- reliability analysis.

The program on the fuel performance has been very useful in identifying those channels with minor defects in the fuel. This is very helpful in that the fuel can be removed with reasonable convenience and prior to enlargement of the defect. This, of course, reduces the possibility of additional radioactive contamination of the system.

Reliability analysis

Electrical power-producing stations try to achieve high-capacity factors to keep the unit energy costs as low as possible. Eighty percent is the usual aim, and most nuclear plants are well below this. A reliability analysis group at Chalk River is engaged in developing methods for assessing the reliability and maintainability of equipment and systems in nuclear power
stations.

The objectives of this group are

- to develop quantitative target capabilities for components and systems;
- to measure capabilities in operating stations and predict capabilities in those currently under design;
- to develop assessment techniques and thereby accelerate the learning process;
- to stimulate awareness of the reliability and maintainability requirements with designers, manufacturers, and site contractors since it is these people who can reduce the built-in unreliability.

The production and maintenance review programs mentioned previously will provide much of the data for reliability analysis.

It is hoped that this review gives you a better understanding of the scope of work available in AECL for the mechanical engineer interested in development. You will have noted the interdisciplinary nature of most work projects. The well-trained development engineer, besides identifying the problem, planning and executing the program, and analysing the results, must recognize the need and importance of support from other branches of engineering, and other professions. In most of the jobs reviewed there is a need for consultation with chemical, metallurgical and physicists experts as well as experts within the mechanical engineering field.

If any of you wish to follow up on any of the items noted during this talk, I would be pleased to have you contact me and I will make arrangements for you, with the Whiteshell, Power Projects or Chalk River personnel most knowledgeable in the area of your interest.