OPERATION OF THE

WR-1 ORGANIC COOLED RESEARCH REACTOR

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ABSTRACT

The organic cooled, heavy-water moderated, Canadian research reactor WR-1 has operated during the past four years at coolant outlet temperatures up to 375°C and with an average availability of over 85%. Its operation is claimed to be more trouble free than that of a pressurized water system, due chiefly to the high temperature obtainable with low operating pressure in the primary system and the very low radiation fields encountered near the primary piping. Coolant chemical control, equipment performance and fuel management are all discussed, as are some of the problems peculiar to the use of organics, such as fire hazards. The future prospects of the organic-cooled concept indicate that overall efficiencies of between 37 and 39% would be expected.

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Fonctionnement du WR-1
réacteur de recherche à caloporteur organique

par D.R. Tegart
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Résumé

Le WR-1, réacteur de recherche canadien modéré par eau lourde et employant un caloporteur organique, a fonctionné au cours des quatre dernières années à des températures allant jusqu'à 375°C à la sortie du caloporteur et sa disponibilité moyenne a été de plus de 85%. On prétend que son fonctionnement donne moins d'ennuis que celui du système à eau pressurisée, principalement grâce aux températures élevées qu'il permet d'obtenir avec une faible pression opératoire dans le système primaire et grâce aux champs de radiation très faibles aux abords des canalisations primaires. Le contrôle chimique du caloporteur, la performance du matériel et la gestion du combustible sont passés en revue ainsi que certains des problèmes particuliers auxquels donne lieu l'utilisation des fluides organiques, par exemple les dangers d'incendie. Le caloporteur organique devrait permettre d'obtenir des rendements globaux de 37 à 39%.

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1. INTRODUCTION

The organic cooled WR-1 reactor, located at the Whiteshell Nuclear Research Establishment of Atomic Energy of Canada Limited, has now had four years of outstanding operation. I am pleased to have this opportunity to tell you about it.

WR-1 is related to OMRE* and Piqua**. These were organic cooled and moderated reactors. Circulation of the organic, as coolant only, in WR-1 has avoided the difficulties encountered in Piqua. This and other developments have dispelled any doubts about the feasibility of the organic cooled reactor concept. These developments include zirconium alloys for fuel sheathing and pressure tubes, use of an organic which is liquid at room temperature, and operating techniques successfully demonstrated in WR-1.

The WR-1 reactor has operated throughout the past four years at outlet coolant temperatures up to 375°C (707°F). Although it is a research facility not being used for power production, the outlet conditions suggest electrical efficiencies approaching 39%. It already has a high utilization for research. As many as 14 of the 37 pressure tube sites contain irradiation experiments and an ambitious loop programme is underway.

Detailed references to the WR-1 reactor design and to the status of the organic coolant technology have been published. In this paper I will discuss the operational aspects of WR-1: Operations involvement in design, commissioning and operation, and equipment performance to date. I will attempt to emphasize differences between operation of organic cooled and other reactor circuits. A short description will put these remarks in context.

The WR-1 reactor, (Figure I), is a heavy water moderated, organic cooled reactor, of vertical pressure tube design. It has 37 fuel sites commissioned with provision for future uprating to 55 fuel sites for a nominal power rating of 60 MW. Organic coolant is supplied by two independent primary circuits, each supplying approximately one-half of the 37 site core.

The reactor is controlled by heavy water moderator level, which is regulated by differential helium pressure between top and bottom of the core space. Rapid shutdown is achieved by dumping the moderator from the core. Boron is used in the moderator to adjust reactivity to suit varying fuel burnup and poison conditions. The boron is adjusted semi-automatically through ion exchange columns.

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* Organic Moderated Reactor Experiment, NRTS, Idaho Falls, Idaho
** Organic moderated power reactor, Piqua, Ohio
FIGURE I: Whiteshell Reactor No. 1
The fuel is 2.4 wt% enriched UO₂ clad in zirconium 2.5% niobium alloy, (Figure II). Each fuel string consists of five 18-pencil bundles on a central shaft to form an eight foot long fuel assembly. These assemblies are contained in readily removable channels, accessible at both ends. Fuelling is carried out under shutdown conditions by means of rotating deck plates and a shielded flask handled by the main building crane.

To be useful, a reactor organic coolant must have good pyrolytic and radiolytic stability, produce decomposition products which are soluble in the bulk coolant and be compatible with system materials. Operational considerations, such as trace heating requirements, assurance of fluid instrument lines and general ease of maintenance, make a coolant which is fluid at room temperature desirable.

The reference coolant for WR-1 design was Santowax OM*. This is a useful coolant as demonstrated by the terphenyl mixtures used in OMRE and Piqua. Unfortunately, it is a crystalline solid at room temperature. Therefore an alternative coolant, HB-40**, was selected for startup of the reactor, after evaluation by our Research and Development staff. HB-40 is a partially hydrogenated terphenyl mixture, fluid at room temperature. Knowledge of its use in the reactor has shown its performance quite comparable to that of Santowax OM for a long range coolant.

2. OPERATIONS INVOLVEMENT IN DESIGN

As in selection of the coolant, operational considerations were emphasized throughout design. I am sure that all operating people, time and again, have wished that they had talked to the designers continually during design. That opportunity was available to Operations in the WR-1 design and we took full advantage of it. Trouble-free commissioning and subsequent smooth operation resulted.

In this, I do not mean to deprecate the designers. Our designers, Canadian General Electric Company Limited, were excellent and did, we think, an excellent job under the monetary restriction we imposed. However, definite benefits, mutual to Operations and Design, were gained by injecting long operating and maintenance experience into the design and by exposing operating personnel to design concepts in the design stage.

In WR-1 we had a team of six operations engineers with long

* Monsanto Company tradename for a terphenyl mixture

** Monsanto Company tradename for a partially hydrogenated mixture of terphenyls
FIGURE II: WR-1 Fuel Bundle Assembly
reactor operating experience, advising, commenting and vetting all design from the preliminary to the final detailed stages. These engineers later formed the nucleus of the commissioning and operating staff. The designers wrote the design manuals, but the operating engineers were responsible for the commissioning and operating procedures and manuals. These were done concurrently with the design, at least in the first draft form. This involvement of operating personnel was invaluable. It aided a smooth transfer from construction to commissioning and provided a competent operating crew with full confidence in the design and equipment.

3. COMMISSIONING

Construction of the reactor started in the summer of 1962. The reactor went critical in November 1965, about 3½ years later. Commissioning was smooth and well within schedule. The operating engineer involved in each system during design continued that responsibility during commissioning and into early operation of the reactor. Full power was reached six weeks after criticality.

4. OPERATION TO DATE

WR-1 has been operating well, perhaps well above our expectations. With an average availability of over 85%, a great deal of the operation has been at a coolant outlet temperature of approximately 370°C (698°F). Long uninterrupted periods of operation have been obtained, diminishing any doubts about the practicability of operation with organic coolants at high temperature. We think that the commissioning and operation of an organic cooled reactor, at least as demonstrated by WR-1 to date, is more trouble-free and straightforward than that of a pressurized water cooled system. That this is so is due to two main characteristics inherent in the use of organic coolants:

(i) The dominant feature of an organic cooled reactor is the high temperature obtainable with low operating pressure in the primary system.

(ii) The radiation fields near the primary piping, feeders and headers are practically negligible.

The advantage of the first of these is quite self-evident, resulting in the easy operation of closures, valves, fuel removal equipment, etc., as well as reduced cost of maintenance. The second is perhaps a less
well defined benefit. It is novel if not remarkable to one who has worked with water cooled reactors for years. The problems of access control for normal operation and maintenance are made minimal. Shielding is reduced and normally restricted areas are open for maintenance not only on shutdown but also during steady operation. The radioactive fields on the outlet feeders of WR-1 are normally less than 5 mR per hour and there is no evidence of mass transfer of corrosion products. We have had major pieces of equipment, such as heat exchangers, out on the main reactor floor dis-assembled with absolutely no evidence of contamination. Even with a low water content of up to 500 parts per million necessary in the coolant to prevent hydriding of the zirconium alloy fuel sheaths, there is no problem with N\textsuperscript{18} activity. This lack of activity in the primary coolant is a normal condition.

5. FIRE HAZARD

Processing organic liquids under high pressure and at high temperatures is quite routine in the petrochemical industry. Based on this, the question of fire prevention in an organic cooled reactor operating at high temperature is also somewhat routine. There is the difference, however, that the reactor organic circuits are in confined spaces and the consequences of a fire would relate to a nuclear hazard which might be involved. Therefore, before we gained operating experience there was some concern. The operation of the Piqua reactor, however, had already shown how good housekeeping and attention to leaks could reduce the fire hazard. In operation of WR-1, apprehensions in this regard have been dispelled. We have had a few small fires, which have been confined to glowing insulation, and two significant hot organic spills with no fire.

Operation of an organic coolant near and above the auto-ignition temperature (AIT) requires special attention. The AIT varies with the high boiler content in the coolant, varying from 350°C if no high boilers are present to 395°C with 30% high boilers. Laboratory tests have shown that piping above the AIT will serve as an ignition source provided the residence time is sufficient (about 10 seconds of contact between the organic and hot piping) and provided the surrounding air temperature is high enough.

We plan on increasing the outlet coolant temperature, and therefore some piping temperatures, to above 400°C so the AIT is an important consideration. This is especially so since we have two areas which could be considered hot boxes with unlagged piping and, at present, insufficient ventilation to cool the air below a critical temperature. One of these areas (Figure III) includes all the closures for the fuel channels and involves a higher probability of a leak than for normal piping.

We have taken certain precautions in these hot boxes as well as in all other rooms containing organic circuits. All such areas are protected with fog and water sprays. Normal ignition sources are eliminated by the use of explosion-proof fittings and thorough grounding of all piping.
FIGURE III: WR-1 Reactor Upper Service Space.
Lagging is carefully installed and 'muddied up' to make sure as little air space as possible is included which might promote auto-ignition. Where practical, ventilation reduces the surrounding air temperature to below critical and reduces the probability of organic vapour concentrations. In the hot boxes, where lagging and sufficient ventilation are impractical, inert gas (CO₂) systems have been installed to purge the oxygen present and eliminate the possibility of a fire. Probably the most important preventive measure is good housekeeping and prompt attention to leaks.

To date, experience in WR-1 indicates that any fire hazard in operating with organic coolants at high temperature can be dealt with in design and operating procedures.

6. COOLANT CHEMICAL CONTROL

Operation of WR-1 has demonstrated that fouling of heat transfer surfaces and hydrogen uptake by zirconium alloys in the primary system can be controlled by coolant chemistry.

Possible fouling of heat transfer surfaces is a concern in an organic cooled reactor, where even the most stable organic compound is altered by radiation and pyrolysis. AECL research has shown, somewhat empirically, that if the organic coolant can be kept free of chlorine and low in metallic oxides fouling of heat transfer surfaces can be controlled. A small amount of water (50-500 ppm) in the coolant and side stream circulation through clay columns aids this control.

Hydrogen uptake by zirconium alloys can be kept to acceptable limits provided the oxide film on the zirconium can be kept intact. The oxide film is an excellent barrier to hydrogen migration. Again, a small amount of water in the coolant is necessary to maintain the oxide film and chloride contamination must be kept below 0.5 ppm.

7. SOME OTHER CONSIDERATIONS

Despite all the precautions that may be taken, some organic vapour escapes into the reactor and building ventilation systems. In such an atmosphere absolute filters in the ventilation stream do not last very long. In WR-1 after two years of incident free operation with filters, we are now bypassing them for normal operation with provision to put them on-stream, automatically, should any activity above normal show up in the ventilating air. This does not satisfy the safety people completely, so development of other means of trapping the organic before it reaches the filters and/or removing possible fission products is underway.
There are a few other areas in which operation of an organic cooled circuit differs from that of a water cooled circuit. For example, there is a need for some trace heating. This is not extensive in WR-1, since we use HB-40, which is fluid at room temperature. Pump seals on standby units are our main concern in this respect.

There is also the necessity of storing spent fuel in organic in the spent fuel storage bays. Any spill would foul the water in the bays. In WR-1, we have had no difficulty in this regard. Organic filled tubes contain the fuel adequately.

8. EQUIPMENT PERFORMANCE

Before reactor startup we were apprehensive about being able to eliminate leaks of organic at high temperatures. Two main areas of doubt were at pump shaft seals and at the numerous piping closures and connections in the heat transport system.

Our main circulating pumps are 1000 h.p. Bingham pumps operating at 350 lbf/in$^2$ and 3600 rev/min. These see one hundred percent duty with no standby. Because there is no standby, we keep a complete internal assembly of impeller, shaft and seals available at all times. Since the first clean-up of the system, shaft seals have been changed only after each 12 - 14,000 hours running time for preventative maintenance only.

There are at least 300 piping connections including channel closures in the system. Grayloc* seals have given excellent service. To conform to the latest code requirements, two-bolt Graylocs are being changed to four-bolt Graylocs as downtime for maintenance permits. Detailed attention is given by our maintenance crews to proper torquing of Grayloc bolts.

To reduce possible leaks, some thought was given during design to elimination of valves wherever practical. For instance, valves were left out of most of the feeders to the fuel channels. For relatively infrequent channel removal, we use the freeze plug technique on the feeders to isolate the channels. The organic coolant is quite amenable to this method, which becomes more or less routine with practice.

The heat exchangers have operated well although two leaks have occurred in the flange gaskets on the organic side. The heat exchangers were removed, disassembled and repaired easily with no evidence of radioactive contamination. The repair of these heat exchangers is a good example of organic circuit maintenance. The heat exchangers and all

* Gray Tool Co., Houston, Texas
components of the primary system are virtually free of radioactive contamination. Maintenance requires no shielding, remote operation, dosimetry or any special techniques.

A leak in a rolled joint in a fuel channel gave some concern for a while. There is a space, vented with CO₂, between each fuel channel and the reactor vessel tube. Monitoring of this space for organic as well as heavy water leaks showed a defective weld in one channel. Although no more leaks have been found, it is interesting to note that the calandria tube, fouled two years ago by the one leak we had, is now clean. It appears that some activated oxygen in the channel/vessel space has been an effective cleaning agent over a period of time. This action had been observed in the laboratory and proposed as a means of cleaning hard films of organic from metal surfaces.

Failed fuel detection in an organic cooled reactor is simple because of the low background activity. Our system comprises bleeds from each channel monitored by Geiger tubes. This has worked well in detecting defected fuel in time to avoid failure.

9. UNUSUAL OCCURRENCES

Although the performance of the reactor has dispelled early apprehensions, there has been a normal complement of problems. Some of these peculiar to the use of organics are recorded as unusual occurrences.

There was one organic fire in April 1966. The fire was caused by auto-ignition of soaked insulation in the lower access space after an organic spill due to a maintenance error. It was extinguished without difficulty and the damage was negligible. As a result the insulation in this area was redesigned to make it less vulnerable to inadvertent spillage of organic.

Two valve component failures releasing a large amount of organic at a normal operating temperature of 370°C have occurred during reactor operation. One was the failure of an over-stressed seal clamp bolt on a control valve. The other was caused by a poorly designed valve stem stop. Needless to say, the recurrence of these has been eliminated by redesign. Neither instance resulted in fire and there was no difficulty in maintaining the reactor in a safe state.

We have had one failure of experimental fuel which thoroughly contaminated one primary circuit. Eight elements of an experimental assembly of uranium-impregnated graphite ruptured. Complete release of gaseous fission products occurred along with some Ba/Laⁱ⁴⁰. Very high radioactive fields, up to 50 R/h, remained on the primary piping after fission gases were removed by purging. Because of this high background, the failed fuel detection system became inoperable and the reactor could not be returned to service immediately. By operating the particulate removal system, the apparent half-life of the activity on the piping walls was reduced.
We were able to resume operation with no residual contamination present in about six weeks.

10. FUEL MANAGEMENT AND SAFETY

WR-1 has a relatively small core and is highly utilized by research. It therefore demands perhaps abnormal detailed attention to fuel management, loading problems and physics calculations. Our Operations people are intimately involved in this, backed up by a reactor technology group. Although research staff are responsible, in theory, for the hazards submissions relative to their particular experiments, the load, in practice, falls to a great extent on the reactor technology and operations personnel. Operations, have the ultimate responsibility for the operation and safety of the reactor. The fact that the coolant itself is still undergoing development puts a somewhat unusual burden on them.

11. CONCLUSIONS

This talk has been directed toward the operational aspects of organic cooled reactors with particular reference to WR-1. Because of this, I have said very little about the present status or future prospects of the organic cooled concept, as an extension to our basic natural uranium fuelled CANDU systems. To put our operational interests in context, I might stress that the technical feasibility of the organic cooled concept is assured and proven at outlet temperatures up to 375°C. The prospect of achieving operation at 400°C is excellent. Relating this outlet temperature to electric power production, overall efficiencies of 37 to 39% would be expected.

The basic advantages of high temperatures attainable with low pressures and the use of mild steels in the systems are now complemented by operational advantages demonstrated in WR-1. The exceptional freedom from radioactive contamination in the primary circuits and the absence of radioactive fields in primary circuit areas are a real benefit for operations and maintenance. To this we can now add successful performance of equipment, control of fouling and fire hazard, and the ease of commissioning and operation of organic circuits at high temperatures.
12. REFERENCES


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