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REPLACEMENT OF CORE COMPONENTS IN THE ADVANCED TEST REACTOR

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ABSTRACT

The core internals of the Advanced Test Reactor are subjected to very high neutron fluences resulting in significant aging. The most irradiated components have been replaced on several occasions as a result of the neutron damage. The surveillance program to monitor the aging developed the needed criteria to establish replacement schedules and maximize the use of the reactor. Methods to complete the replacements with minimum radiation exposures to workers have been developed using the experience gained from each replacement. The original design of the reactor core and associated components allows replacements to be completed without special equipment. The plant has operated for about 20 years and is expected to continue operation for at least an additional 25 years. Aging evaluations are in progress to address additional replacements that may be needed during this period.

1. INTRODUCTION

The Advanced Test Reactor (ATR) is a 250 MWt high flux research reactor located at the Idaho National Engineering Laboratory (INEL) that is used for materials irradiation and radioisotope generation. It has been in operation since 1969 and, consequently, has achieved very high total neutron exposures in components in and near the core. Irradiation damage to the core components has necessitated a partial replacement of components and two complete replacements of core internals with a third complete replacement scheduled for 1992. This paper describes the factors necessitating replacement of the components and the unique design features of the ATR that make it possible.

2. FACILITY DESCRIPTION

The ATR is designed to operate at relatively low temperature and low pressures using light water as the coolant and moderator. The primary coolant system (PCS) is designed accordingly. It consists of 304 SS piping and a vessel that is also 304 SS. The vessel is a right circular cylinder about 3.7 m (12 feet) in diameter and approximately 8.1 m (26.5 feet) long as shown in Fig. 1. The core is about 1.2 m (4 feet) in

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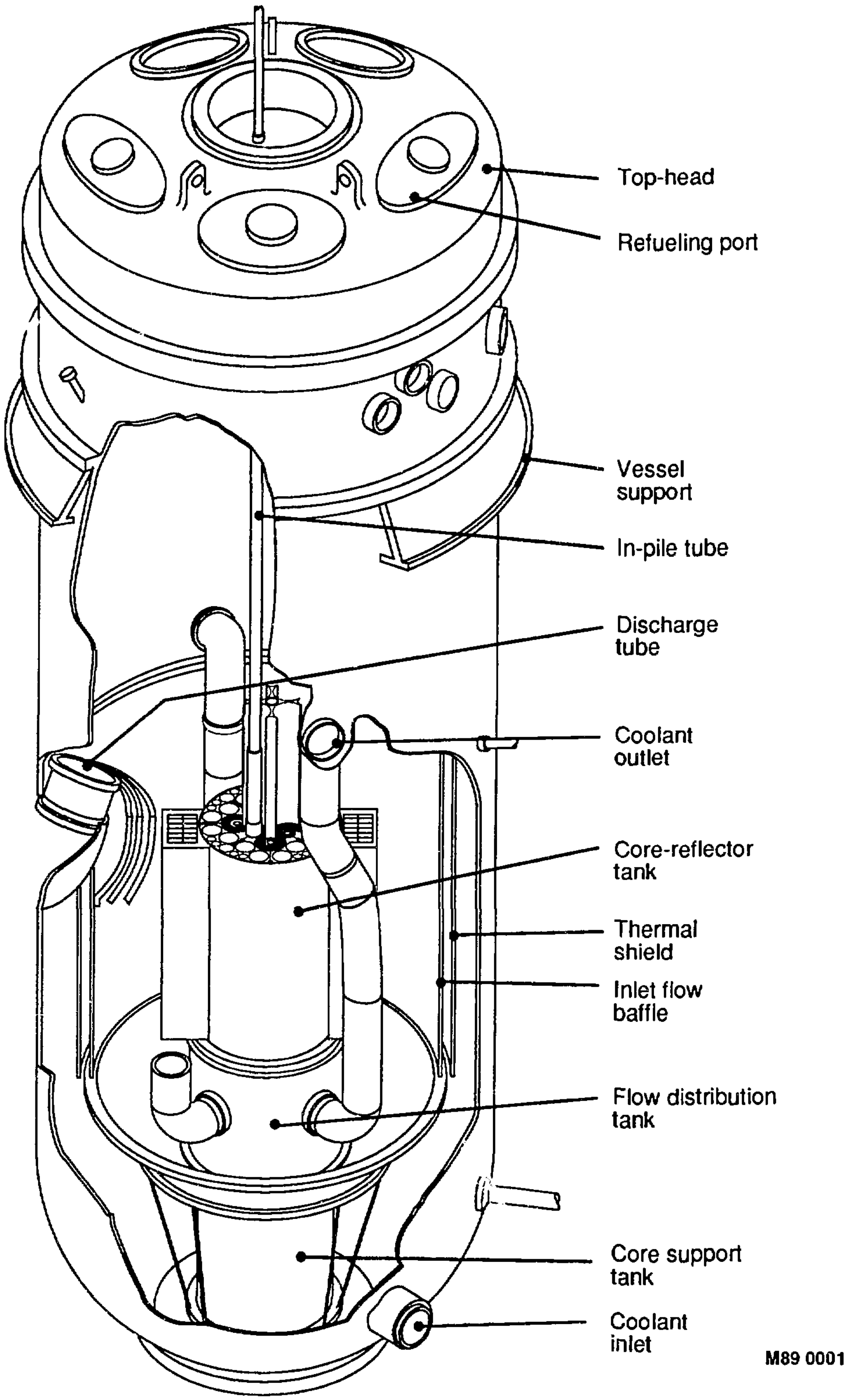

Fig. 1. ATR vessel.

diameter providing considerable distance between the fuel elements and the vessel wall. The coolant is circulated through the system at a rate of 2400 l/s. (38,000 gpm) to 3100 l/s (49,000 gpm) depending on the mode of operation. Heat is rejected to the atmosphere through a forced-draft, counterflow cooling tower.

The core contains 40 U-Alx plate type fuel elements with aluminum sideplates and cladding. The elements are each 1.2 m in length and are arranged in a serpentine array as shown in Fig 2. This serpentine arrangement forms nine flux traps that are irradiation positions containing in-pile tubes made of 348 SS. The tubes are double wall with an intervening space for helium used for the adjustment of heat conduction from the tubes. The in-pile tubes are surrounded by the flux trap baffle which supports the fuel elements. The safety rods are concentric to six of the in-pile tubes and occupy the space between the in-pile tubes and the baffles. The safety rods are constructed of aluminum with hafnium plates attached to provide neutron absorption. The central cruciform fixture (neck shim housing) is constructed of aluminum and supports 24 small diameter hafnium rods that are used to compensate for the fuel burnup. The housing also provides a number of irradiation positions used for testing and isotope production. The fuel is surrounded by a beryllium reflector containing a number of moveable beryllium drums with a hafnium plate attached to the outer diameter to provide neutron absorption. These rotating drums provide the control of the reactor by adjusting the power distribution and compensating for the burnup of the fuel. The design of the control system results in an axial power distribution that is nearly constant in time and permits a considerable neutron flux gradient from one quadrant of the core to another. The reflector also contains a number of capsule irradiation positions. The thermal neutron flux in the region of the in-pile tubes is about 10^{15} n/cm2 and about 10^{14} n/cm2 in the reflector.

3. AGING CONSIDERATIONS

The two main concerns with the components that are highly irradiated apply to the beryllium reflector and the stainless steel in-pile tube. The aluminum and hafnium components generally do not support significant loads and loss of ductility as a result of irradiation is not a concern. The irradiation damage is generally embrittlement or loss of ductility as a result of the high energy neutron interactions. The neutron energy range monitored for component damage due to embrittlement is one MeV and greater.

3.1. Beryllium Reflector

The reflector is installed in eight segments or blocks. Each block has two thin ligaments that are adjacent to the fuel annulus and experience considerable irradiation damage. The axial power distribution is cosine shaped resulting in more neutron interactions at the core midplane than at the top and bottom of the core. As a result, the nonuniform growth of the ligaments results in considerable stress with eventual cracking of the ligaments. This aging of the reflector can eventually lead to large segments of the reflector becoming free and causing damage to the adjacent fuel element. The reflector is replaced before this condition occurs.

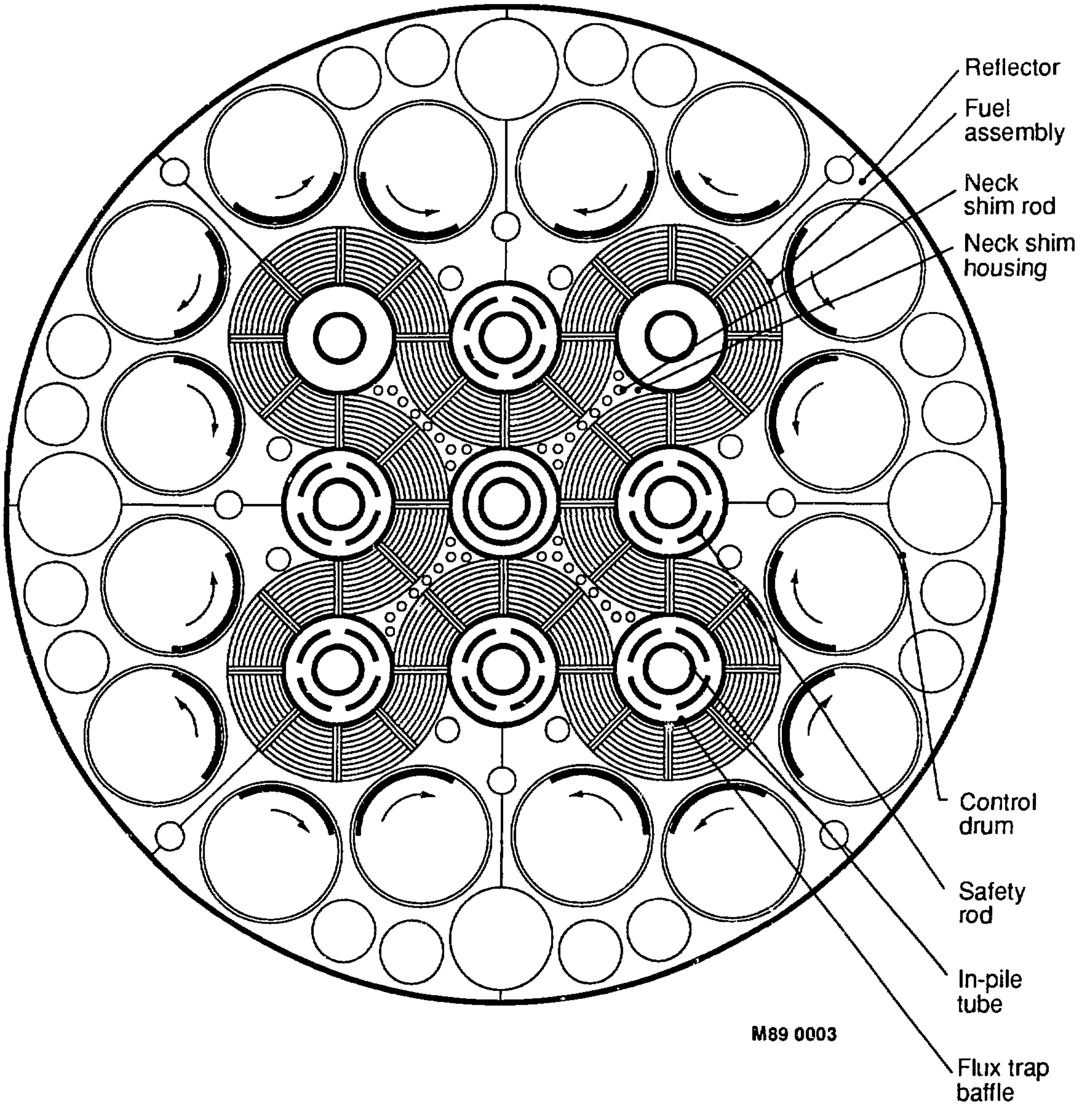

Fig. 2. Horizontal cross section of ATR core.

The reflector design was modified in 1977 relative to the original design to minimize the effect of the nonuniform growth. A number of horizontal cuts were made into the face of the thin ligaments allowing some expansion and thereby reducing the stress for a given exposure. The modification extended the life of the reflector by nearly a factor of two.

The exposure of the reflector is monitored to allow calculation of the stress distributions. These stress distributions are used to predict the aging of the component and allow it to be replaced before significant deterioration occurs. The calculations are complemented by a surveillance program to assess the extend of the aging. This surveillance includes visual examination of the exposed surfaces as well as monitoring of the PCS chemistry to obtain indications of beryllium and tritium which can indicate changes in the component.

3.2. In-pile Tubes

The in-pile tubes are located in high neutron flux positions and experience embrittlement from the interaction with the high-energy neutrons. The tubes are operated at relatively high pressure to allow experiments to be tested at elevated temperatures. The resulting stress on the tubes can lead to brittle fracture in the presence of a flaw and the reduced fracture toughness of the embrittled material. In order to preclude the brittle fracture which could lead to a damaging power transient for the reactor, a fluence limit has been established for the tube using code rules contained in the ASME Boiler and Pressure Vessel Code.

This fluence limit is based on an evaluation completed for the ATR. The data supports operation to a fluence level of 5.5×10^{22} nvt which is higher than exposures found in the literature. The data base was generated from irradiated in-pile tubes and from specimen specifically irradiated to support the ATR program. A considerable amount of experience is available for the operation of these in-pile tubes since the ATR is a third generation test reactor operated at the INEL.

The operation and analysis of the in-pile tube are supported by surveillance of the tubes to assure that the operation is within the established limits. This surveillance includes calculation and measurement of the neutron flux in the immediate vicinity of the tubes and the measurement of flaws in the tube wall. The flaw size, which is important to the analysis of the tube lifetime, is determined using ultrasonic techniques. This surveillance provides assurance that the tubes can be replaced before the limit is exceeded and the margin of safety is compromised.

3.3. Neck Shim Housing

The neck shim housing is adjacent to the fuel annulus and accumulates significant neutron exposure. Due to the operating power divisions, the exposure is typically nonuniform leading to uneven growth with subsequent bowing. This bowing will tend to close the fuel annulus and result in difficulty in replacing the fuel elements. The housing experiences some reduction in ductility, but the component does not support any significant loads and embrittlement is not a major concern.

Surveillance of the neck shim housing aging is performed using ultrasonic methods to measure the decrease in the size of the fuel annulus. The rate at which the annulus decreases provides information to project the time that replacement is required.

3.4. Flux Trap Baffle

The flux trap baffle is an aluminum structure supporting the fuel elements. As a result, the exposure to neutrons is significant. Some amount of loss of ductility results from the interactions, but the significant effect is the nonuniform growth of the component resulting in bowing. The bowing is more severe for the baffles that have fuel on one side and reflector on the other. This bowing results in a change in the fuel annulus as does the concurrent bowing of the neck shim housing.

3.5. Safety Rod Assemblies

The safety rod assemblies are located in the flux traps adjacent to the fuel elements. The assembly consists of a long tube of aluminum that moves vertically to position hafnium pieces attached to the circumference above the core during operation and within the core for shutdown. The incore portion during operation, which is aluminum, experiences the largest exposure. However, the loss of ductility is not significant to the performance, and the lifetime of the component is limited by the embrittlement of the hafnium. The bottom edge of the hafnium experiences sufficient neutron exposure to cause some loss of ductility thereby limiting its lifetime.

The fluence limit for the hafnium is 5.0×10^{22} based on evaluation of specimen irradiated in the reactor as well as evaluation of components removed from service. The surveillance of the exposure to the hafnium is based on measurements adjacent to the safety rod assembly and on calculations of the flux distribution using a standard neutron diffusion code.

3.6. Control Shims

The shims located in the neck shim housing are small diameter hafnium rods that are driven in the axial direction. These shims are attached to aluminum followers such that the aluminum is within the core when the shim is withdrawn. The hafnium experiences a loss of ductility due to neutron interactions, although the limiting consideration for these shims is loss of reactivity rather than any loss of ductility in either the aluminum or the hafnium. The loss of reactivity is monitored using standard physics measurements to assure that the minimum required reactivity is maintained.

The shims located in the reflector are hafnium pieces attached to beryllium drums. The performance of the beryllium is enveloped by the reflector performance. The aging concern for the hafnium component of these shims is the loss of ductility due to interactions with high energy neutrons and the transmutations due to thermal neutrons in the reflector.

The limitations were established by testing of specimen and by analysis of the neutron interactions and production of new isotopes. The surveillance of the exposures is based on measurements of neutron flux within the reflector and by calculations of neutron distributions using a standard neutron diffusion code.

3.7. Fuel Elements

The fuel elements are composed of aluminum clad plates with a matrix of U-235 in aluminum and aluminum side plates and end boxes. The limit on operation is based on the burnup of the fuel. Testing of the element supports operation to a burnup of 2.3×10^{21} fissions/cc. However, in practice, replacement due to the loss of reactivity as a result of depletion of fuel results in lower fission densities. The fission density is calculated using a standard neutron diffusion code.

3.8. Other Components

Other components located within the vessel and below the core are made of either aluminum or stainless steel and are typically located in regions of relatively low exposures. With the exception of the gearing for the shims located in the reflector, none of these components have been replaced. The gear assembly for the shims was recently redesigned and replaced. The replacement was not entirely age related since some performance improvement was desired. Evaluation of the other components for long term service is currently being completed.

4. AGING PLAN

The service of the components within the reactor vessel has been monitored since the beginning of reactor operation. In particular, the effect of neutron exposure has been evaluated and monitored. This has resulted in the replacement of the components listed above (3.1 through 3.6) several times. The formal evaluation of the exposures has been limited to the components located in the high flux regions of the reactor. This plan has been adequate to address the operation to date which has covered 20 years.

In preparation for an extended operation to at least 45 years, more formal evaluation of the other components in the plant are in progress. This formalized plan is patterned after the developing plans in the commercial nuclear industry. It will specifically address those components within the vessel that support and locate the more highly-irradiated components that have been routinely replaced. This additional evaluation will establish the capabilities that must be developed for replacement of components or establish the end of life when replacements are not feasible.

Recent improvements in the aging plan for the ATR include evaluations of the component lifetimes to obtain a reasonable match in lifetimes that results in changing most of the core components at the same time. This minimizes the shutdown time for the reactor and minimizes the exposure to the workers involved in the replacement.

5. REPLACEMENT EXPERIENCE

The current approach to the vessel internals replacement is to replace components in the vessel when the reflector reaches its end of service life. Generally, the in-pile tubes, control shims, neck shim housing, flux trap baffles, and some of the safety rod assemblies will be near the end of life and can be economically replaced at the same time. As a result, the life of the reflector tends to establish the frequency for the replacement activity.

The early replacement experience includes a more piece-meal replacement activity. The first reflector was replaced without replacing any other components at the same time. At various times single components such as in-pile tubes and flux trap baffles were also replaced. The reactor is presently using the fourth reflector, the third set of control shims, and the third neck shim housing.

The design of the vessel includes a top or head that can be removed to provide direct access to the internal components. Prior to removal of the head, it is necessary to remove the in-pile tubes. These components penetrate the bottom and top heads of the vessel through seals and are welded to the piping that provides the cooling water to the tube and its contents. After cutting the tube free from the piping it can be lifted into a cask and moved to a storage canal. Following the removal of the in-pile tubes and the vessel head, it is possible to access the other components using appropriate tools that are manipulated manually or with crane assistance.

The components are generally supported from the bottom and simply attached together with common fasteners such as captive bolts. The bolts are loosened through the open head using socket-wrench tools. The components are then removed from the vessel and placed in an adjacent canal shown in Fig. 3 for storage until disposal. The largest components, the neck shim housing and the reflector blocks, are taken out through the open head. The removal is done in air without shielding by evacuating all personnel from the building with the exception of a crane operator and supervisory personnel who work from a shielded station to move the components from the vessel to the adjacent canal. This approach of unshielded transfer has been very successful and cost effective.

Smaller components are removed using a transfer mechanism built into the vessel. This mechanism depicted in Fig. 3 is used routinely during normal operation to transfer fuel elements and capsule experiments between the storage canal and the vessel. It is essentially a long tube located in the canal that can be pivoted into an opening in the vessel thereby allowing access to the top of the tube from the vessel. The opening to the vessel for this transfer tube is closed during normal operation. The tube is used during the replacement of vessel internals to transfer the smaller components such as control shims and flux trap baffles.

The components removed to the canal remain there until appropriately packaged for transfer to the disposal site. The disposal is in a controlled disposal area maintained at the INEL. Some of the components such as the in-pile tubes and the safety rod assemblies which are rather long are cut into smaller lengths to facilitate handling and packaging. The cutting is accomplished using a commercially available, electric-arc saw contained in the storage canal.

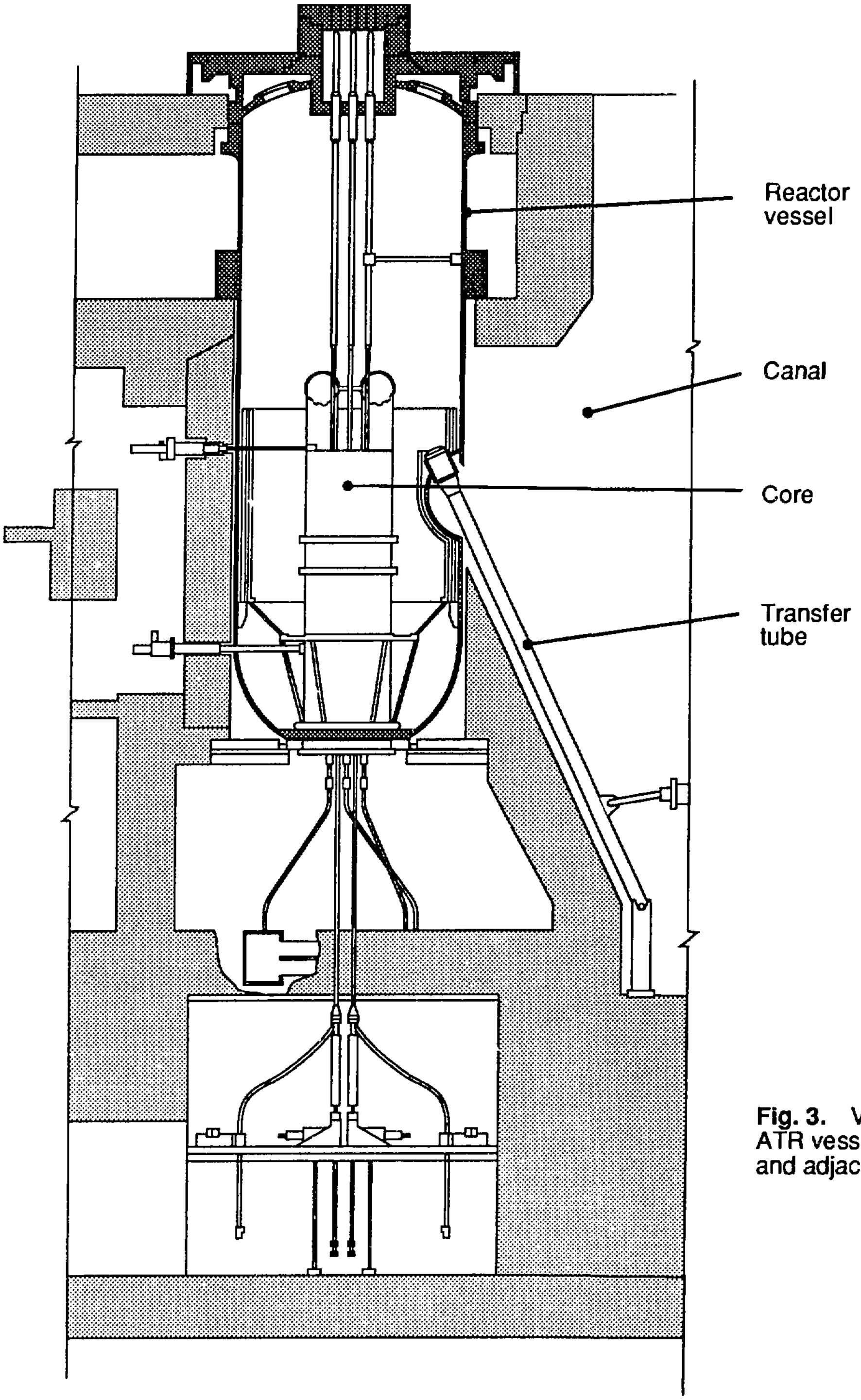

Fig. 3. Vertical cross section of the ATR vessel showing the transfer tube and adjacent canal.

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The experience gained with each activity to replace components is maintained to assure that the lost irradiation time and the exposures resulting from the activity are minimized. This record is reviewed prior to each replacement and used to develop the formal plan written to describe the replacement activities. This plan is reviewed and accepted by contractor management as well as the U. S. Department of Energy. The time required for the replacement is typically about four months including a brief testing period prior to restarting the facility. Since the replacements are normally like for like, the testing is not detailed and extensive. However, a minimum amount of testing is completed to assure that the components are properly in place and performing their intended function.

6. SUMMARY

The ATR has a number of core components that experience considerable exposure to neutrons which results in damage that necessitates replacement at regular intervals. The highly irradiated components have been replaced several times to date without a significant interruption to reactor operation. The design of the vessel and the core components makes replacement relatively easy. Standard tooling used at the top of the open vessel generally is sufficient to complete the required manipulations. The components removed are stored in an adjacent canal until packaged and removed to a waste disposal area. The facility has successfully operated for 20 years with several replacements completed. With plans for continued operation, detailed evaluation of the aging effects during this continued operating period is in progress.