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Control Rod Cladding Failure on a AGN-201 Reactor

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Abstract

In June 1997, the AGN-201 reactor located at Idaho State University suffered a failure of a primary fission-product barrier when a welded end cap of a fueled control element detached from the rest of the cladding. Radiological contamination and exposures were minimal and no exposures or contamination above threshold detection limits were found.

The AGN-201 reactor utilizes four fueled control elements which are inserted from the bottom of the core. The control elements contain fuel disks which consist of nominally 20% enriched uranium dioxide dispersed in polyethylene. These fuel disks are encased in a aluminum capsule. Three of these control elements, Safety Rod No. 1, Safety Rod No. 2, and the Coarse Control Rod, are scrammable and are identical, both in physical dimensions and reactivity worth. After the control elements are ejected from the core following a scram, they are decelerated at the end of their travel by pneumatic or hydraulic dashpots. Failure of one of these dashpots, and the subsequent scamming of Safety Rod No. 2, without the benefit of damping, is believed to be the primary cause of the cladding failure.

A replacement capsule has been obtained by transferring decommissioned AGN-201 control elements from Oregon State University. A replacement for the failed dashpot has also been obtained. Discussions of this event, causes, and recovery actions are presented in the paper.

INTRODUCTION

The Idaho State University AGN-201 is a self-contained, graphite-moderated research and training reactor that is licensed to operate at a maximum thermal power of 5 watts. It consists of two basic units, the reactor unit and the control console. The reactor unit is composed of a central sealed cylindrical core can containing the nuclear fuel material enclosed in a 20-cm-thick graphite reflector, which is surrounded by a 10-cm-thick lead shield, followed by a 55-cm-thick water shield for shielding against fast neutrons. Figure 1 shows a cross-sectional view of the reactor unit. Table 1 lists some physical parameters of the AGN-201.

Figure 1. Cross-sectional view of AGN-201 reactor unit.

The AGN-201 reactor has four active control elements containing the same nuclear material as the reactor core proper. Fuel consists of 15 ± 10-mm diameter UO_2 particles, enriched to 20% in ^{235}U, dispersed homogeneously throughout a matrix of 100-mm diameter high-density polyethylene particles. Fuel disks were made by pressing weighed quantities of UO_2/polyethylene powder in a mold under high pressure. The control elements, each containing 4 fuel disks (cylinders) with a total active length of about 16 cm, are inserted vertically upward into the reactor core from the bottom of the reactor unit to increase reactivity.

Table 1: AGN-201 parameters.

Reactor Type	Self-contained homogeneous thermal reactor
Physical Dimensions	1.98-m (6.5-ft) diameter, 2.9-m (9.5-ft) tall
Weight	6800-kg (15,000-lbs) (less shield water)
Shield water	3800-liters (1,000-gallons)
Core dimensions	25.6-cm (10.1-in) diameter, 23.8-cm (9.4-in) high
Fuel material	UO_2 (20%-enriched in ^{235}U) particles homogeneously distributed in solid polyethylene moderator
Fuel loading	Nominally 670-grams (1.48-lbs) ^{235}U
Core fuse	2.2-cm (0.87-in) diameter 0.9-cm (0.35-in) high, 0.40 g ^{235}U distributed in polystyrene. Designed to melt at 120C (248F).
Thermal neutron flux	$1.5x10^8$ n/cm^2-s, average, $2.5x10^8$ n/cm^2-s, peak
Experimental facilities	(1) 2.22-cm (0.875-in) diameter glory hole passing through center of core. (2) Four 10-cm (4-in) diameter access ports passing through graphite reflector tangentially to the core. (3) Thermal column tank above the core.

Table 2 summarizes the physical properties of the AGN-201 control elements. Three of the four control elements, Safety Rod No. 1 (SR-1), Safety Rod No. 2 (SR-2), and the Coarse Control Rod (CCR), are identical, having the same physical dimensions and the same approximate reactivity worth. The fourth control element, the Fine Control Rod (FCR), is smaller (about one-half the diameter) and has approximately one-fourth of the reactivity of each of the three large control elements. All large control elements are electromagnetically coupled to a drive carriage which moves vertically along lead screws connected by a chain linkage to a reversible DC motor. The FCR is coupled directly to the drive carriage and has no scramming capability.

Table 2. Summary of physical properties of AGN-201 control elements.

Control Element	Fuel Disk Dimensions (4 disks per element)	Nominal Fissile Content[1] (gm)	Reactivity[2] ($, [%k/k])
Safety Rod No. 1 (SR-1)	4.7-cm diameter 4.0-cm height	14.4	$1.56, [1.15%]
Safety Rod No. 2 (SR-2)	4.7-cm diameter 4.0-cm height	14.4	$1.54, [1.14%]
Coarse Control Rod (CCR)	4.7-cm diameter 4.0-cm height	14.4	$1.59, [1.18%]
Fine Control Rod (FCR)	2.3-cm diameter 4.0-cm height	3.6	$0.42, [0.31%]

[1]Total fissile mass per control element (4 fuel disk-cylinders per element).
[2]Most recent reactivity measurements, completed 3/11/97.

A control element assembly is comprised of the capsule, which provides the primary fission-product barrier, four fuel disks, one graphite reflector disk at the bottom, a ferrous compression spring, and the extension tube or shaft. The capsule is fabricated from 0.065-inch-thick aluminum (6061T6) tubing by welding a flat end cap to the capsule tubing. The welded joint was then mechanically ground to make a smooth and slightly rounded cylindrical surface. The capsule is loaded with the four fuel disks, followed by the graphite disk and the compression spring. The open end of the capsule, which is threaded, screws onto the extension shaft to form the integral control element. An O-ring allows the capsule to be hermetically sealed when the capsule is tightly screwed onto the extension shaft. Within the capsule, fuel is held against the distal end cap under spring loading. The control element assembly is connected to the armature plate by means of a threaded joint thus forming the complete control element drive assembly, as shown in Figure 2.

Figure 2. AGN-201 control element and drive mechanism.

This latter assembly is suspended from the reactor tank by threaded studs within a recessed cavity below the sealed core can. The cavity is covered by the control access cover which serves as a secondary barrier against the release of fission products.

The AGN reactor is brought to operating power by inserting, in sequence, the two safety elements, which must be latched, or "cocked," into their fully inserted positions before the coarse and fine control elements may be driven. The coarse and fine control elements are then inserted to make the reactor slightly supercritical to allow the power to increase to the desired level. Once the desired operating power is reached, one or both of the moveable control elements are withdrawn to stabilize the power level. The reactor may then be operated at steady state as necessary until the operation is to be terminated.

Normal shutdown of the reactor is accomplished by scramming the safety and coarse control elements. Shutdown usually occurs by pressing the manual scram button which deenergizes the electromagnets and causes the three scrammable control elements to be ejected rapidly from the core to their safe positions. Ejection occurs within 130 ms under the combined action of gravity and spring loading giving an initial acceleration of approximately five times gravitational acceleration (5g). Each scrammable element is equipped with a shock-absorbing dashpot to gradually decelerate the element during the last 10 cm of travel. SR-1 is equipped with the original hydraulic (oil-damped) dashpot, whereas the SR-2 and CCR elements are equipped with replacement pneumatic (air-damped) dashpots. Once the control element reaches the safe or fully-withdrawn position it activates a proximity switch that causes the carriage to drive down so that the electromagnet engages the control element armature plate thereby allowing the reactor to be restarted. Figure 3 is a photograph of the CCR drive assembly and its accompanying pneumatic dashpot.

Figure 3. CCR drive assemble and accompanying dashpot.

DISCOVERY OF DASHPOT FAILURE

On June 25, 1997, two members of the reactor operating staff, a Senior Reactor Operator (SRO) and an SRO trainee, were operating the AGN-201 nuclear reactor during a routine, after-hours training run. The purpose of the operation was to provide supplemental operating experience for the SRO trainee, who was preparing for an imminent NRC SRO examination, and an opportunity for the SRO to meet quarterly requalification operating requirements by supervising the activities of the trainee.

Approximately 1.5-hours into the operation, the operator trainee inadvertently scrammed the reactor by switching the Channel No.3 range selector switch in the wrong direction during power increase to a planned power of 1.0 watts. During the attempt to restart that followed, it was noted that the Safety Rod No. 2 detached from the electromagnet as it reached its fully inserted position within the core. A second restart attempt was made with the same results. Again as SR-2 neared the end of its travel, as the element was fully inserted in the core, the element again dropped away from the electromagnet. Both staff members present noted an abnormal sound accompanying the dropping element. The sound was described by the operators as "louder than usual and more metallic in nature".

The reactor was shutdown and the SRO entered the pedestal area beneath the reactor to investigate. After removing the control element access cover it became apparent that the dashpot for the SR-2 control element had failed. The graphite piston within the dashpot had disintegrated. Pieces of the piston were clearly visible through the transparent dashpot cylinder. At this time, the Reactor Administrator and acting Reactor Supervisor was promptly notified. Figure 4 is a photograph of the failed dashpot.

Figure 4. Failed SR-2 dashpot showing disintegrated graphite piston.

The next morning, July 26th, the manufacturer of the failed dashpot, Airpot, Inc., (Norwalk, Connecticut) was contacted. A check of their records indicated that this particular model of dashpot had not been manufactured since the early 1980s. Airpot agreed to manufacture replacement units according to the original dashpot specifications. Three dashpots were ordered and promised for delivery the next week.

DISCOVERY OF FAILED CONTROL ELEMENT

By July 3rd the replacement dashpots had not yet arrived. In preparation for replacement of the dashpot, the SR-2 control element was removed from the reactor core and inspected to ascertain if it had sustained damaged when it was dropped after the dashpot had failed. As soon as the control element came into view a problem was observed. The welded end of the control element capsule was missing, and a polyethylene fuel disk was protruding several centimeters through the end of the capsule. Figures 5 and 6 are photographs, showing the failed element with the protruding fuel and a close up of the same, respectively.

Figure 5. Failed SR-2 shown with CCR for comparison.

Figure 6. Closeup of failed SR-2. Note protruding fuel disk, and fractured end cap.

Discovery of the failure of a primary fission-product barrier, a reportable occurrence as defined by the facility Technical Specifications, prompted the following actions. First, the control element was placed on a plastic sheet to prevent any spread of radioactive material. Next the element was thoroughly surveyed for direct radiation exposure levels and for removable contamination. The dean of the College of Engineering, a Certified Health Physicist, was notified of the incident and came to the reactor laboratory to inspect the breached control element. The ISU Technical Safety Office (TSO) was also notified. A TSO staff member came to the facility and provided assistance in completing the radiological surveys. An air particulate sampler was set up next to SR-2 near the end of the capsule and sampled airborne material for 78 minutes. All contamination wipes and the air particulate sample were counted in the facility and then given to the TSO for further analysis using a liquid scintillation counter. As required, the NRC was promptly notified of the event by telephone that afternoon.

The following Monday, July 7th, the incident was reported to the ISU Radiation Safety Officer (RSO), who had been absent from campus when the capsule breach was discovered. The RSO ordered in vivo thyroid counting of all personnel present during the incident. In addition, the wipe samples were analyzed with a high-purity germanium spectrometer to identify gamma-emitting contaminants present in the samples. The results of various radiological surveys were consistently negative.

ASSESSMENT OF PROBABLE CAUSE AND CONSEQUENCES

Facility personnel, after examination of the evidence, concluded that the control element capsule failure was a direct result of the dashpot failure. The abrupt and unattenuated impact of SR-2 against the steel frame of the drive assembly is believed to have been sufficient to fracture the weld joining the end cap to the capsule tube. Subsequent attempts to latch SR-2 during reactor restart failed as the exposed fuel came into contact with the top of the control element thimble, compressing the internal spring and generating enough force to push the control element away from the electromagnet.

A conservative estimate of the inventory of ^{131}I in the control element at the time of capsule failure was calculated to be 28 mCi. Assuming that 1% of the total radioiodine content was released at the time of the breach of the primary fission-product barrier, a very conservative assumption since the polyethylene matrix retains virtually all of the fission products, gives 280 nCi as the amount of ^{131}I that was released to the environment. This quantity, divided by the building exhaust rate and averaged over a 24-hour period following the incident, is well below federal effluent concentration limits published in 10 CFR 20, Appendix B, Table 2; i.e., $2x10^{-10}$ mCi/ml. Furthermore, results of the thyroid counting by the TSO showed that none of the facility personnel approached the instrument's verification level of 9.4 nCi for uptake by the thyroid gland.

The overall assessment of the radiological consequences was that this event had no adverse impact on the health and safety of facility staff, the public, or the environment.

RECOVERY

Several options were considered in regard to repairing or replacing the failed capsule, including welding and pressure testing the broken capsule, and manufacturing a new capsule. After careful consideration, it was decided that the only viable option was to acquire salvaged components from a decommissioned AGN reactor.

Suitable replacement elements were eventually located at Oregon State University, whose AGN reactor was decommissioned from 1978-1980. Following decommissioning and the subsequent termination of the AGN operating license by the NRC in 1981, OSU elected to retain the intact control elements and core can, having transferred these materials to the facility's TRIGA reactor operating license. Discussions were initiated with the director of the OSU Radiation Center and with representatives of the U.S. Department of Energy, which owns the fuel, to arrange for transfer of one or more of the large control elements. As a result of these discussions, it was decided to transfer all of the OSU AGN control elements to ISU.

Acceptance of this additional fuel, however, required that the ISU AGN operating license be amended to increase the limit on the amount of fissile material that could be possessed by ISU. An application for an amendment increasing the fissile material possession limit was submitted to the NRC on July 23rd. The license amendment was granted by the NRC on August 18th, permitting the shipment of the control elements to proceed. The four control elements were shipped from OSU on September 8th and were received by ISU on September 9th. After inspecting the transferred control elements, one of elements was disassembled and its contents inventoried. The internal components of the failed ISU control element were then installed in the replacement capsule in order to keep reactivity constant. Figure 7 is a photograph showing the contents of the disassembled ISU control element. Figure 8 is a photograph of the OSU capsule and extension shaft used to repair the ISU element.

Figure 7. Contents of ISU control element.

Figure 8. OSU control element used to repair ISU control element.

The replacement capsule containing the ISU fuel and the new dashpot were installed in the SR-2 control element drive assembly. This assembly and the other control elements, in their respective control element drive assemblies, were mounted in a test rack to measure the ejection time of each of the scrammable elements. All control element drive assemblies were then installed in the reactor and checked for proper alignment. The reactor was subsequently operated to measure control element reactivity worths and reactivity insertion rates to complete the required maintenance surveillances and verify that operation was in conformance with facility technical specifications.

CURRENT STATUS

A final comprehensive report on the incident has been prepared for submittal to the ISU Reactor Safety Committee (RSC). Members of the RSC will review the report and provide comments to the operating staff as necessary. Once all issues and comments have been resolved, it is anticipated that the RSC will grant permission to resume normal reactor operations. At that time a courtesy copy of the final report will be submitted to the NRC.

FUTURE ACTIONS

In an effort to prevent recurrence of this event, the following actions will be taken.

Future annual inspections of the control elements will be aggressively performed. In particular, inspections will focus on the end region of the capsule for any evidence of weld cracking or other signs of deterioration, and on the dashpot for evidence of excessive wear of the seal or excessive play in the piston which might indicate impending failure. Any evidence of degradation of either the capsule or the dashpot will be sufficient reason for immediate replacement.

In addition, the control element drive logic will be modified to allow the safety elements to be manually withdrawn from the core at the conclusion of reactor operation, instead of scramming the reactor. Currently both safety elements must be cocked before either of the two control rods can be driven for reactor startup. Once the safety elements have been cocked, the only method for lowering them is to scram the reactor. Modification of the drive logic circuit will allow for the manual withdrawal of these safety elements, while retaining the original design feature requiring that the safety elements be fully cocked before insertion of the remaining control elements is permitted. This modification will reduce the number of scram cycles imposed on the scrammable control elements and associated components and should prolong the dashpot's lifetime.

Further, all existing dashpots will be replaced with new units. The existing dashpots are in good working condition and will be retained as spare components in case of failure or deterioration of any of the new units. Once installed, should one of the new units fail or otherwise deteriorate to the extent that failure is probable, it will be replaced temporarily by one of the existing units until an equivalent unit can be obtained from the manufacturer for immediate installation.

An analysis of possible modifications to the dashpot mounting hardware will also be undertaken. The goal of such modification will be to improve the mounting of the dashpots in two areas and possibly reduce the chance for a similar dashpot failure in the future. The first modification will be designed to constrain the lateral motion of the plunger shaft. It is believed that wear of the dashpot plunger shaft seal over time, and the subsequent impact of the control element against the dashpot plunger shaft at a slight angle may have contributed to the failure of the dashpot. The second modification will be designed to reduce or eliminate the static load on the dashpot while the control element is fully withdrawn from the core. This modification will reduce stress placed on the piston within the dashpot and should help prolong dashpot life.

SUMMARY

The capsule failure was most likely the direct result of failure of the dashpot, and the subsequent scramming of the SR-2 control element without the benefit of damping.

The incident had negligible radiological consequences. The fuel material retains virtually all of the fission products, although a small amount of the gaseous fission products may diffuse into the extra space within the control element capsule. The release of radioactive materials to the environment was negligible. There was no spread of contamination and only components directly in contact with the fuel material showed any signs of removable contamination. The radiation doses to members of the operating staff and general public were negligible. In vivo counting showed no measurable uptake of radioiodine in the thyroid glands of personnel present during the incident.

Replacement components have been obtained and repair work has been completed. The facility awaits Reactor Safety Committee approval to resume operations. Administrative and design changes are being implemented which should prevent the possibility of recurrence of this problem in the future.

REFERENCES

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Fuel Leak at Reed College (Phase III)

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Abstract

On August 22, 1997 the Reed Reactor experienced its third fuel element leak in six years. A variety of techniques were used to identify which of the sixty fuel elements was leaking. Using a sniffer proved unsuccessful. Reviewing videotape records of previous inspections proved useless. Replacing several elements at a time and operating the reactor to look for fission products was finally successful. The leaking element was identified and removed from the reactor on September 24, 1997.

Installation of a Stainless Steel Liner in the Bulk Shielding Tank of the Oregon State University TRIGA Reactor

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Abstract

On August 6, 1996, the Oregon State University TRIGA reactor began leaking water from the bottom edge of its thermal column liner. Over the next five months a total of 15 liters of water was absorbed by staff using paper towels. No water was released outside of the reactor radiation restricted area. Volume and radioisotope tracer studies were inconclusive in determining the source of the water. However, two pieces of information indicated that the Bulk Shielding Tank was the source of the leak. The first is a statement in the OSTR Mechanical and

Operating maintenance manual supplied by General Atomic in 1967. It states "A water leak in the thermalizing column will be indicated by water draining from beneath the thermal column liner." The thermalizing column is located at the core elevation between the BST and the reactor core. The second item was the leak experience of another TRIGA Mk II facility where a BST leak was repaired by repainting the inner surfaces of the BST and replacing the gasket on the thermalizing column plate.

The facility staff decided to replace the existing epoxy paint, water proofing barrier of the BST with a 1/8 inch thick 304 welded stainless steel liner and a 3/8 inch 304 stainless steel plate over the thermalizing column. This task was completed during a three week maintenance outage in January and February of 1997. This paper will describe the preparations for the liner installation, the actual installation process and subsequent results.

Groundwater Tritium Plume at the HFBR: Review of History, Consequences, and Current Status

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Abstract

The discovery of a plume of tritium contamination in the groundwater in January, 1997, which has been attributed to a leak in the spent fuel pool amounting to approximately 6 to 9 gallons per day. This leak, which had been undetected for at least 12 years, deposited an estimated total of 7 Ci of tritium in the groundwater since its inception. The reactor remains shut down since the discovery of the plume; all fuel has now been removed from both the reactor itself and from the leaking spent fuel pool. Plans are being made to install a double-walled stainless steel liner in the pool, and to implement other upgrades to assure that any spills or leaks of tritiated water in the plant will not leak into the groundwater. This incident has attracted wide attention in the press and has become a focal point for the anti-nuclear movement. The political debate over whether the HFBR should ever be restarted has recently become more heated with the introduction of bills in the Senate and House by Senator D'Amato and Congressman Forbes calling for the permanent shutdown of the HFBR. Secretary of Energy Peña has outlined a plan for arriving at a decision in January on whether or not to pursue restart of the HFBR, based on scientific need, cost, ES&H impact, and input from the local community.