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Assessment Results of the South Korea TRIGA SNF to be Shipped to INEEL

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DISCLAIMER

ASSESSMENT RESULTS OF THE SOUTH KOREA TRIGA SNF TO BE SHIPPED TO INEEL

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ABSTRACT

This paper describes the Training, Research, Isotope, General Atomics (TRIGA) spent nuclear fuel (SNF) examination at the Seoul and the Taejon Research Reactor Facilities in South Korea. The examination was required before the SNF would be accepted for transportation and storage at the INEEL. The results of the aluminum and stainless steel clad TRIGA fuel examination have been summarized. A description of the examination team training, the examination work plan and examination equipment is also included. This paper also explains the technical basis for the examination and physical condition criteria used to determine what, if any, additional packaging (canning) would be required for transportation and for the receipt and storage of the fuel at the INEEL.

This paper delineates the preparation activities prior to the fuel examinations and includes (1) collecting spent fuel data; (2) preparatory work by the Korean Atomic Energy Research Institute (KAERI) for fuel examination: (3) preparation of a radionuclide report, "Radionuclide Mass Inventory, Activity, Decay Heat, and Dose Rate Parametric Data for TRIGA Spent Nuclear Fuels" needed to provide input data for transportation and fuel acceptance at the Idaho National Engineering and Environmental Laboratory (INEEL); (4) gathering FRR Facility data; (5) preparation of Appendix A; (6) and coordination between the INEEl and KAERI. Included, are the unanticipated conditions encountered in the unloading of fuel from the dry storage casks in Taejon in preparation for examination, a description of the damaged condition of the fuel removed from the casks, and the apparent cause of the damages. Lessons learned from all the activities are also addressed.

A brief description of the preparatory work for the shipment of the spent fuel from Korea to INEEL is included.

INTRODUCTION

The return of foreign research reactor (FRR) fuel to the United States is the result of the Atoms for Peace initiative undertaken in the 1950's. The intent of the initiative was to provide peaceful use of nuclear technology to foreign nations in the form of research reactor fuel. Part of the agreement was the return of the nuclear material either at end of life or whenever the fuel was no longer needed. In 1978, the United States initiated the Reduced Enrichment for Research and Test Reactors (RERTR) program to reduce the use of high enriched uranium (HEU) in civilian programs and promote the conversion of these reactors to low enriched uranium (LEU) fuels. The program allowed the return of FRR HEU and LEU under an Off-Site Fuels Policy which expired for HEU in 1988 and for LEU in 1992. The March, 1996 Record of Decision based on the Final Environmental Impact Statement on a Proposed Nuclear Weapons Nonproliferation Policy Concerning Foreign Research Reactor Spent Nuclear Fuel reestablished the return program for spent nuclear fuel enriched in the United States. The program allows for return of fuel discharged from the reactor within a ten year period and returned within a thirteen year period. As part of this decision, the INEEL was designated as the receiving site for TRIGA fuels.

The inspection of TRIGA fuel in Seoul and Taejon, South Korea was conducted during May and June 1997. The fuel inspected was from two TRIGA Research Reactors located in Seoul, the TRIGA Mark-II (KRR-1) which was operated from 1962 to 1994 at 150 and 250 KW and the TRIGA Mark-III (KRR-2) which operated from 1972 until 1995 at 2 MW. Both of these reactors have been shut down and were replaced by a new 30 MW reactor constructed in 1995 at the HANARO Center in Taejon

INITIAL PREPARATIONS

Plans for return of the TRIGA fuel from Korea were set in motion in October 1996 with the initial visit by DOE and contractor personnel to provide introductions and discussion of the SNF return program along with an initial assessment of the fuel and facilities. Fuel examination plans and acceptance criteria were developed, design and fabrication or selection of equipment was completed and training of inspection personnel was implemented.

Original fabrication data and drawings of TRIGA fuel rods, instrumented fuel rods, and fuel follower control rods were obtained from General Atomics for all fuel shipped to South Korea. Additional information on TRIGA fuels was obtained from the Characterization of TRIGA Fuel report[2]. KAERI personnel completed an INEEL questionnaire providing points of contact, preliminary fuel data and projected availability, agreement with the general terms of the FRR Program, and agreement to host a fuel and facility assessment team visit. Routine e-mail and telecons were established between DOE/INEEL and KAERI personnel to address questions and provide information on facility status, personnel support, fuel availability for inspection, inspection procedures, and International Atomic Energy Agency (IAEA) coordination to allow access to fuel stored dry in IAEA sealed casks. Schedules were established for the INEEL team to examine the fuel and to assess the facilities for cutting, canning, loading and shipment of the fuel to INEEL.

As part of the overall INEEL Spent Nuclear Fuel Program, the "Radionuclide Mass Inventory, Activity, Decay Heat, and Dose Rate Parametric Data for TRIGA Spent Nuclear Fuels[3]" report was prepared providing data estimates for the addressed parameters based on TRIGA fuel type, fuel burnup, decay time, and distance in air from fuel for dose rate calculations. The data presented in this report may be used by the FRRs in completion of Appendix A and will be useful to INEEL personnel in verification of information supplied by the FRRs.

Prior to arrival of the INEEL team, KAERI personnel selected, prepared, and surveyed areas where fuel examination equipment would be located and fuel inspections performed. Fuel storage racks were also in the canal at the Taejon facility in preparation for removing the fuel stored dry in casks at that facility.

WORK PLAN FOR TRIGA FUEL EXAMINATION

The Work Plan for the examination of TRIGA reactor fuel was developed based upon visual examination methods and acceptance criteria determined to be adequate to ensure the integrity of the fuel would be maintained during transport and handling at the INEEL. Included in the Work Plan are instructions covering the fuel examination process and microbial sampling; equipment requirements; and personnel training requirements.

Fuel examination instructions include equipment setup, check/test, and general positioning of the equipment in the storage pool for fuel examination in addition to specific requirements for visual examination, video recording, and photographic and written documentation of the condition of each fuel rod by sector. The instructions also address positive identification of each fuel rod and the dimensional and straightness checks utilizing the vertical scale/inspection station and the Go,No-Go gauge.

The Work Plan includes instructions for microbial sampling of the storage facility water, surfaces within the storage pools, and the fuel cladding. Instructions identify desirable sampling locations, handling of samples, inoculation of culture media, documentation requirements, and interpretation of results.

TRIGA FUEL ACCEPTANCE CRITERIA

The fuel meat section of the aluminum and stainless steel (SS) clad TRIGA fuel is composed of an intrinsically brittle[1] zirconium-uranium hydride matrix which has been subjected to thermal conditions during reactor operation that may have lead to micro fracturing of the fuel. This can lead to breakage into small particle sizes should the fuel be physically impacted. The aluminum and stainless steel cladding provide the structural containment to prevent dispersion due to fracturing and/or fuel breakage.

Storage of aluminum clad fuel in water can lead to increased galvanic attack of the aluminum cladding should a pin hole or crack develop in the cladding. This results in a potentially higher corrosion rate from the inside out and external visual observations can not be relied upon to determine the structural integrity of the cladding. Perforations of aluminum clad TRIGA fuel due to pitting, or for either aluminum or stainless steel clad TRIGA fuel, due to cracking, or mechanical damage were therefore determined to be unacceptable. Perforations of stainless steel clad TRIGA fuel due to pitting are considered acceptable unless located randomly over greater than ten percent of the cladding surface or localized such that structural integrity is suspect. Corrosion in the form of polyps or heavy scale/oxide stains on either aluminum or stainless steel clad fuel is considered unacceptable. Also unacceptable are visual indications of blistering or bowing/bulging of the fuel in excess of 100 mils, as determined by insertion of the fuel into a Go,No-Go gauge, which may be indicative of abnormal thermal stresses or internal corrosion product buildup that could result in cladding failure. The final criteria is being developed by an independent committee consisting of cask vendors and site receivers based on their requirements for fuel contamination containment. Failure to meet the acceptance criteria was used as the basis for requiring the fuel to be canned prior to shipment, not as a basis for refusing to accept for return to the INEEL.

While not a condition of acceptance, results of microbial sampling are used to determine if organisms associated with possible corrosion of fuel cladding materials exist in the water or on the surfaces of the storage pool. Results will be retained for possible later consideration of long term effects when fuel is placed in a final repository.

EXAMINATION EQUIPMENT

Remote fuel inspection equipment design was based upon experience derived at the Idaho Chemical Processing Plant (ICPP). State of the art SVHS underwater camera equipment was selected to improve the marginal quality of standard VHS underwater camera equipment currently used at ICPP.

The selected camera system incorporates a moderate telephoto capability and a pan and tilt option. This allows positioning the camera head to zoom for closeup focus and still allow full sequential coverage of the fuel. Resolution of the SVHS equipment allowed viewing of pits less than 1/16 inch diameter to be identified approximately six feet from the camera head. Figure 1 shows the camera head and auxiliary lighting.

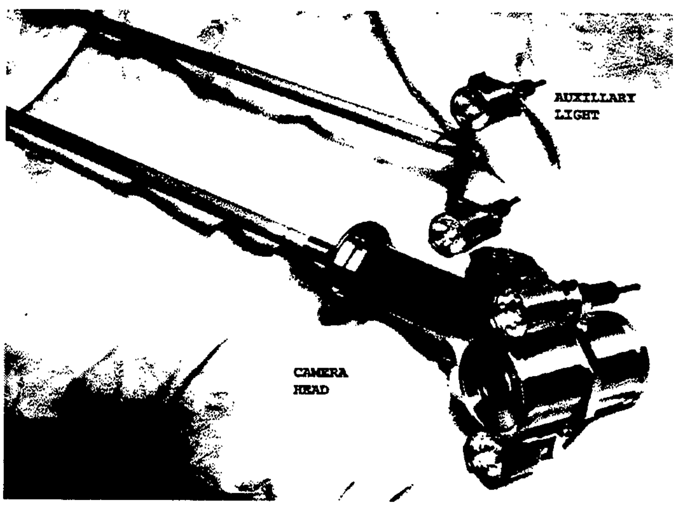

Figure 1 - Underwater Camera Head Assembly and Auxiliary Lighting

To provide contrast to surface areas, the camera was fitted with two adjustable lights with a second light source containing two adjustable lights were mounted on a separate pole and positioned independently to provide additional back lighting and contrast control.

Each camera system has two monitors, an intercom system, and voice recording capabilities on the

SVHS recorder, to provide communication between members of the team. These features provide for independent verification of visual observations by allowing two team members to view the examination. Figures 2 and 3 are representations of the signal and power diagrams for equipment hookups.

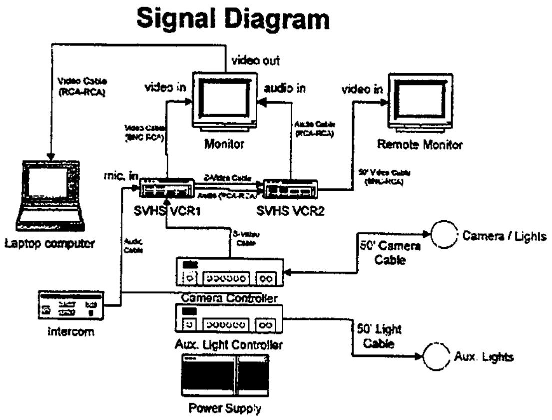

Figure 2 - Signal Diagram

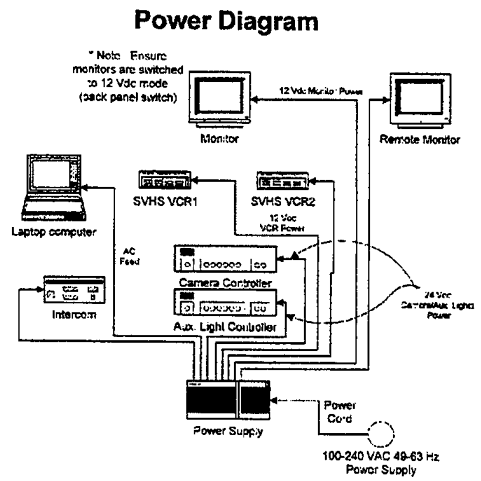

Figure 3 - Power Diagram

Vertical movement of the camera head was accomplished through use of a manually operated sliding clamp block to which the camera handling extension tube was attached. The sliding block was moved by a hand crank driven reel through a pulley and rope system and allowed movement of the camera over a three foot span. Additional vertical range could be obtained by repositioning the camera handling extension tube in the sliding block clamp.

Each camera system was designed with two SVHS recording tape decks. This allowed for a primary copy and a simultaneous backup copy of the inspection. The backup copy could then be retained by each facility for their record of the examination.

A vertical scale/inspection station and Go,No-Go gage, see figures 5,6, and 7, provided dimensional reference for documenting observations during fuel inspection and allowed determination of the extent of bowing or swelling of a fuel rod by the known diameter of the smallest of the five graduated tubes allowing full insertion of the rod. Graduated holes drilled in the vertical scale/inspection station provided comparison reference for estimating sizes of pitting, pin holes, or corrosion observed.

The serial number, fuel type, cladding type, length of the can or fuel rod and evaluation of each piece of fuel was recorded and mapped on data sheets using a sector format. This allowed identification of any pits, cracks, or deformations to be identified by location and sector as the fuel was rotated and examined end to end.

A 35mm camera, 135 mm lens and high speed film was also furnished to photograph each fuel element or can to provide an independent copy of the inspection should the video tapes be lost or damaged during transit.

A microbial sampling kit containing sterile swabs, bottles of sterile water for sample preparations, bottles containing culture solutions, gloves, alcohol, syringes, a handling tool, and sample documentation forms was provided for each facility. Three types of culture media were included to determine if acid producing microbes, sulfate reducing bacteria, or heterotrophic microbes exist in the fuel storage environment.

Additional equipment included sectional extension tubes and hanger brackets for underwater equipment, a modular equipment stand, hand tools for equipment assembly and maintenance, spare lights, and sealing tape. Backup spare video equipment was also included for components that were not easily repaired and unavailable at the FRR. All equipment with the exception of the 35mm camera and laptop computers, which were hand carried, was packaged into two large overpack containers for transport.

EXAMINATION TEAM TRAINING

INEEL fuel examination personnel were selected based on education and previous fuel handling or examination experience. Training was conducted by qualified instructors to a quality assurance approved training plan. The initial training session was held in a dry mockup facility to familiarize personnel with the setup and operation of the underwater video and lighting systems and to ensure work plan instructions were adequate. This training session allowed team members to identify deficiencies in, and modifications required to, the equipment and the work plan. A mockup of a TRIGA fuel rod with various intentional defects; pits, scratches, and simulated corrosion products; incorporated was used to ensure personnel and equipment could readily detect and identify conditions expected during actual fuel examinations.

Following work plan revisions, equipment modifications, and correction of equipment deficiencies, a second training session was held in an available tank to check out underwater operation of the video camera and lighting equipment.

Training for microbial sampling provided hands-on familiarization with sampling equipment, obtaining samples, sample preparation and inoculation of cultures, and interpretation of results. Included were techniques to avoid sample contamination and documentation requirements.

Prior to departure of the examination team for South Korea, a final fuel examination training session covered all examination requirements from unpacking and setup of equipment through fuel examination, decontamination, and repacking for return.

FUEL EXAMINATION

South Korea has an inventory of 310 TRIGA fuel rods consisting of 178 LEU rods and 132 HEU stainless steel clad fuel life improvement program (FLIP) rods. Of the LEU rods, 69 are aluminum clad and 109 are stainless steel clad. 186 of the fuel rods are located in Seoul and are stored in wall or floor mounted storage racks with 5 of the rods in suspended storage pipes in the TRIGA Mark III, KRR-2, pool. 113 spent fuel rods including 9 canned fuel rods were stored dry in four casks along with 11 new fuel rods stored in a storage vault at the HANARO facility in Taejon.

The Seoul facility was selected for initial fuel examination. KAERI provided personnel for handing the fuel and health physics monitoring along with anti-contamination gloves and shoes or shoe covers. The examination team performed a facility assessment initially noting area and facility access, handling equipment, hot cell capabilites, and overall storage pool conditions for later fuel canning and cask handling/loading considerations. Microbial sampling of the storage pool water, pool structural surfaces, and fuel cladding was conducted and fuel examination equipment set up adjacent to the storage pool. The fuel at the Seoul facility was examined and with the exception of 20 rods were found to be acceptable for shipment as stored. Of the 20 fuel rods, 14 were determined to require further review of the data and video recordings. These were all aluminum clad fuel rods with suspect pitting, corrosion, or abnormal weld indications that were initially indeterminate as to cladding penetration. Of the remaining 6 fuel rods, 4 were also aluminum clad and had observable cladding penetration and 2 were stainless steel clad and ruptured. The upper section of one of the stainless steel rods was retrievable from the storage pipe for identification while the other could not be retrieved and was identified from facility records. Following the fuel examination, equipment was decontaminated and packaged by the examination team for transport by KAERI personnel to the Taejon facility.

During the final day of Seoul examination, the spare TRIGA fuel handling tool and one of the KAERI support personnel were transferred to Taejon to support unloading of the dry storage casks and prestaging of the fuel into storage racks in the HANARO facility storage canal prior to arrival of the examination team. KAERI personnel had coordinated the removal of IAEA seals from the cask storage area and casks for the examination. Upon opening each of the casks, KAERI personnel found that the major portion of the fuel could not be removed due to apparent binding between the cask inserts (grids) and the fuel. Upon arrival of the examination team and after considerable effort by KAERI personnel, the underwater video examination equipment was set up and used to identify the cause of the binding. KAERI personnel determined that the fuel had been deformed and was binding at the deformations in the upper grid of the cask inserts. The cask inserts containing the fuel were removed from each cask, disassembled, and the freed fuel rods moved to the storage racks. KAERI personnel indicated that the probable cause of the fuel cladding deformation was an unregulated pressurization of the casks with nitrogen following loading and draining.

Following cask unloading, microbial sampling of the storage canal water, the storage canal structural surfaces, and the fuel cladding was conducted. An additional sample was obtained from the surface of one of the fuel cask insert grids that had been disassembled and removed from the canal following fuel unloading. The fuel examination equipment was set up adjacent to the storage canal. The fuel in Taejon was examined and 74 were found acceptable for shipment as stored. All uncanned stainless steel clad fuel rods were found to be deformed in the upper and lower graphite reflector (or air gap for fuel follower control rods, FFCR) sections. These were determined acceptable for shipment as stored unless interference was found during the Go,No-Go gauge test, or in the case of the FFCR's, the cladding was torn from the extensive deformation. 41 fuel rods plus a can labeled as debris, but indicated by the IAEA inspector present as containing significant fuel, were determined to require further review of the data and video recordings. These consisted of 6 cans in which the contents could not be observed, 1 aluminum and 1 stainless steel clad fuel rod with suspect pitting indications that were initially indeterminate as to cladding penetration, and 34 deformed stainless steel clad fuels rods which had localized ridges in the area of deformation that precluded passing thru the Go,No-Go gauge. The remaining 8 fuel rods were determined to require canning due to ruptures, cracks corrosion products, or for the FFCR's, cladding tears in the deformed area. KAERI indicated that the fuel will remain in the storage canal until shipped.

Upon completion of examinations, the equipment was decontaminated and repacked for shipment back to the INEEL. Excessive contamination or inaccessible areas resulted in the extension tubes and Go,No-Go gauge being left at the HANARO facility. Copies of the examination data sheets, videos and photographs were provided for the KAERI facilities records.

Post-return results of the microbial sampling indicated excellent storage facility water quality with only heterotrophic microbes at the Seoul facility and, with the exception of the cask grid sample which is believed to non-representative due to contamination of the grid surfaces during handling, heterotropic and a slight indication of possible acid producing microbes at the HANARO facility.

Figure 4 shows an illustration of a damaged aluminum TRIGA fuel element due to the galvanic corrosion mechanism in aluminum clad fuel rods with cladding penetration. Figure 5 is an example of an aluminum fuel element that has the cladding perforated. Visual examination showed air bubbles coming out near the bottom weld. Figure 6 shows an instrumented aluminum fuel rod which has been cut off.

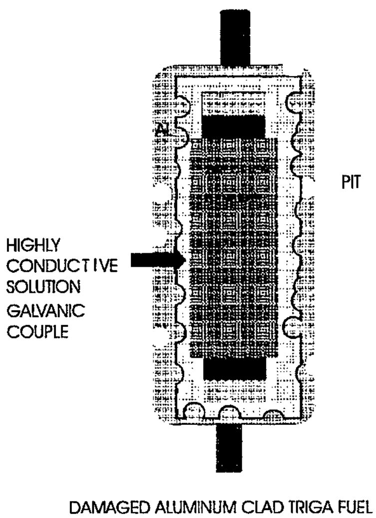

Figure 4 - Illustration of Corroded Aluminum Clad TRIGA Element

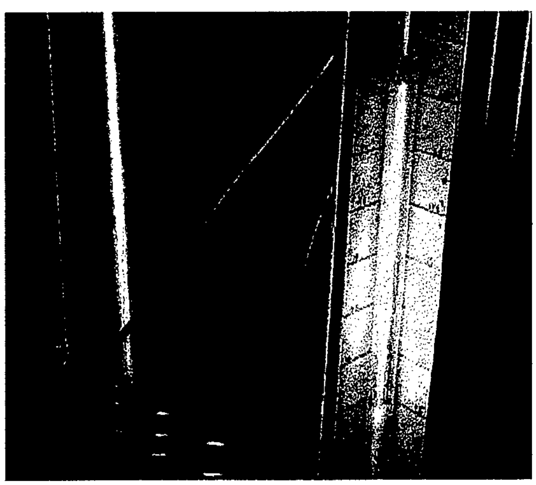

Figure 5 - Leaking Aluminum TRIGA Fuel Element

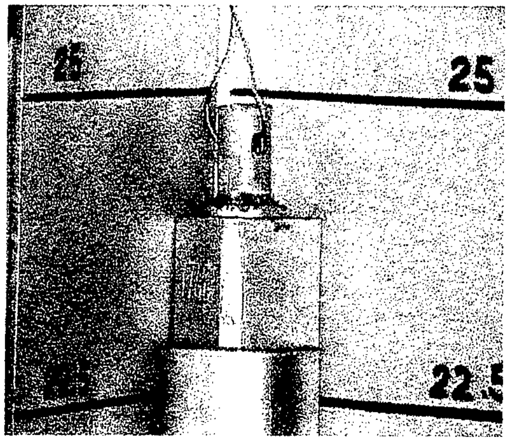

Figure 6 - Instrumented Aluminum Fuel Rod (FTC)

Figure 7 shows the condition of a typical stainless steel clad TRIGA element which had no observed problems. Figure 8 shows a stainless steel fuel element broken in the area of the graphite reflector.

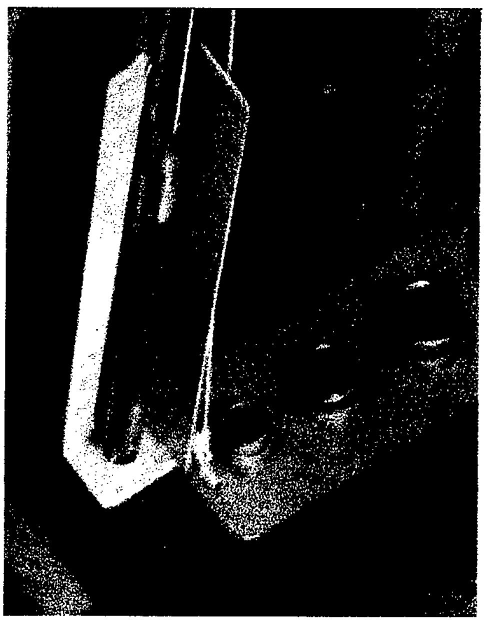

Figure 7 - Typical SS Clad TRIGA Element

Figure 8 - Failed SS Clad TRIGA Element

Figure 9 shows the aluminum basket and fuel from the cask in Taejon. The deformed stainless steel fuel elements are a result of inadvertent over pressurization using nitrogen as a cover gas. Figures 10 and 11 are typical examples of deformed fuel elements and fuel follower control rods from the over pressurization. Figure 12 is an example of the type of can in which the broken fuel rods and debris are stored and handled

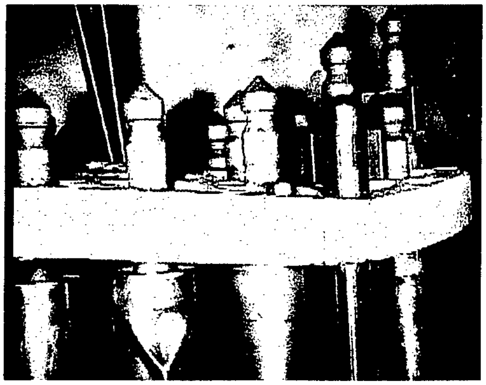

Figure 9 - Deformed Cask Basket with deformed SS TRIGA Fuel

Figure 10-Collapsed SS Clad TRIGA Fuel Element

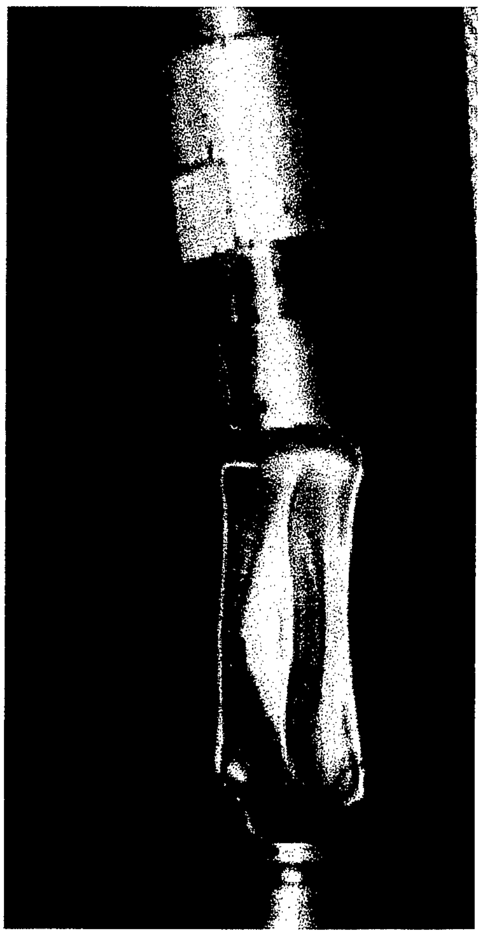

Figure 11 - SS Fuel Follower Control Rod(FFCR)

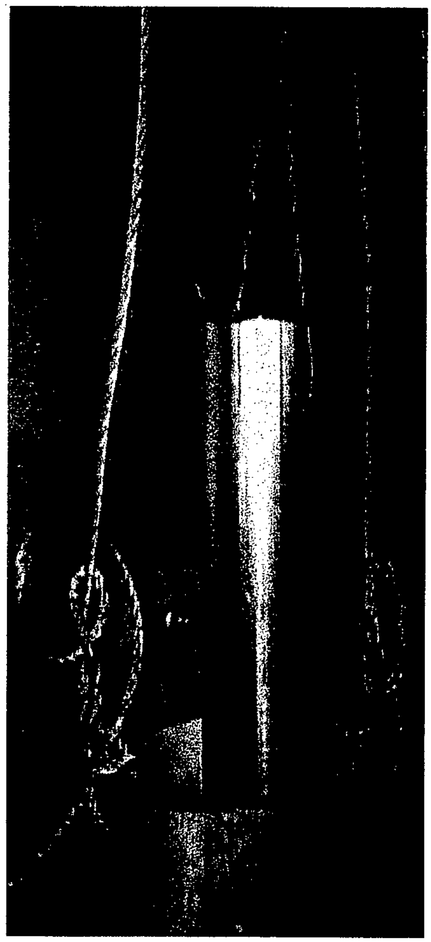

Figure 12- Fuel Storage Can

APPENDIX A PREPARATION

During the visit, facility personnel provided the latest draft of their Appendix A, Spent Nuclear Transfer Data Form, input. Facility personnel had nearly completed Appendix A prior to the team's visit. The data was reviewed by the team and discussed with the authors. The results of the fuel inspection provided most of the missing information. Remaining significant issues include:

- Burn up calculations are still required for a few elements
- Source document references need to be included to satisfy Quality Assurance requirements for the information provided.
- Burn up values are in question for several fuel elements that had locations swapped in their storage positions. Also one element listed as being in dry cask storage was actually in wet storage. It is unknown when during their life cycle the elements were swapped, so it is unlikely that burn up values can be adjusted.

The team provided new references and drawings from General Atomics (GA), the Tomsio report[2], and the Sterbentz report[3] to aid in completion of the form.

PREPARATIONS FOR SHIPMENT

NAC International was selected as the transportation services contractor for the South Korean fuel return to the INEEL and recently completed a site and fuel assessment visit to the South Korean facilities. ICPP facility modifications are in progress to accommodate the dry run operation and operator training. NAC is preparing the design of the fuel can and documentation necessary to certify their cask system for TRIGA fuels.

LESSONS LEARNED

The equipment used during this inspection had been previously evaluated during the mockup phase. Field use identified some problem areas which if corrected, would facilitate future inspections. The main items identified are listed below.

- Provide video recorders with on/off indicators other than orange and red as these colors do not stand out from each other readily and it is not immediately evident that the data is not being recorded. This is a human factors engineering issue to preclude undetected tape stoppage and loss of record.
- Provide a time counter on the video recorder. Record start and stop times for each fuel piece examined.
- Test all head sets and correct any internal noise interference which caused feedback and noise during audible recording of inspection data.

- Provide electrical shielding of the lighting rheostats on the controller to reduce noise during recording.

- Use smaller lockable shipping crates for equipment. This will facilitate easier shipping and handling at fuel inspection locations.

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