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Irradiated-Fuel Examination Using the Cerenkov Technique

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IRRADIATED-FUEL EXAMINATION USING THE CERENKOV TECHNIQUE

by

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ABSTRACT

A technique for monitoring irradiated nuclear fuel inventories located in water filled storage ponds has been developed and demonstrated. This technique provides sufficient qualitative information to be useful as a confirmatory technique to International Atomic Energy Agency inspectors. Measurements have been made on the Cerenkov glow light intensity from irradiated fuel that show the intensity of this light to be proportional to the burnup of the fuel and inversely proportional to the cooling time. Fieldable instruments used in several tests confirm that such measurements can be made easily and rapidly, without fuel assembly movement or the introduction of apparatus into the storage ponds. The Cerenkov technique and instrumentation have been shown to be of potential use to operators of reactor spent fuel facilities and away from reactor storage facilities, and to the International Atomic Energy Agency inspectors who provide surveillance of the irradiated fuel stored in these facilities.

I. INTRODUCTION

A large fraction of the special nuclear material (SNM) inventory in the nuclear fuel cycle, both domestic and international, is contained in irradiated fuel assemblies in the form of plutonium and unburned ^{235}U. Because of the implications of nuclear proliferation internationally and the potential for diversion domestically, the safeguarding of this material has become a subject of great interest. Techniques that allow for the confirmation of declared irradiated fuel inventories in storage ponds at both reactor and away from reactor (AFR) installations has resulted in a number of studies that address this problem. Under the U.S. program for technical assistance to international safeguards, Los Alamos Detection and Verification Group Q-2 has evaluated[1] eight possible attribute measurement techniques that would provide confirmation of irradiated fuel. The criteria used for selecting promising techniques included ease of implementing the technique, simple interpretation of the measurement data, and minimal impact on the facility operators routine schedule. Strict adherence to these criteria precludes any movement of fuel assemblies. In addition, simple interpretation of the measurement data eliminates the sampling of nuclear radiation fields above the assemblies because interpretation of this data would require complex unfolding algorithms.

Of the eight techniques evaluated, the most promising technique that satisfied the criteria is the Cerenkov glow intensity measurement technique. It is the only technique investigated that does not require disturbance of the storage ponds and provides quantitative, as well as qualitative, information for confirmation of the attributes of irradiated fuel. Because water has a very small attenuation coefficient for visible and near-ultraviolet light, the measurements can be made from the storage pond surface, thereby allowing the measurements to be made with all instrumentation totally out of the water. For the standard vertical assembly storage, the penetrations in the upper mechanical structure of the assembly, as in a PWR assembly, and the interstices between fuel pins, as in BWR assemblies, serve as Cerenkov light channels and allow the sampling of the nuclear radiation intensity to be much deeper than the top of the fuel assembly. This measurement is also much less susceptible to cross talk among adjacent assemblies than are nuclear radiation intensity measurements made at the tops of the assemblies.

II. THEORY

Cerenkov radiation is produced whenever a charged particle passes through a medium at a velocity greater than the phase velocity of light in that medium. In water, for example, any electrons with energies greater than 0.26-MeV will produce Cerenkov radiation. The origins of these energetic electrons in the case of spent fuel include Compton electrons produced by gamma radiation, beta rays that escape directly into the water, and the interactions of high energy neutron capture gamma rays that produce electrons from Compton scattering and pair production. All of these sources of high energy electrons are produced from the decay of fission products. It was expected, and later experimentally shown to be true,[2] that the intensity of Cerenkov light generated by the irradiated fuel is proportional to the radiation field intensity in the vicinity of the irradiated fuel. This field intensity is proportional to the burnup of the fuel and inversely proportional to the cooling time.

The number of Cerenkov photons generated by gamma rays of any energy passing through water has been calculated in earlier reports[1,2] and the results of these calculations have been experimentally verified. The theoretical basis for the Cerenkov technique has been described in some detail in the earlier referenced reports and will not be repeated here. We have calculated the Cerenkov light intensity as a function of exposure and cooling time, and these calculations were used as the basis of comparison of the experimental data obtained at Los Alamos' Omega West Reactor (OWR), which is a Materials Testing Reactor (MTR), at the Zion Nuclear Station, which is a Pressurized Water Reactor (PWR), at the Morris Irradiated Fuel Storage Facility, which contains both PWR and Boiling Water Reactor (BWR) fuels, and at the Irradiated CANDU Fuel Storage Bay at the NRX facility at the Chalk River National Laboratory. These data all confirm that the intensity of Cerenkov light generated by irradiated fuel assemblies is proportional to the burnup and inversely proportional to the cooling time of the assembly.

III. EXPERIMENTAL PROCEDURES AND EQUIPMENT

The Cerenkov light generated by MTR, PWR, and BWR fuel is highly collimated when viewed along the axis of the assembly. This is the normal view for light water reactor irradiated fuel because this fuel is stored vertically and viewed from above the pond from a bridge that spans the storage pond. The highly collimated nature of the light requires that the instrument used to measure the Cerenkov glow have its optical axis positioned along the axis of the assembly in order to view the maximum light intensity emitted by the assembly.

A. Los Alamos Omega West Reactor

For the measurements made at Los Alamos' OWR, a Silicon Intensified Target (SIT) video camera was used to record the images of the irradiated MTR fuel. Five fuel assemblies of varying burnup and cooling time were used in a number of configurations designed to provide a comparison between calculated and measured light intensity and to estimate the effect of cross talk among assemblies arranged in a tightly packed array. The results of these measurements provided assurance that the measured intensities of assemblies in a close-packed array differ from their nominal value by no more than about 10% in most situations. The measured light intensities of the MTR fuel were found to be consistent with the calculations based on the recorded burnup and cooling times for those assemblies.

B. ZION Nuclear Station

Measurements at the ZION Nuclear Station were made using an SIT video camera as the primary detector of the Cerenkov light. The images were recorded on video tape and analyzed later. The SIT video camera was clamped to the irradiated fuel storage pond bridge railing so that the camera was pointed as nearly as possible along the axis of the assemblies. Because each storage location is somewhat larger than the size of an assembly, the axis of the assembly was not always vertical and, consequently, the alignment of the camera was not always optimum. This misalignment did not reduce the effectiveness of the measurements but did somewhat decrease their precision. The assemblies were measured in rows perpendicular to the bridge. The bridge was used to transport and position the camera above the irradiated fuel assemblies. Two complete rows were imaged through eight meters of water, each row containing 14 assemblies. Of these 28 assemblies, 15 contained the standard PWR burnable poison pin clusters and the remainder were unpoisoned. An assembly containing poison pin rods is shown in Fig. 1 and one without the poison pins is shown in Fig. 2. The highly collimated nature of the Cerenkov light generated by these assemblies is evident from these pictures. The Cerenkov glow from only one assembly in each picture is obvious and this is the one whose axis is aligned with the SIT camera directly above it. Both pictures were taken by storing the original image information on video tape, then replaying the tape via a video editor that had a storage disk capability. The storage disk was used to display a single frame of video information on the monitor. A plate camera was used to photograph this video monitor image. Each frame on the disk was displayed in conventional 512-line TV format. Selected portions of the frames were addressed with a raster address using x-y cross hairs. The raster address size was a single pixel whose area is equivalent to one element out of a 512 x 512 matrix. An associated electrometer indicated the electron current forming the intersection pixel. The electron current is directly proportional to the pixel brightness. The brightness of pixels representing the Cerenkov glow was obtained in digital form directly from the electrometer reading. To obtain a relative real-image brightness from the measured pixel brightness, the SIT camera lens aperture size variable was removed by normalizing all brightness to a common f/stop value. This technique was used to measure the brightness of the Cerenkov glow generated by all 28 irradiated fuel assemblies. Although the exposure of these assemblies varied between 19,000 and 38,000 MWd/tU, we assumed an average burnup of 30,000 MWd/tU because we did not expect the measurement precision in this particular test to be sufficient to distinguish among assemblies of exposures that vary ±50%. When the measured intensities of the 28 assemblies were plotted against the curve predicting the Cerenkov intensities,

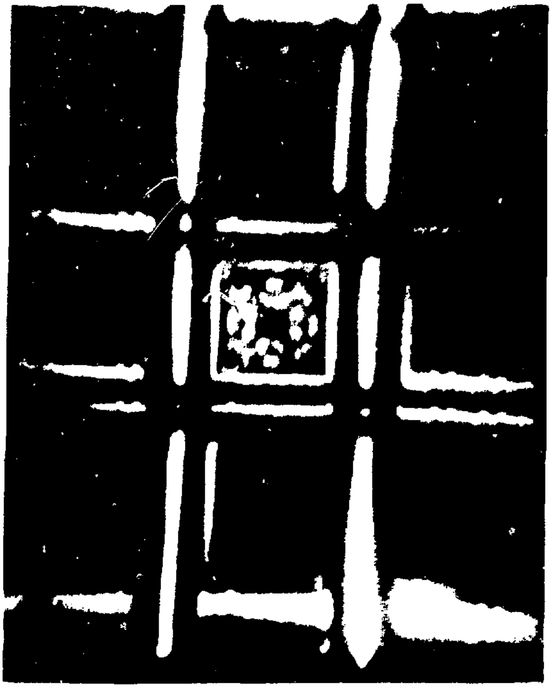

Fig. 1.
Cerenkov image of a PWR assembly containing a burnable poison pin cluster. A typical "rosette" light pattern results.

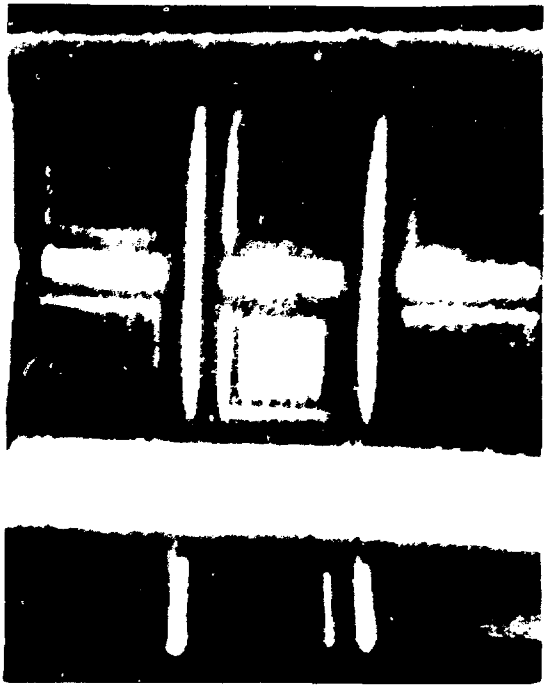

Fig. 2.
Cerenkov image of an unpoisoned PWR assembly. The bright light from the poison pin holes is clearly discernible.

shown in Fig. 3, the experimental data fit the predicted curve very well. The 28 irradiated fuel assemblies were divided into five cooling time groupings that varied from 45 days to about 1000 days. These measurements showed that the normalized measured Cerenkov photon intensities depend on the cooling time of the assemblies as predicted. The calculated values for the Cerenkov intensities are based on the Cerenkov photon production in water due to gamma emissions from all significant fission fragments and their composite half-lives.

An additional capability of the Cerenkov photon intensity measuring technique was demonstrated at the Zion Nuclear Station. A single assembly was extracted from its storage rack so that it was suspended vertically above the other assemblies. The SIT video camera was set on a tripod at one end of the pond and video images of the extracted element were recorded on video tape. Although this image was an oblique view of the assembly, it was seen that this video information could be used as a rapid profiling of the radiation intensity along the axis of the assembly. A typical frame of the video image is shown in Fig. 4.

The video-disk recorded image was displayed on the CRT with the x-y cross hair raster address. The y value provides the axial Cerenkov intensity profile and this trace is shown in Fig. 5.

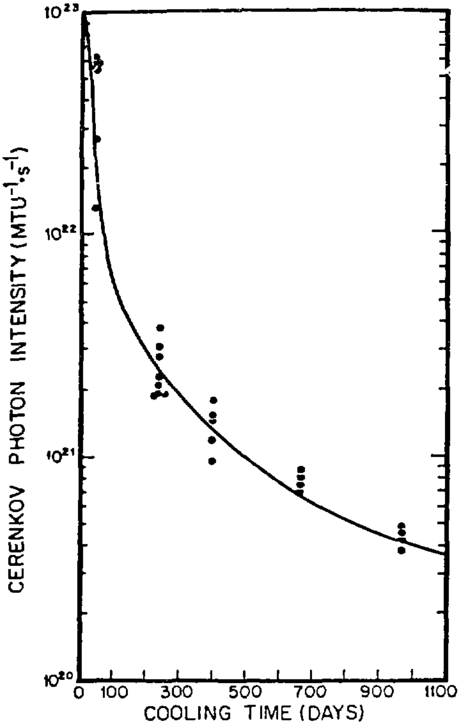

Fig. 3.
Cerenkov intensity measurements of the Zion assemblies normalized to the calculated value at 270 days' cooling time. Solid curve is calculated curve for 30 000 MWd/tU exposure.

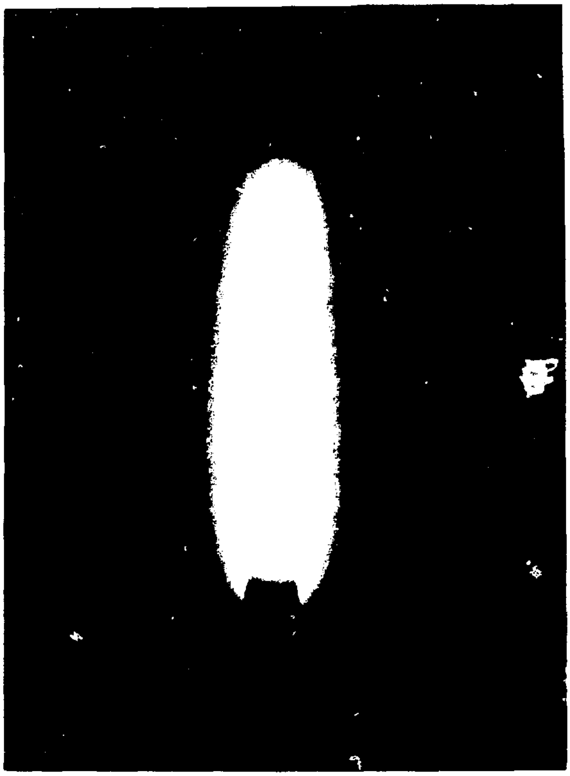

Fig. 4.
Cerenkov image of a single PWR assembly extracted from the storage rack.

Fig. 5.
Axial profile of the Cerenkov intensity of a single PWR assembly. Obtained by analysis of a single video frame (1/30 s).

Although no detailed comparisons have been made with other measurements, this profile is typical of such PWR assemblies. It provides a rapid technique for estimating the uniformity of burnup along the axis of PWR or BWR fuel that could be used in estimating the fissile content of irradiated fuel in storage if used with single absolute axial point measurement.

Additional details of the calculations and measurements made on MTR and PWR irradiated fuel can be found in our earlier work.[1,2]

C. General Electric Morris Facility

Three prototype Cerenkov glow detectors were taken to the GE Morris Facility for tests and evaluation and to demonstrate these instruments to International Atomic Energy Agency (IAEA) and International Safeguards Project Office (ISPO) personnel. This equipment consisted of the following:

1) System 1 consisting of a Pritchard photometer coupled by a transfer lens to an RCA ISIT television camera. This instrument was affixed to an aluminum channel and suspended vertically from an articulating arm that mounts to the bridge railing (Fig. 6).

2) System 2 consisting of a Javelin Model 226 Cerenkov Viewing Device (CVD) consisting of a first-generation image intensifier, a 135-mm telephoto lens, and a mount on the rear of the device that accommodates a biocular viewer and a 35-mm Olympus OM-2 camera. The instrument was mounted horizontally on the bridge and viewed the irradiated fuel assemblies through a 45° mirror, as shown in Fig. 7.

3) System 3 consisting of a Javelin Model 222 CVD that is smaller and lighter than the Model 226 because it has a second-generation image intensifier and a smaller, lighter objective lens. A biocular viewer and a camera may also be used with the Model 222, as shown in Fig. 8.

System 1, the photometer-ISIT television camera, was used to get a precision measurement of the intensity of Cerenkov light generated by the irradiated fuel assemblies. The ISIT camera was used to aim and align the photometer because the Cerenkov glow is usually not bright enough for the unaided eye to see it through the photometer viewer. The ISIT and the photometer were optically coupled with a transfer lens by taking the image from the viewing port of the photometer and focusing it on the target of the ISIT. The normal objective lens of the television camera was not used in this application. The intensity of light generated by a single assembly was measured by using the variable aperture size of the photometer. The articulating arm mechanism that

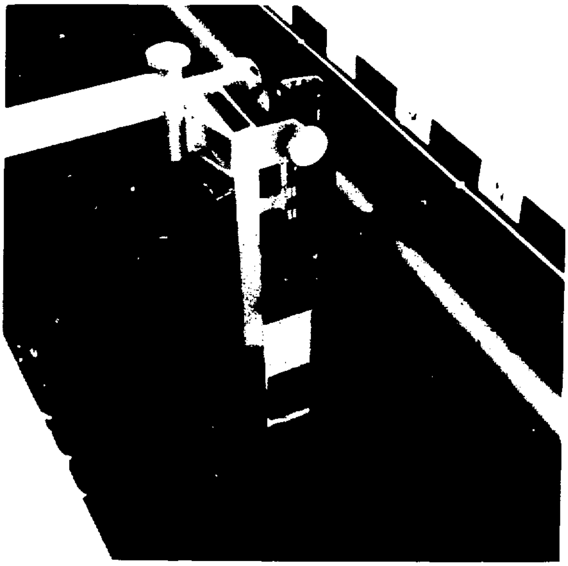

Fig. 6.
Photometer-ISIT system for viewing Cerenkov radiation at GE-Morris.

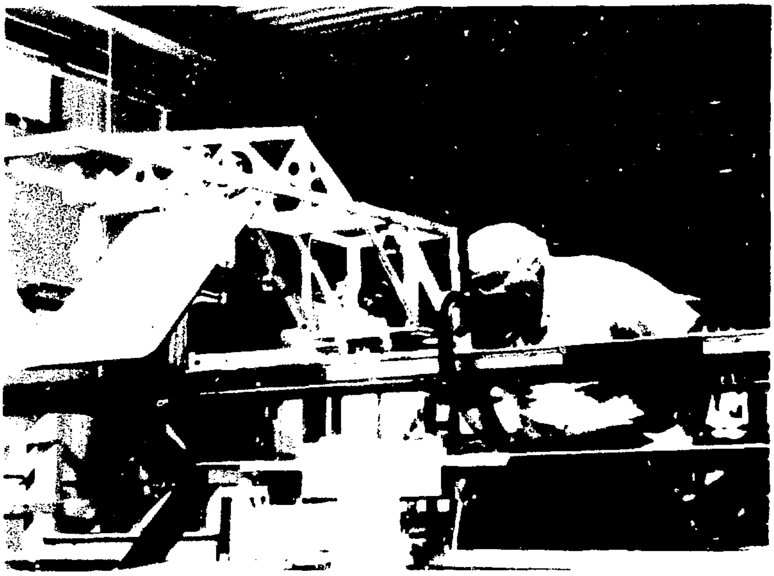

Fig. 7.
Model 226 night-vision device mounting at GE-Morris.

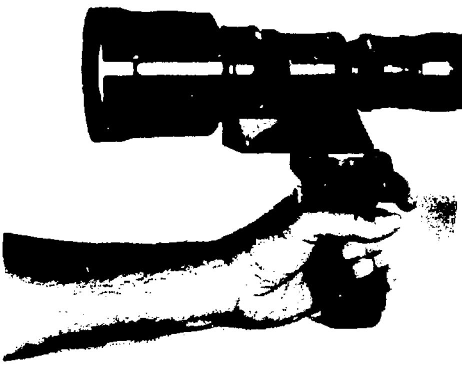

Fig. 8.
Hand-held Model 222 night-vision device evaluated at GE-Morris.

clamped to the bridge railing was used to align the photometer-ISIT tandem alignment would have been easier if the motion could have been made in directions parallel and perpendicular to the bridge rather than the circular motion that the articulating arm assembly afforded.

The System 2 apparatus could be moved parallel and perpendicular to the bridge, which permits relatively fast and easy alignment. Measurements were made with the 135-mm and 300-mm telephoto lenses. The Cerenkov light was to be quantified by using the light meter built into the Olympus OM-2 camera when mounted on the rear of the Model 226. However, the light meter did not have enough sensitivity to measure the brightness of the image formed on the phosphor. Another technique, using the aperture preferred automatic feature of the OM-2, was used to meter the image brightness. An internal light meter integrates the incoming light incident on the film plane and automatically adjusts the exposure time accordingly. Thus, recording the exposure time for each fuel assembly quantifies the brightness of the image. Figs. 9 and 10 are photos taken with this system of PWR and BWR irradiated fuel assemblies, respectively. The highly collimated nature of the light from these assemblies is again quite apparent from these pictures.

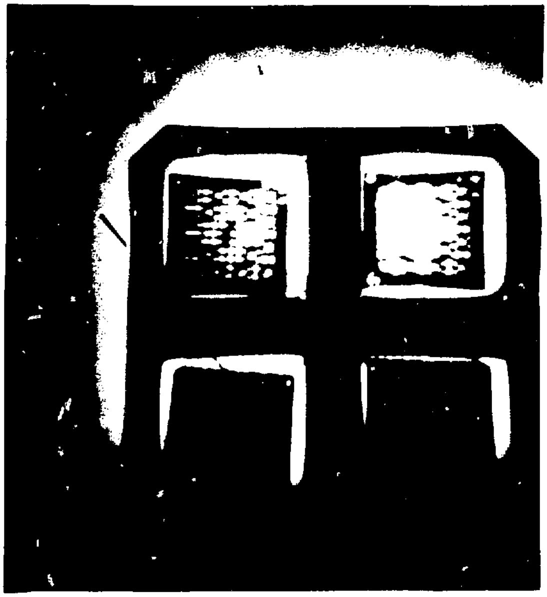

Fig. 9.
The Cerenkov glow of spent PWR assemblies at GE-Morris.

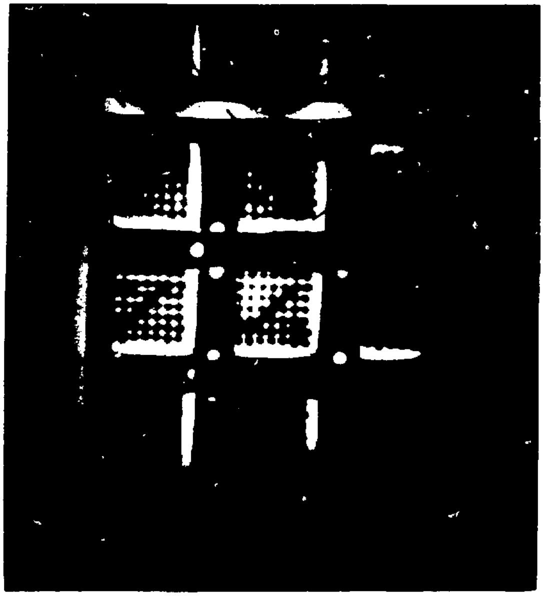

Fig. 10.
The Cerenkov glow of spent BWR assemblies at GE-Morris.

System 3 is well suited for qualitative examination of irradiated fuel. It can be used with a biocular viewer and a 35-mm camera. With the standard eyepiece, it is smaller and has a mass of only 1 kg compared to 1.75 kg with the biocular viewer. Because of its light weight and small size, this device was well received by the Agency inspectors. The inspectors asked whether this device could be used to estimate the light intensity emitted by the irradiated fuel in some semiquantitive way so that it could be used to verify the inventory of irradiated fuel in storage ponds. A technique was developed that does yield a semiquantitive measure of the brightness of the Cerenkov glow by noting the aperture of the telephoto lens that is necessary to bring the phosphor brightness to a common level for each assembly. Described as the "extinction" method, the technique was applied to 36 assemblies. The results were consistent with the measurements taken with the photometer in System 1. This instrument is commercially available and, with minor modifications, has been delivered to the IAEA for test and evaluation. Systems 1 and 2 were used to measure the light intensities from 52 PWR and 45 BWR assemblies that were selected for the largest possible dynamic range in exposure. The System 1 (photometer) data were compared with the declared burnup and cooling time. These data differed by less than 30% from the declared values. A repeat of the photometer measurements taken several days later required a remounting of the equipment on the bridge. That set of data varied less than 10% from the earlier measurements and shows that the photometer data are self-consistent and that the alignment of the instrument along the axis of the assemblies is not as critical as initially thought. The Javelin Model 226 CVD was used to measure the light intensities of the same elements, and these results were found to be within 30% of the photometer data.

The Javelin Model 222 CVD has been tested by the IAEA inspectors for a period of one year. It has become a popular device with the inspectors, and the agency has ordered two more instruments for use by the inspectors. It is anticipated that because of its light weight and simplicity of operation, this instrument, or some modification of this basic model, will be used by agency inspectors to confirm irradiated fuel inventories of the various facilities under their purview. Work is underway to transform this basic instrument into a quantitative device that would allow the inspector to approach a true verification of the irradiated fuel inventory at these facilities.

D. Chalk River Facility

Qualitative and quantitative measurements were made at the Chalk River Facility, Chalk River, Canada, of the intensity of Cerenkov radiation generated by irradiated fuel assemblies from Canadian heavy water-moderated, natural uranium-fueled (CANDU) reactors. These measurements were made with the cooperation and participation of Atomic Energy of Canada, Ltd. personnel from the Chalk River and Whiteshell Facilities. Three IAEA inspectors also participated in these measurements.

The Javelin Model 222 CVD, the same model that was given to the IAEA for test and evaluation, and the Javelin Model 226 CVD, were used in these measurements. An Olympus OM-2 35-mm camera was used with the Model 226 to photograph the Cerenkov glow generated by the CANDU irradiated fuel. The Model 226 CVD was mounted on a heavy-duty tripod on the bridge over the irradiated fuel pond and was oriented vertically in order to view the irradiated fuel directly below the bridge railing.

Thirteen irradiated fuel assemblies were chosen by the IAEA to provide a large range of burnup and cooling time. Fig. 11 is a photograph of a basket containing the 13 irradiated fuel assemblies taken with the Model 226 CVD and the Olympus OM-2 35-mm camera. These assemblies, approximately 50-cm long and 10-cm in diameter, range in cooling time from 10 to 34 months and in burnup from 4,800 to 11,300 megawatt days per ton of uranium (MWd/tU). The assembly located in the second column from the left (the only assembly in that column) is the weakest Cerenkov generator and is the assembly that has the lowest burnup and longest cooling time.

CANDU irradiated fuel is normally stored horizontally in trays containing 24 assemblies with these trays stacked 15 or more high. These vertical stacks of trays can be stored as closely as a few centimeters apart. The orientation of the irradiated fuel found at Chalk River is not at all typical of the normal storage configuration but did provide a good configuration to photograph and measure Cerenkov intensities adjacent to these assemblies. Fig. 12 shows an assembly lying on its side on a table in the pool. Intensity measurements were again made using the automatic aperture preferred feature of the OM-2 camera. By measuring the film exposure time, the intensity of the Cerenkov glow generated by each assembly was determined. Except for three outliers, the calculated Cerenkov intensity agreed with the measured value to within 20%. We had no obvious explanation for the discrepancies of the three outliers. In reality, these bundles experience different burnup rates depending on the fuel channel they travel through and the uniform rate model used in the calculations is expected to be faulty.

An unirradiated fuel assembly was placed in the basket adjacent to both the hottest and coolest assemblies. In Fig. 13, if the columns are counted from left to right and rows from top to bottom, the unirradiated assembly was placed in the second row, second column, immediately above the weakest assembly referred to earlier. The hottest assembly in the basket is located in the first row, first column. When comparing the unirradiated assembly with all of the other irradiated fuel, it is clearly not generating any

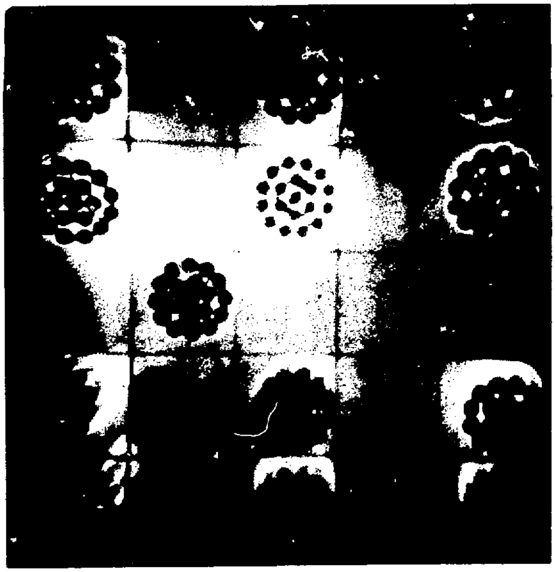

Fig. 11.
Thirteen selected spent CANDU fuel assemblies viewed on end.

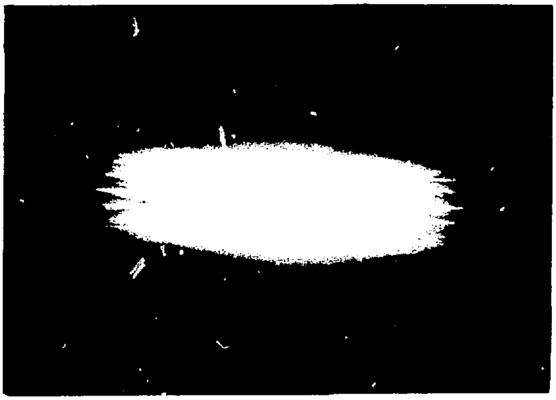

Fig. 12.
A typical spent CANDU fuel assembly viewed from the side.

light in the interior of the assembly. A small amount of light appears to be reflected off the right side of the assembly. An interesting characteristic of the CANDU Cerenkov glow that was not noticed in previous investigations of light water reactor fuel is a distinct halo of brightness surrounding each pin of the assemblies that extends not more than several millimeters from the surface of each pin. Note that the unirradiated assembly in Fig. 13 does not have any indication of a halo surrounding its pins as do the other pins in the photograph. Fig. 14 shows an assembly in the fifth column, second row, with a pin that has come loose from the assembly. This shows the halo completely surrounding the pin. The significance of this picture is that it demonstrates that a single pin has its own discrete Cerenkov glow and demonstrates that single pins can be verified to have a Cerenkov halo even in the presence of other pins with their halos. The ability to verify single pins in an assembly was a feature that the agency inspectors felt was quite important.

Two explanations for the short range, high intensity halo have been offered. Because the halo is a short range phenomenon and its intensity drops off abruptly, it is most likely produced by electrons originating in the irradiated fuel pin rather than gamma interactions in the water. The possible sources of electrons from within the pins include beta emissions from the fission products that would have to penetrate 0.4 mm of zircalloy before entering the water and Compton electrons or photoelectrons produced in the fuel or in the zircalloy near the surface of the cladding. Calculations show that the betas can penetrate the thin cladding on the pins and that Compton electrons and photoelectrons are both produced energetic enough (greater than 0.26 MeV) to give rise to Cerenkov radiation. The range of a 1-MeV electron in water is about 4 mm, and the halo extent is somewhat less than this. Since relatively few photoelectrons are produced by gamma rays with energies above several hundred keV, the two most likely sources of the Cerenkov-producing electrons are from fission product beta emitters and Compton electrons.

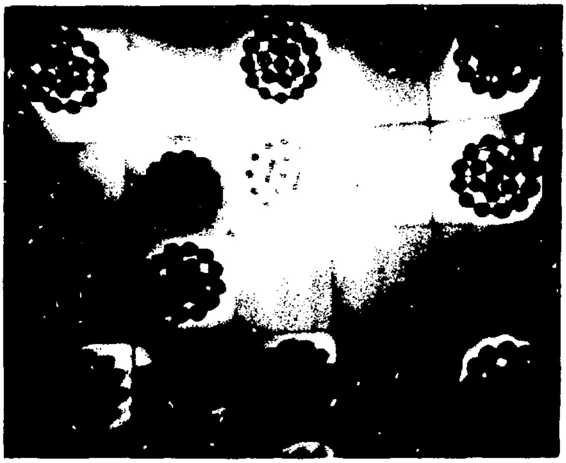

Fig. 13.
An unirradiated CANDU fuel assembly (first assembly in the second column) compared with spent CANDU fuel assemblies.

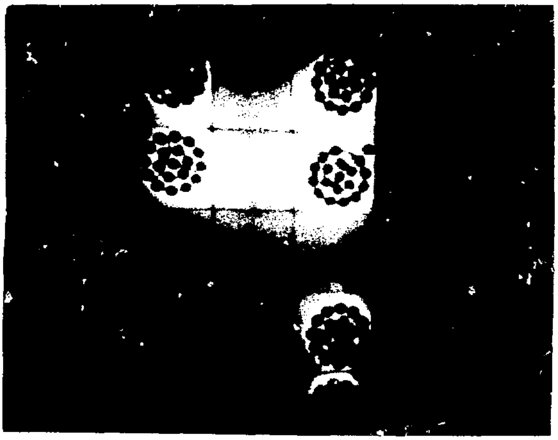

Fig. 14.
Photograph showing the discrete halo surrounding the detached fuel pin in the second assembly, right column.

A full basket of irradiated fuel containing 25 assemblies is shown photographed from an oblique angle in Fig. 15.

The dark, circular object in the right-hand column, second location from the top, is a cylindrical can slightly taller than the other assemblies and containing the pieces of a broken assembly.

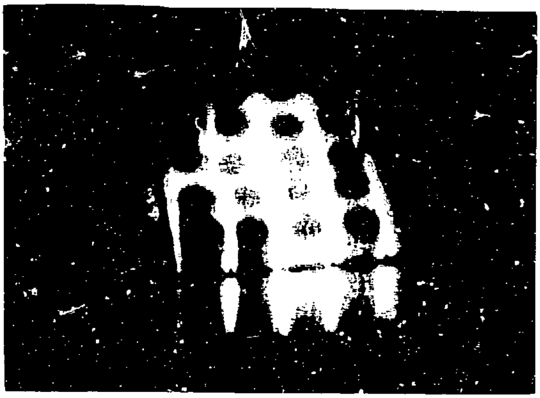

Fig. 15.
Oblique view of a full basket of spent CANDU fuel assemblies.

E. WAK Facility, Karlsruhe, Germany

A field test of the Cerenkov technique was conducted at the WAK facility in Karlsruhe, Germany. Two Javelin Model 222 CVDs were brought from Vienna by IAEA personnel. The objectives of the field test were to:

--- Determine the usefulness of the CVD in providing identification of irradiated fuel.

--- Evaluate the effectiveness of the CVD under various light level conditions.

--- Obtain facility operator comments regarding the requirements for extinguishing lights and operating the bridge during inspections.

--- Provide a basis for preparation of detailed procedures for inspectors.

Eight irradiated fuel assemblies were proposed for examination with the CVDs. The exposures ranged from 18,000 to 31,000 MWd/tU, and the cooling times ranged from 4 to 9 years.

Because of the similarity in burnup and cooling time for many of the assemblies proposed, examination of only five of the assemblies was necessary. In addition, an assembly in a covered container, a covered container with a loose fuel pin, and a VAK fuel assembly were examined. A set of light conditions was selected to evaluate the usefulness of the CVD under low level lighting conditions.

As a result of these tests, the following observations were made:

--- With all of the lights off, the Cerenkov glow generated by all irradiated fuel assemblies, even those with covers, was visible with the unaided eye. The CVD provided a much more precise view of the view of the uncovered assemblies where the patterns of light emitted are clearly discernible.

--- Examination of one of the assemblies quickly disclosed an unfamiliar pattern of spots. It was determined that in addition to the 16 bright spots associated with the control rod channels, there were six additional bright spots that were attributed to missing pins. The facility operator confirmed that six pins were missing, a fact not revealed to the agency participants prior to this test.

--- The Cerenkov glow due to the assembly in the covered container could be seen on all four sides of the container. The top of the assembly could not be seen because of the cover.

--- The glow from the loose pin in the covered container was very difficult to see with the unaided eye but was readily apparent using the CVD. The glow was limited to the corner of the container where the fuel pin was located. This observation indicated the potential value of the CVD in cases of a covered fuel assembly with a significant number of pins missing from a sector of the array. This should be apparent by a lack of Cerenkov glow from the corresponding side of the container.

--- The VAK fuel assembly had a special mechanical fixture over the top of the assembly that precluded detailed observation of the normal light pattern.

--- One PWR assembly had a large number of pins missing from the central portion of the assembly in the pattern of a Swiss cross. This pattern was readily observable with the unaided eye.

--- Various lighting conditions were produced, and the operation of the CVD was evaluated. Only the most dimly lit condition, viz., a fluorescent light fixture located halfway up a wall facing away from the storage pool in an adjacent area, provided a light arrangement that did not produce an excessive amount of reflection from the water or light into the pool. This light level appeared to be adequate for operations and safety in the pool area and had no serious effect on the operation of the CVD. The Cerenkov light was also visible with the unaided eye under this condition.

--- Flashlights could also be directed on nearby walls away from the pool with all of the facility lights off, providing adequate light for operations and producing no serious effect on the operation of the CVDs.

The CVD was shown to be able to provide qualitative information regarding relative brightness of the Cerenkov glow generated by the assemblies and to distinguish assemblies with similar burnup that have significantly different cooling times or assemblies with similar cooling times that have significantly different burnup values. Variations in cooling time or burnup of 50% can be detected.

As a result of this field test, it was made clear that extinguishing all lighting is of some concern to the facility operator. Agreement and cooperation of the facility operator and national regulatory authorities is likely to be a prerequisite, particularly when it comes to determining acceptable light levels. However, if use of the CVD can be shown to be less intrusive than other techniques for irradiated fuel verification, the use of the Cerenkov technique as an inspection tool appears likely.

Taking photographs of the Cerenkov glow from irradiated fuel assemblies may also have to be negotiated. The WAK security authorities would not permit the use of the 35-mm camera with the CVD, and similar objections might be encountered at other facilities.

IV. APPLICATION OF THE CERENKOV TECHNIQUE TO AFRS

It is anticipated that the IAEA inspectors will be using the Cerenkov glow imaging and measuring technique for verifying irradiated fuel at reactor and AFR facilities throughout the world. Furthermore, the technique will most likely be adopted in a gradual fashion as more and more inspectors become familiar with its use and the simplicity and speed that the technique offers. At present, the inspectors only routinely read the serial numbers from the assemblies. Additional NDA measurements can be made, but these are difficult and time consuming to make. The Cerenkov technique provides the inspectors with an attribute measurement capability that is rapid, easy to perform, and somewhat difficult to spoof.

Facilities that will be inspected by IAEA inspectors might find it advantageous to have a similar inspection performed by their own personnel in some routine fashion. Such verification by facility operators will allow them to understand what information the inspectors are analyzing and may help to expedite inspections and to unravel any discrepancies that may arise. The Cerenkov glow technique will also be helpful to the facility operator by providing him with a rapid means of verifying incoming and outgoing shipments of irradiated fuel and in inventory control of the irradiated fuel in his storage pond.

Another feature of the Cerenkov technique that the facility operator will find useful is the ability to obtain a rapid intensity profile measurement of the irradiated fuel in his inventory. The profile of the radiation intensity of a irradiated fuel assembly will provide a good estimate of the uniformity of the burnup which will result in a better estimate of the fissile content within each assembly in storage.

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