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A SHIELDED ENCLOSURE FOR NEUTRON RADIOGRAPHIC INSPECTION OF ENCAPSULATED, IRRADIATED SPECIMENS

by

W. N. Beck and H. Berger

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A SHIELDED ENCLOSURE FOR NEUTRON RADIOGRAPHIC INSPECTION OF ENCAPSULATED, IRRADIATED SPECIMENS

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ABSTRACT

A neutron shield enclosure for neutron radiographic inspection of encapsulated, irradiated fuel specimens has been fabricated. An existing shielded cask was modified to handle a complete irradiation experiment from the CP-5 reactor. The inspection technique makes use of a potentially radioactive screen to detect the neutron imaging beam after it has passed through the inspection object. The radioactive image on the screen is made visible by allowing it to decay in close contact with photographic film. Contrast resolution of the system is 0.76 mm (0.030 in.) or better. Contrast sensitivity is in the order of 1 to 2 percent.

INTRODUCTION

In the evaluation of a fuel material for power reactors, it is essential to subject prototype fuel specimens to various conditions of high temperature and high burnup. Such experiments can be performed with suitable instrumented capsules in which fuel specimens are introduced into an irradiation facility.(1) In lieu of a destructive examination of the capsule, periodic nondestructive radiographic inspections of the contents are essential in determining if the irradiation period should be terminated or if the condition of the specimens warrants a continuation of the irradiation.

A pinhole autoradiographic technique has been used successfully in imaging the outline of highly radioactive objects within capsules. (2) An improvement of this technique is found in the application of neutron radiography, which makes it possible to identify components within the irradiated capsules other than the individual sections of fuel material. (3)

To be able to extract a complete test capsule from the reactor, to neutron-radiograph the contents, and then to return it to the irradiation facility, it was necessary to prepare special handling devices and shielded enclosures. A portable shielded enclosure with a cassette discharge and recharge magazine was therefore designed and fabricated. This enclosure



was designed for use with an existing neutron radiographic facility, horizontal neutron beam hole, 6Hl, of the Juggernaut reactor. $^{(4)}$ An existing fuel-transfer cask which had been modified for pinhole autoradiography was further modified to handle a complete 3.35-m (11-ft) CP-5 irradiation experiment.

THE SHIELDED ENCLOSURE

The beam hole opening at the side of the Juggernaut reactor is located 67.3 cm (26.5 in.) above floor level. The collimated beam aperture is 64 mm x 102 mm (2.5 x 4 in.) and has a neutron beam intensity of the order of 10^7 neutrons/cm²-sec at a thermal to epithermal flux ratio of approximately 3.6 to 1.

In the design of the enclosure, three conceptual requirements had to be met: (1) adequate gamma shielding should be provided to allow operating personnel to work in close proximity to the experiment,* (2) the neutron beam intensity and scatter should be reduced to a level which would not present a hazard to personnel, and (3) provisions should be made whereby the cassette containing the detectors could be positioned directly behind and in line with the neutron beam, and be removable and replaceable without disturbing the irradiation capsule.

The enclosure in which the radiograph is taken is a lead-filled steel casing. A minimum thickness of 25.4 cm (10 in.) of lead is used in the immediate vicinity of the radioactive material, but is tapered to 6 in. at the extremity which fronts the reactor face. A cross section of the installation is shown diagrammatically in Figure 1. Shielding is provided on three sides and top, but not on the bottom, which rests on the floor, or on the front which butts against the reactor. The top of the shield is provided with a 10.2-cm (4-in.) hole which aligns with the hole of the transfer cask. Special cone-shaped sleeves fit the hole, which serve to guide and position the capsules within the shielded enclosure. Proper alignment of the transfer cask over this hole is assured by the large, tapered ring bolted to the top of the shielding.

Positioned directly behind the vertical hole in the shielding is a sliding cassette rack which is supported by rollers and is guided in a track. The rack is made to hold a standard aluminum-front X-ray cassette for 12.7 x 17.7-cm (5×7 -in.) film. The cassette is frame caged in the middle of the rack. A 20.3-cm (8-in.)-wide slab of lead on either side of the cassette serves as biological shield to prevent gamma activity from streaming from the slot opening in the enclosure. The portion of rack

^{*}The gamma activity of the irradiated capsules has been measured to be in excess of 5 x 10^3 R/hr at 30 cm (1 ft).

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THE SHIELDED ENCLOSURE

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guides which projects out from the enclosure is further encased in 5.1 cm (2 in.) of steel. Manipulation of the slide rack is accomplished with a handle attached to the rack, operated through a slot in a 5.1-cm (2-in.) steel projection casing. Removal of the cassette from the rack is aided by a plunger at the bottom of the casing, which pushes against the bottom of the cassette. In order to assure adequate shielding of the enclosure at the slide rack projection, a 15.2-cm (6-in.) block of lead shielding was added to compensate for displacement of shielding made necessary by the rack guide extension. The placement of this shielding can be seen in Figure 2.



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Figure 1. Diagram of Shielded Enclosure and Capsule Transfer Cask gundes which projects out from the enclosure is further encased in 5.1 cm (2 in.) of steel. Manipulation of the slide rack is a complished with a handle attached to the rack, operated through a slot in a 51-cm (2-in.) steel projection casing. Removal of the carsette from the rack is aided by*a plunger at the bottom of the casing, which pushes against the bottom of the cassette. In order to assure adequate shielding of the enclosure at the side opposite the slide rack projection, a 15.2-cm (b-in.) block of lead shielding was added to compensate for displacement of this shielding nacessary by the rack guide extension. The placement of this shielding can be seen in Figure 2.



Figure 1. Disgram of Shielded Enclosure and Cananie Transfer Cask



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Figure 2. Neutron Shield Enclosure and Transfer Cask Adjacent to the Reactor

Neutron backscatter affecting the detecting foils is minimized by a 0.6-cm (0.25-in.)-thick boron plate mounted in the rack, directly behind the cassette.

TRANSFER CASK

The cask which was suitable for handling a complete irradiation assembly was one which is also used for pinhole autoradiography. The cask has a 10.1-cm (4-in.) central hole and 25.4 cm (10 in.) of lead shielding. The bottom is equipped with one gate, and the top is closed with a



plug. The cask was modified by the addition of a 10.1-cm (4-in.)-thick extension tube which is bolted to the top of the cask. A steel collet, 10.1 cm (4 in.) thick, which is at the top of this extension, clamps against the body of the assembly shield plug. This collet immobilizes the assembly and prevents gamma radiation from streaming out of the top of the cask. The cask is normally transported horizontally on a dolly but is turned upright when being loaded and unloaded.

In operation, the cask is placed over a vertical thimble hole of the CP-5 reactor, which contains an experiment. The capsule is pulled into the cask, the gate is closed, and the shield plug is clamped in the collet. It is transported to the Juggernaut reactor and placed on the shielded enclosure. The gate is opened, the collet loosened, and the experiment is lowered until the capsule is directly in front of the cassette-holder carriage. The cassette containing the foils is then transferred into the enclosure, directly behind the capsule.

A photograph of the transfer cask is shown in Figure 2.

NEUTRON RADIOGRAPHY TECHNIQUE

The inspection method makes use of a potentially radioactive screen to detect the neutron imaging beam after it has passed through the object to be inspected. The radioactive image on the screen can be made visible by allowing the screen to decay in close contact with photographic film. Since the gamma activity of the specimen will not influence the radioactivity of the detecting screen, it will therefore not influence the final radiograph.

Neutron radiographs based on this autoradiographic technique have been successfully taken by the use of any of several potentially radioactive screen materials to detect the neutron image. Materials such as rhodium, silver, indium, dysprosium, and gold have been particularly useful. The specific detection techniques used in the initial experiments for the inspection of radioactive specimens employed silver, dysprosium, and indium screens, as reported previously. (3)

These methods provide both a coarse, fast result for alignment purposes when screens of short-half-life silver are used (the half-life of Ag^{108} is 2.3 min) and a slower, fine-grain film image for the actual inspection when the longer-half-life materials are used (the half-lives of In^{116} and Dy^{165} are 54 min and 2.3 hr, respectively). The major change made since this procedure was reported has been in the alignment procedure. plug. The cases was modified by the addition of a 10 l-cm (4-in.)-thick extension tube which is bolted to the top of the case. A steel collet, 10.1 cm (4 in.) thick, which is at the top of this extension, clamps against the body of the assembly shield plug. This collet immobilizes the assembly and prevents gamma radiation from streaming out of the top of the case. The cask is normally transported horizontally on a doliv but is turned upright when being loaded and unloaded.

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The alignment of the inspection object, that is, placing the object in the neutron beam in such a position as to reveal the desired information, had been checked by obtaining a neutron image on a silver screen, transferring it to a fast X-ray film such as Kodak Type KK film for the autoradiographic exposure, and then developing the film. This procedure took some time in that the neutron exposure time was about 7 min, the autoradiographic exposure required a three half-life decay (about 7 min), and the film development required at least 5 min. This technique was improved by modifying the neutron beam to provide a higher neutron intensity,* which permitted a reduction in the exposure time. A second, and more significant, improvement in the technique, in which a fast Polaroid film was used, resulted in further decreases in exposure and development time. The combination of these improvements results in the production of a neutron Polaroid print suitable for alignment purposes in a total time of less than 3 min. The technique employed a rhodium screen and Polaroid Radiographic Packets Type 3000X. A complete description of the method has been given elsewhere. (6)

The complete exposure technique for a typical capsule is then as follows:

(1) After the capsule is lowered into the first exposure position, the alignment is checked by making a neutron exposure with a 0.025 x 12.7 x 17.7-cm (0.010 x 5 x 7-in.) rhodium metal screen detector in an aluminumfront X-ray cassette. Neutron exposure time is 15 sec open time on the remotely controlled shutter. Shutter open and close time adds another $1\frac{1}{2}$ min. The rhodium screen is then placed in contact with the Polaroid film and allowed a 1-min decay. The Polaroid print is then developed and inspected.

(2) When the alignment is as desired, a $0.025 \times 12.7 \times 17.7$ -cm $(0.010 \times 5 \times 7$ -in.) indium metal screen is placed in a cassette and inserted into the exposure position. The neutron exposure time required is 4.5 min, plus shutter open and close time. The indium screen is then taken to a darkroom and placed into a cassette containing 2 sheets of Kodak Type AA X-ray film, one on each side of the screen. The cassette is then closed and the indium is allowed at least a 1-hr decay before the films are developed.

The radiographs produced by this latter procedure are of reasonably high quality. Since the object-detector distance is held to less than 5.08 cm (2 in.) by the design of the exposure chamber, the high-contrast

^{*}The removal of extra graphite in the beam collimater improved the neutron intensity by a factor of about 3. Further discussion of the beam characteristics are contained in reference 5.

The alignment of the inspection object that is, placing the object in the neutron beam in such a position as to reveal the desired information, had been checked by obtaining a mentron image on a silver acreen, frantferring it to a tast X-ray film such as Kodak Type KK (inn for the autoradiographic exposure, and thes developing the film. This precedure took atome time in that the neutron exposure time was about 7 mm, the autoradiographic exposure required a three half-life decay (about 7 mm), and the film development required at issue 5 mm. This technique was improved which permitted a reduction in the backware time. A second, and more asignificant, improvement in the technique, in which a tast Polaroid litm mautich permitted in further decreates in exposure and development time. The combination of these improvements results in the production of a neutron Polaroid print softable for alignment purposes in a total time. Radiographic Packets Type 2000X. A complete description of the method has been given elsewhere (b)

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•The removal of extra graphite in the beam collimator improved the reutron intensity by a factor of about 3. Further discussion of the here characteristics are contained in reference 5. resolution capability of the radiographic system is 0.076 cm (0.030 in.) or better.⁽⁵⁾ Radiographic contrast sensitivity normally achieved with use of the indium screen method is of the order of 1 to 2 percent.

An example of the radiographic result is shown in Figure 3.



Gamma Autoradiograph of Unopened Capsule

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Neutron Radiograph of Unopened Capsule



Optical Photograph of Clad Fuel Specimens after Capsule Was Opened

Figure 3. Comparison of Gamma Autoradiography and Neutron Radiography of Highly Irradiated Refractory Alloy-clad U-Pu-Fs Alloy Fuel Specimens in Unopened Irradiation Capsule. The heater coils are not visible in the autoradiograph. The heater was also removed before the optical photograph was taken.

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