NEUTRON RADIOGRAPHIC INSPECTION OF IRRADIATED SNAP FUEL

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INTRODUCTION

Post-irradiation test samples of SNAP reactor fuel elements have been nondestructively examined using neutron radiography. The results of the neutron radiographic (N-ray) examinations have been correlated with measurements made using standard hot cell destructive testing. Fuel swelling, cracking and decomposition were readily discernible in the first series of N-ray tests conducted at Atomics International (AI). Further examination of the N-rays revealed that information was available to determine hydrogen content in the uranium-zirconium hydride fuel and that the gap between the fuel and the cladding could be measured. Additional tests were performed using nonirradiated fuel samples of known hydrogen content and known gaps between fuel and cladding to establish procedures for neutron radiography of fuels and to provide standards for comparison with future tests. Hydrogen differences of 0.02 H/Zr atom ratio can be determined from the radiograph using known standards for comparison and gaps between cladding and fuel can be measured to 0.001 inch accurately.

Future AI fuel irradiation experiments will use neutron radiography as the principle tool for examinations. It is expected that enough information is available through neutron radiography that only a limited number of samples, selected by examining the radiographs, will be destructively examined.

FUEL DESCRIPTION

Three sets of SNAP fuel irradiation experiments either have been or will be neutron radiographed. The NAA 120-4 irradiation experiment has been examined. The NAA 121-1 is being examined and two hundred and eleven SNAP 8 Developmental Reactor (S8DR) operating reactor fuel elements will be examined shortly after reactor shutdown. Both the 120-4 and 121-1 experiments are in support of the S8DR. The SNAP, S8DR type fuel element is approximately 17 inches in length by 0.53 inches in diameter. The 10 w/o highly enriched uranium alloyed with zirconium hydride fuel is contained within a 10 mil Hastelloy cladding and has a nominal 8 mil gap across the diameter. The H to Zr atom ratio is about 1.70. The 120-4 test samples are about 4 inches in length and the 121-1 and the S8DR fuel elements are 17 inches long. The 120 and 121 experiments were irradiated in the Hanford reactor.

NEUTRON RADIOGRAPHY

Neutron radiography, while being similar and complementary to x-radiography in many areas, has unique features which makes it particularly attractive to the examination of reactor fuel. Some of these features are: (1) the ability to distinguish between isotopes of an element such as U-235 from U-238, (2) the ability to radiograph irradiated fuel, and in the case of U-ZrH fuel, (3) the ability to distinguish and determine hydrogen content.

Figure 1 illustrates a comparison between X-ray and N-ray of the mass attenuation coefficients versus atomic number. One can see that elements of similar atomic mass which have essentially the same mass attenuation coefficient for X-ray or isotopes such as U-238 and U-235 quite often have good separation in thermal neutron mass attenuation coefficients. It also illustrates the neutron radiography advantage for some of the light elements that have high scattering coefficients (example hydrogen) and the rare earth elements that have high absorption coefficients.

For the work described in this paper the photographic method using standard x-ray film was used. The image definition available in neutron radiography is dependent on many factors. Some of these are: (1) neutron optics or resolution of the beam, (2) object to converter distance, (3) scattering within the object,

(4) type of converter, (5) contact between converter and film, and (6) film emulsion type. We use a small aperture and separation between the aperture and object to provide good optics. Resolution (R) is defined as (L) the distance from aperture to object divided by (D) the aperture diameter. For objects such as the SNAP fuel elements a resolution of ~300 is required to resolve 0.001 inch since the object to converter distance is 0.300 inch. The U-ZrH fuel has considerable neutron scattering so some image definition is lost within the fuel. Thin (~0.001 to 0.005 inch) metal converters were generally used. Dysprosium or Indium foils were used for irradiated fuel examination where the image was transferred from converter to film after neutron exposure. Gadolinium was used for the examination of unirradiated fuel where the film was sandwiched

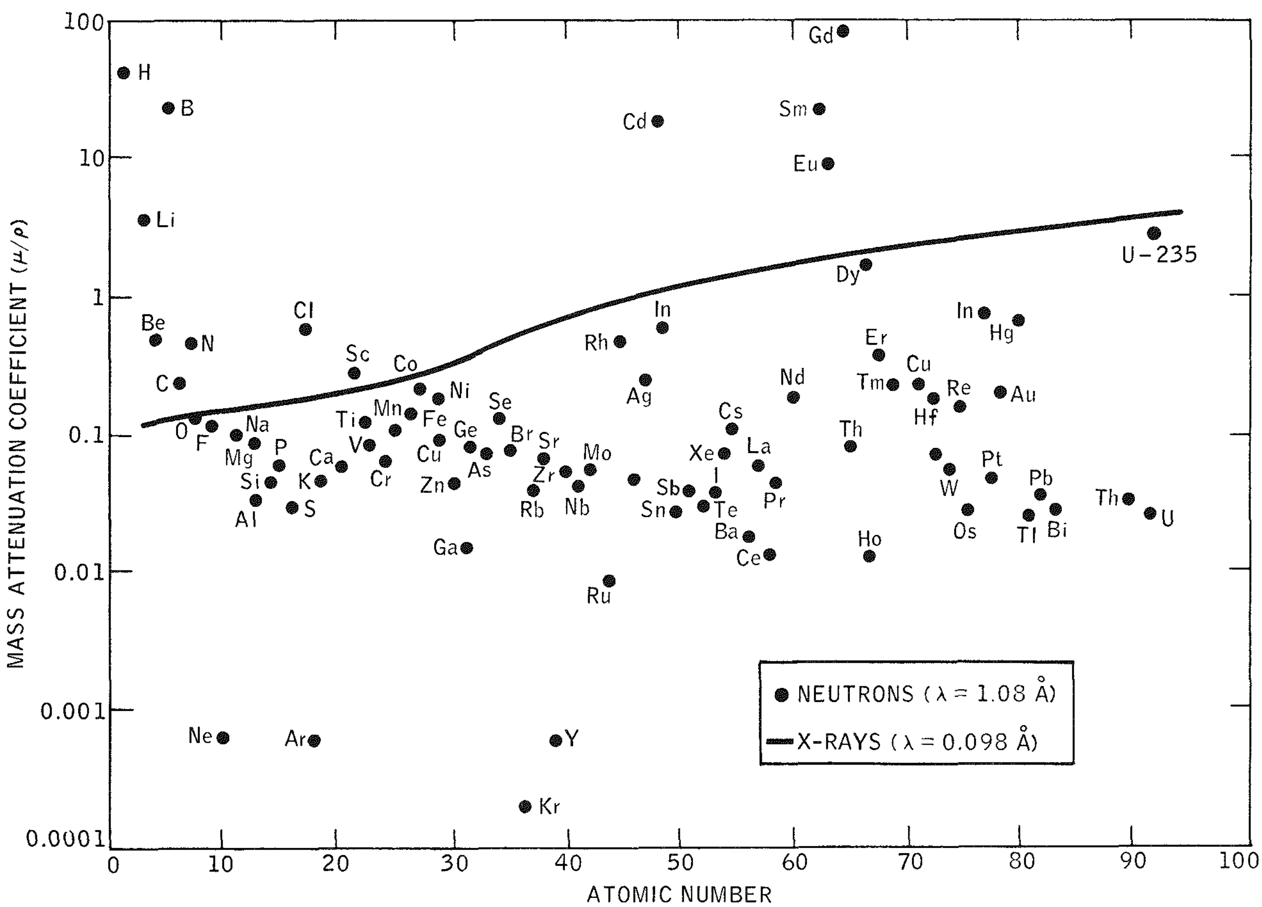


Figure 1. Mass Attenuation Coefficient vs Atomic Number

with the converter to directly (during neutron exposure) transfer the image. Vacuum cassettes are used to provide intimate contact between the converter and film. Different speed films were used to answer different requirements: slow film for fuel to cladding gap detail and fast film to provide denser images in the difficult to penetrate areas for determining hydrogen content.

NEUTRON RADIOGRAPHY FACILITY AND FUEL HANDLING

The Shield Test and Irradiation Reactor (STIR), Figure 2, is used for neutron radiography. The 1 Megawatt pool type reactor provides the neutron source. Generally, thermal energy neutrons are used for radiography although some work has been done using neutrons of epithermal energy. In the former case a graphite thermal column is used to moderate the neutrons to the desired energy while for the epithermal neutron radiography a beam hole is provided in the graphite column to extract neutrons of higher energy directly from the core. The facility, due to the large test vault and the relatively intense neutron beam ($\sim 5 \times 10^{10}$ n/cm^2-sec) at the aperture, allows for radiography of large objects with good resolution.

The STIR facility, not originally designed for neutron radiography, is not a part of the Atomics International Hot Laboratory. Therefore, neutron radiography of irradiated fuel requires transfer of fuel specimens from the hot cell to the reactor facility. To overcome this problem a reactor (L-88) has been designed specifically for neutron radiography and for use in a hot cell facility. Presently special remote handling equipment and techniques are used to radiograph fuel. Figure 3 shows the fixture, fuel handling cask and converter cassette as used in this work. The elements are loaded at the hot cell into the four aluminum tube fixture and capped using O-ring seals to provide leak tightness. The fixture is raised out of the cask at the reactor facility and placed on a geared, motorized assembly for turning the elements for different views. Contact between the fixture and converter cassette is maintained to optimize image definition. After neutron exposure, the specimens are returned to the cask so the converter image detector can be changed or for return to the hot cell. The examination of the 211 S8DR elements will utilize a 12 tube fixture and a means of remotely changing the image converters.

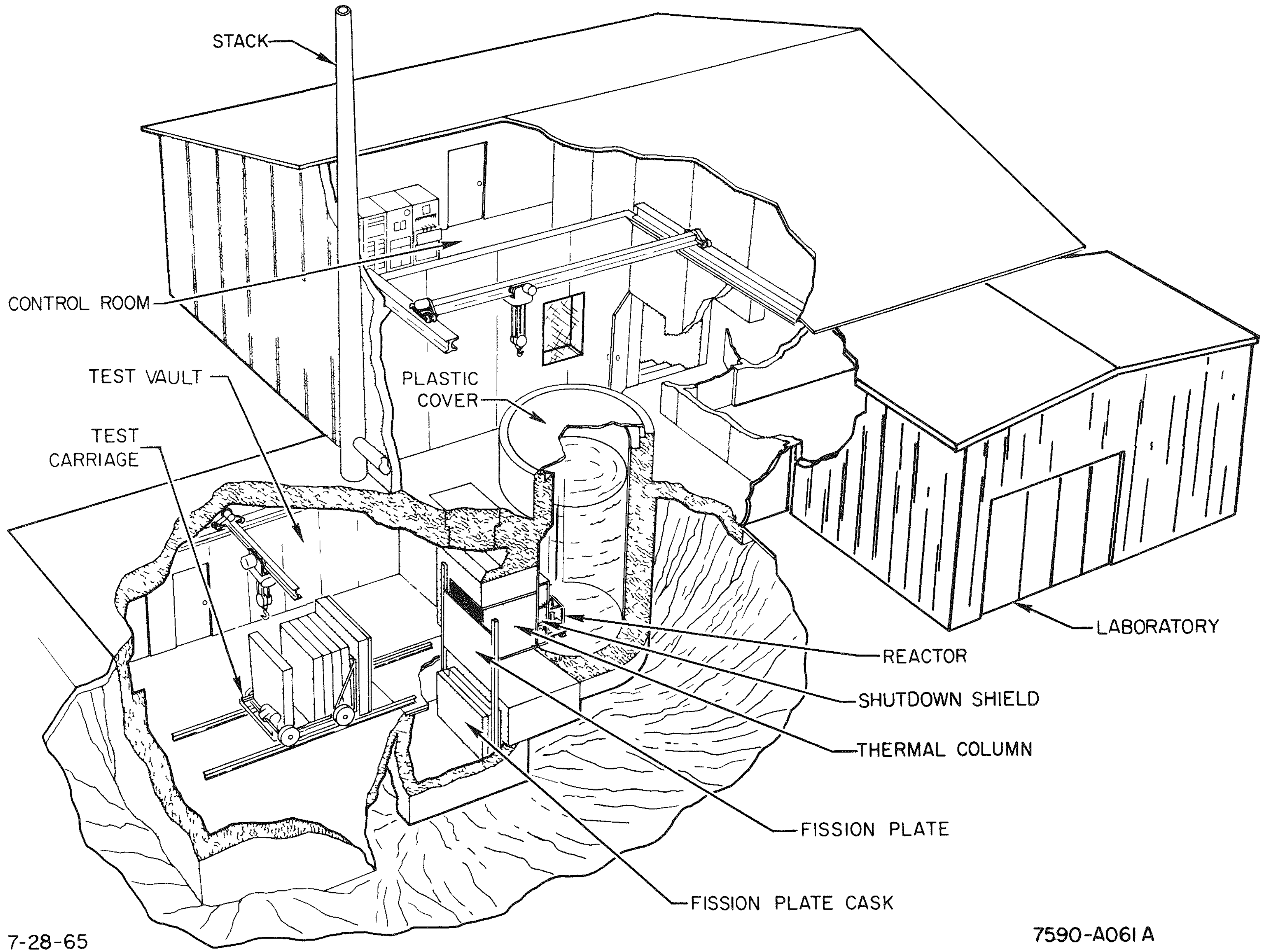


Figure 2. Shield Test and Irradiation Reactor

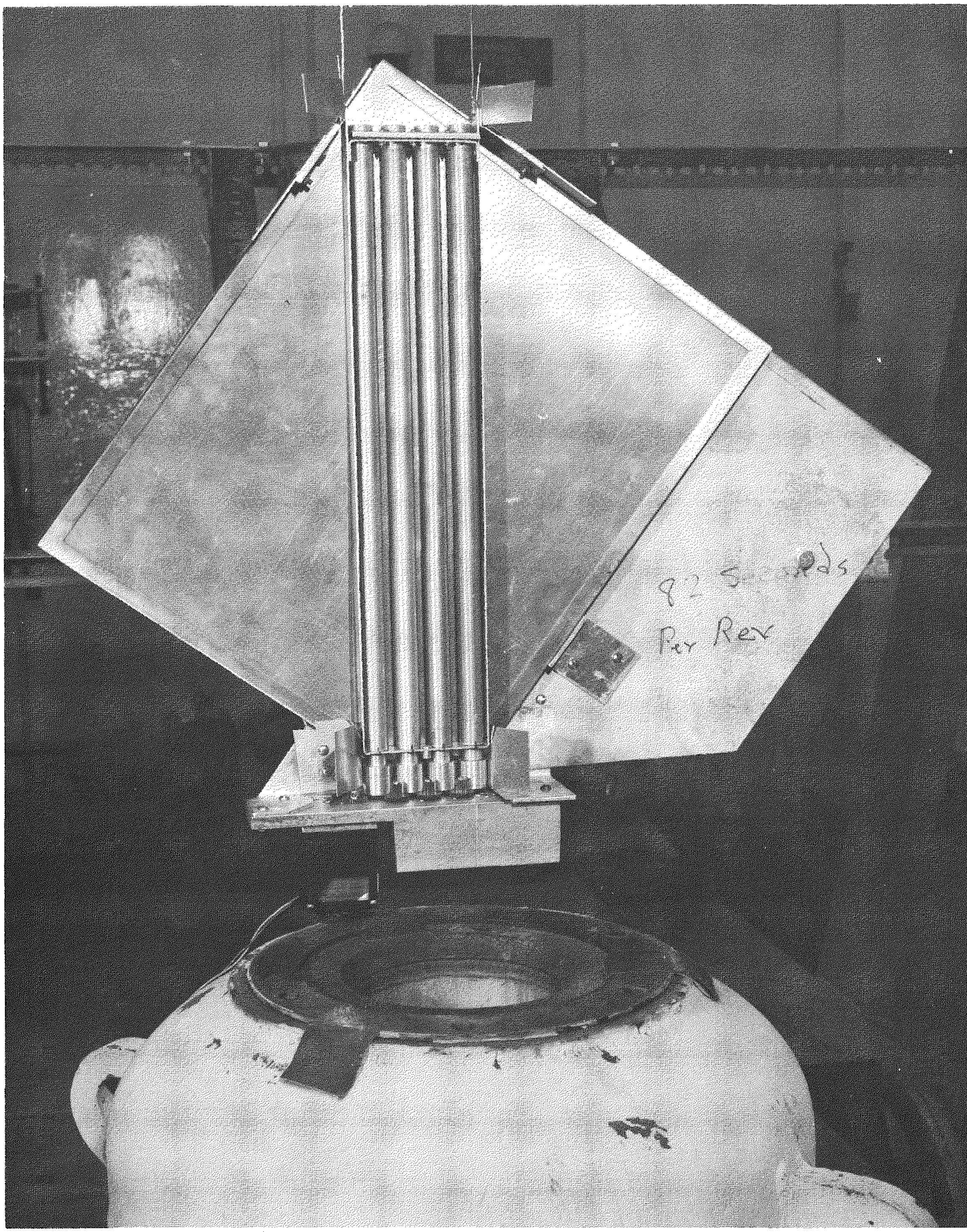


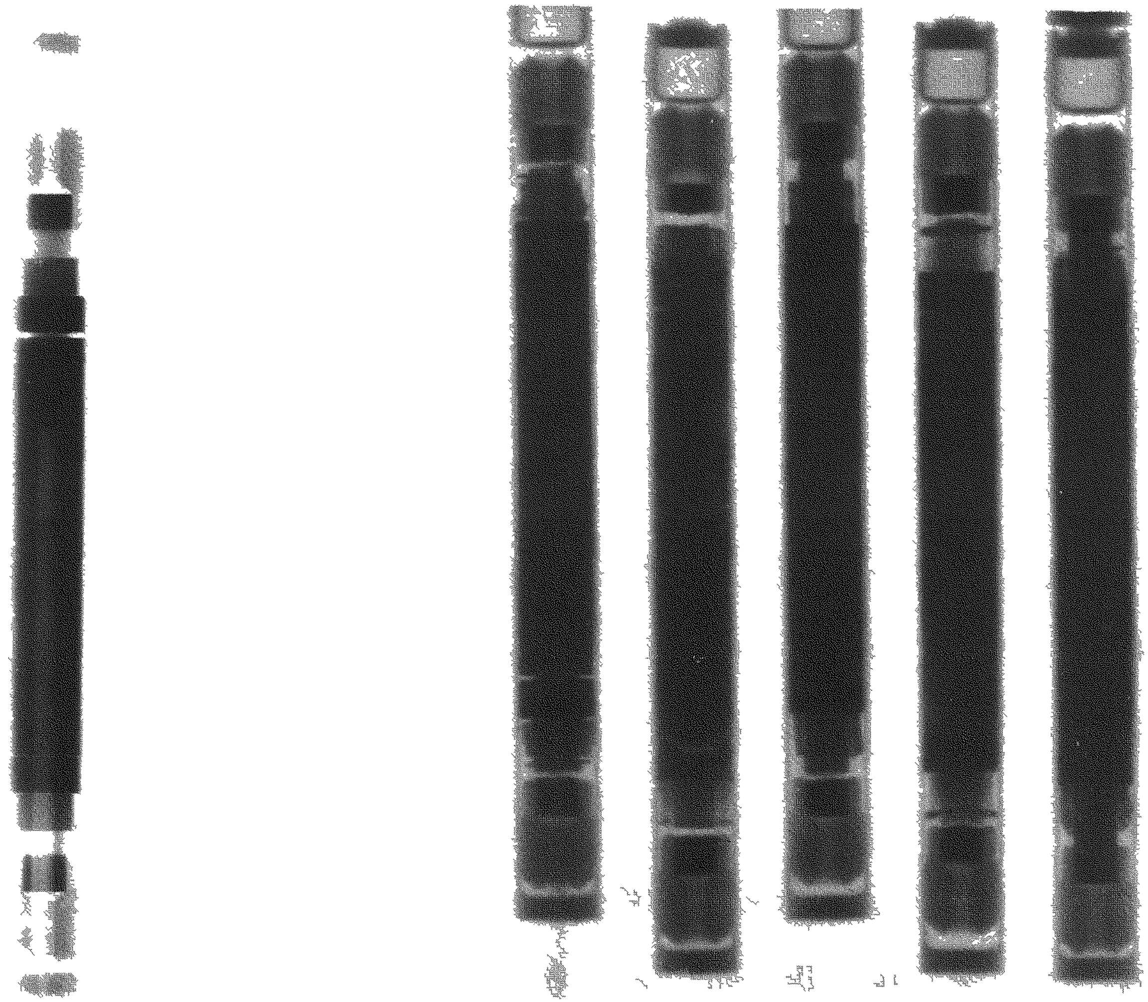
Figure 3. Fuel Handling Fixture for Neutron Radiography

NEUTRON RADIOGRAPHY RESULTS*

The NAA 120 irradiation experiment was designed to provide a dissipation of SNAP fuel material irradiation stability as a function of burnup and operating temperatures. The objectives were to correlate the effects of irradiation temperatures, burnup, and selected compositional variables on fuel swelling behavior, and to evaluate the effects of phase transformation (due to hydrogen losses during irradiation) on the performance of the fuel material. Figure 4 shows radiographs of fuel materials before and after irradiation at Hanford. Although neutron radiography was initially intended as a replacement for pin hole auto radiography to assist in the destructive testing of the fuel samples, it proved to be of far greater value. The radiographic negatives, which are of considerably higher quality than Figure 4, revealed information on swelling, cracking and disintegration. Measurements of swelling made on the negatives agreed with later actual measurements of the fuel samples. The figure shows disintegration of the fuel at the sample ends and cracking in some samples. Optical densitometer measurements were made of the N-ray negatives. Regions of low hydrogen appear more dense in the negative, less dense on the positive (Figure 4). These density measurements correlated very well with measurements of the hydrogen content. The H to Zr atom ratio in fuel before irradiation is ~ 1.70. The densitometer measurement agreed to within 0.02 in. H/Zr with hydrogen measurements.

The results of the 120 series prompted further studies to improve the N-ray technique for post-irradiation fuel examination. Indium converter foil (0.020 inch thick) had been used. Better image definition is available with thin metal converters such as gadolinium for the direct transfer method (cannot be used with irradiated fuel) and dysprosium for the indirect transfer method. Studies have been made with these and dysprosium (0.005 inch thick) will be used for future studies.

*Some of the results of these tests are classified. Only the use of neutron radiography and interpretation of the radiographs will be discussed.



PRE-IRRADIATION

POST-IRRADIATION

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Figure 4. NAA-120-4 SNAP Fuel Irradiation Samples

Two fuel elements were made with fuels of known H/Zr atom ratios. Each element contains fuel samples ranging in H/Zr from 1.415 to 1.795. These standard elements will be radiographed with each batch of irradiated fuel studied and comparative densitometer measurements of the N-ray negatives will be used to determine hydrogen content. Figure 5 shows a densitometer trace of one standard and as can be seen, the results correlate with the H/Zr atom ratios listed.

In addition to having known H/Zr ratios, the standard fuel elements have known gaps between the fuel and cladding. Examination of the N-rays show that the gaps can be read to about ±0.001 inch accuracy. The gap measurements were made in two ways. They are: (1) an enlargement (4x) was made and a comparator magnifying glass was used to measure the gap, see Figure 6, and (2) a densitometer with a 10 micron slit was used to traverse the gap at slow speed, see Figure 5. Both the traverse of Figure 5 and the enlargement of Figure 6 can be interpreted with good results, ±0.001 inch.

Future planned studies are: NAA 121 irradiation experiments in support of the S8DR test and examination of the 211 fuel elements from S8DR. Neutron radiography of the 121 series is now in progress. In each study full length, two view (0° and 90°) N-rays will be made. It is expected that enough information (fuel swelling axially and radially, cladding condition, hydrogen content and gap) will be available so that only a small fraction of the elements will be destructively examined.

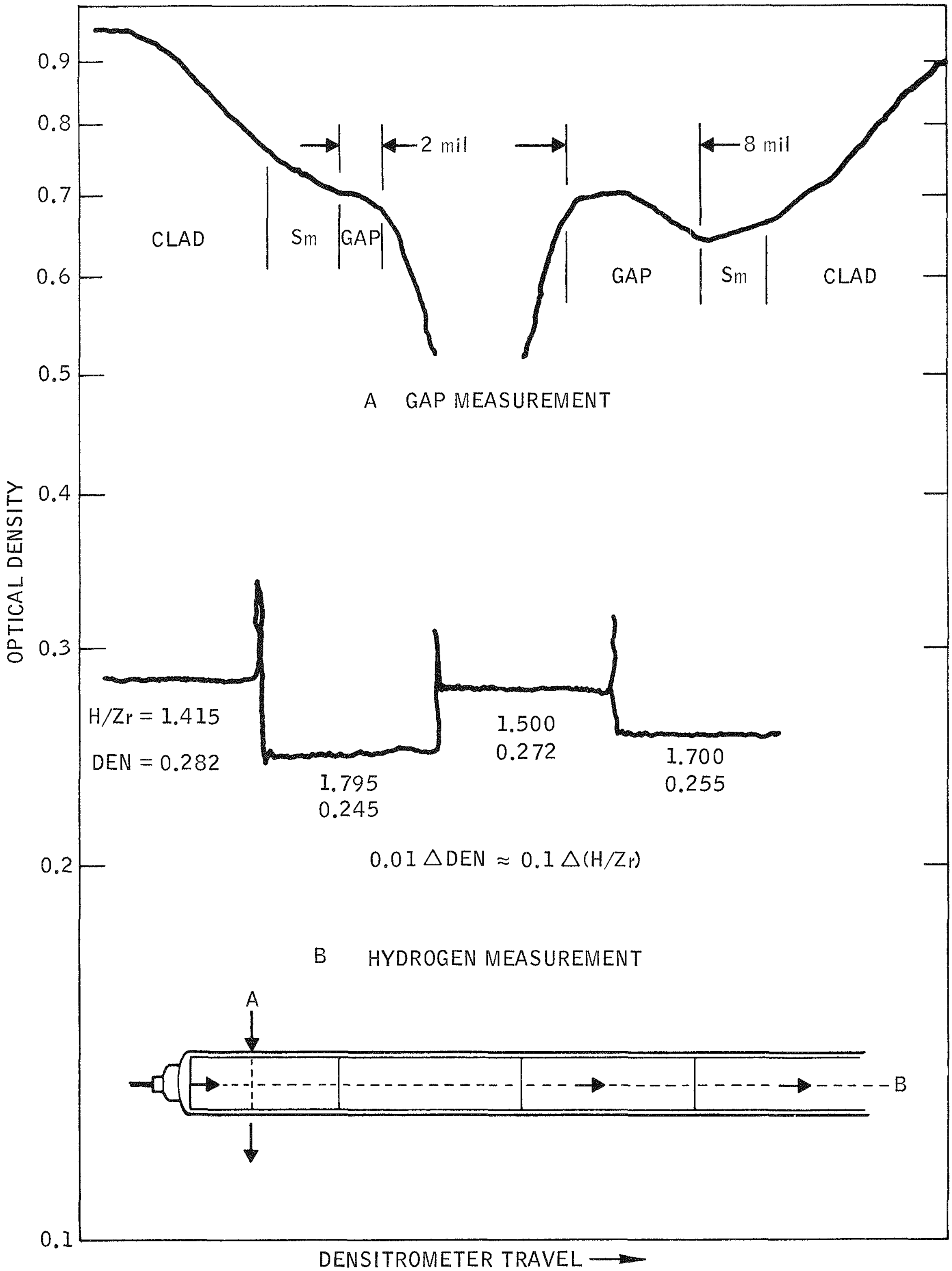

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Figure 5. Results of Densitrometer Measurements

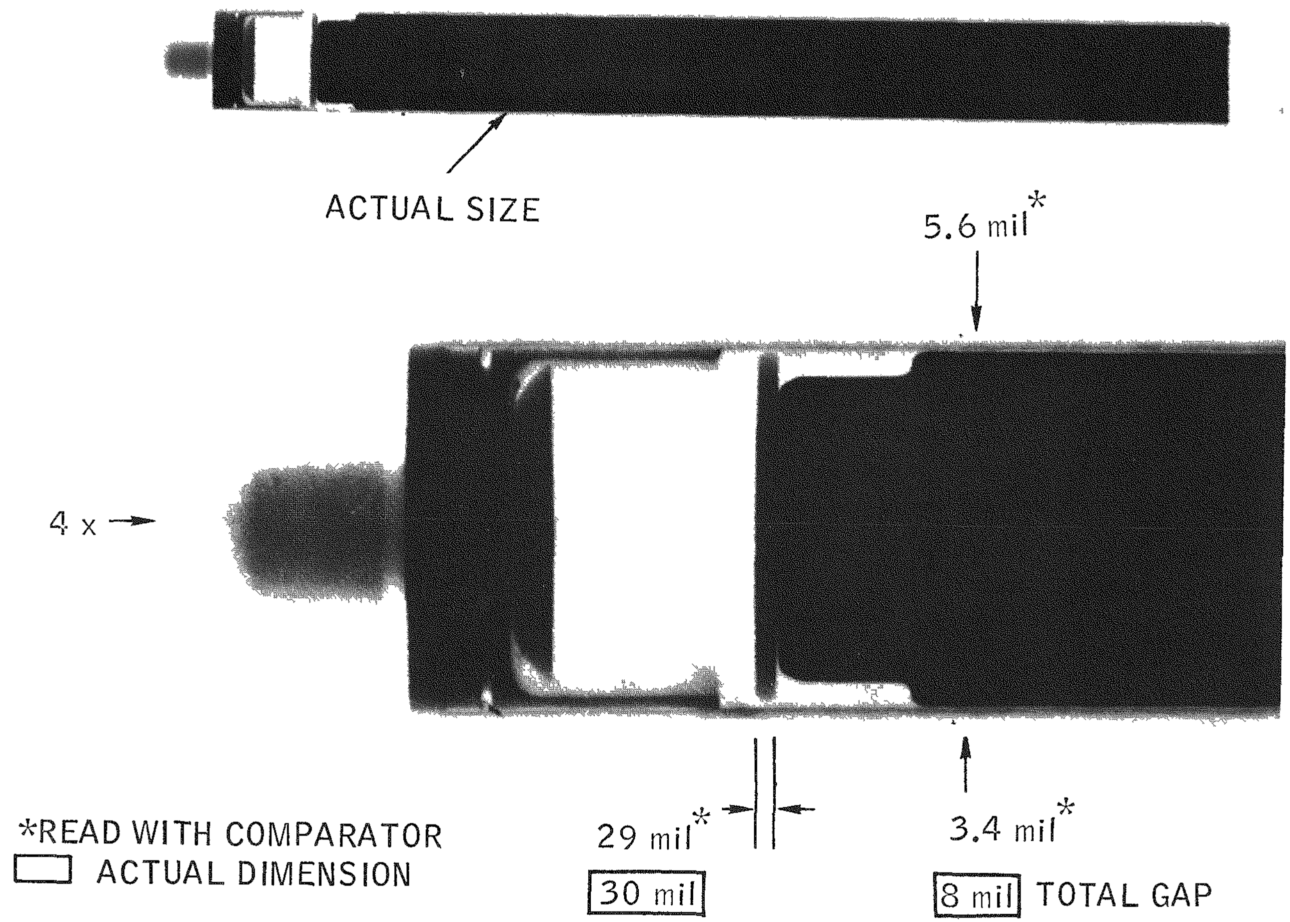

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Figure 6. Fuel to Cladding Gap Measurement