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CESIUM MIGRATION IN MIXED-OXIDE FUEL PINS

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CESIUM MIGRATION IN MIXED-OXIDE FUEL PINS

This paper summarizes observations of cesium migration in mixed-oxide fuel pins irradiated in EBR-II at peak powers of >12 KW/ft, and with burnups of from 20 to 80 Mwd/Kg. The bulk of the data are from the PNL-8 and PNL-5 subassemblies⁽¹⁾ clad with annealed type 316 SS and 304 SS, respectively.

Cesium has been observed to migrate both axially and radially in mixed-oxide fuel pins.⁽²⁻⁷⁾ Localized concentrations of cesium at insulator pellets have been associated with local cladding strain or cladding rupture.⁽⁶⁻⁷⁾ Gamma scan data from PNL-8 and PNL-5 pins indicate that cesium migration has occurred to some extent at burnups greater than ~ 50 Mwd/Kg. At ~ 80 Mwd/Kg major concentrations of cesium activity were found to occur at or near the fuel-insulator interfaces in nearly all fuel pins. In addition, many of the fuel pins exhibited localized concentrations of cesium activity within the fuel column itself.

For 34 fuel pins from the PNL-8 subassembly that were irradiated from ~ 50 to ~ 80 Mwd/Kg, peak concentrations of cesium activity in exterior pins (those pins adjacent to the duct) tended to occur in the fuel column ($\sim 53\%$) or near the top fuel-insulator interface ($\sim 40\%$). Only $\sim 7\%$ of the exterior pins showed maximum concentrations of cesium activity at the bottom fuel-insulator interface. In interior pins, peak concentrations of cesium activity occurred predominately ($\sim 84\%$) in the vicinity of the bottom fuel-insulator interface. The interior pins also had larger local concentrations of cesium activity than the exterior pins. This dependence on subassembly position is believed to be due to higher cladding temperatures and steeper axial temperature gradients in the interior pins.

Comparison of gamma scan and profilometry data indicates that local concentrations of cesium are often associated with areas of local cladding strain. While this can occur within the fuel column, the fuel-insulator interfaces are the most frequent locations. Figure 1 shows a comparison of the profilometry and gamma scan data from a PNL-8 fuel pin. Regions of cladding strain can be seen at the bottom and top of the fuel column, as well as in the

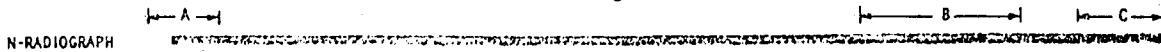
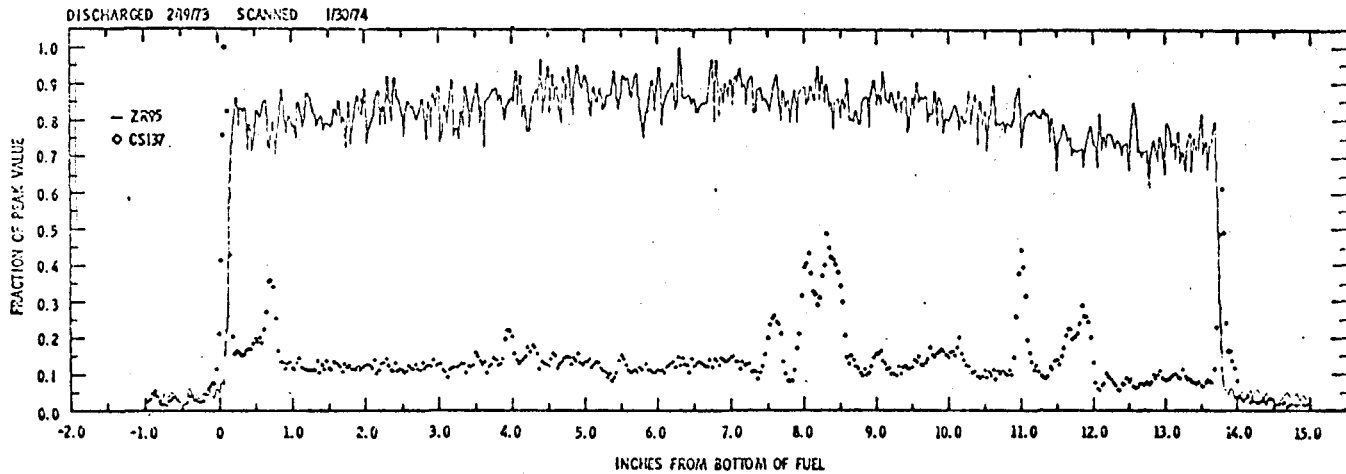
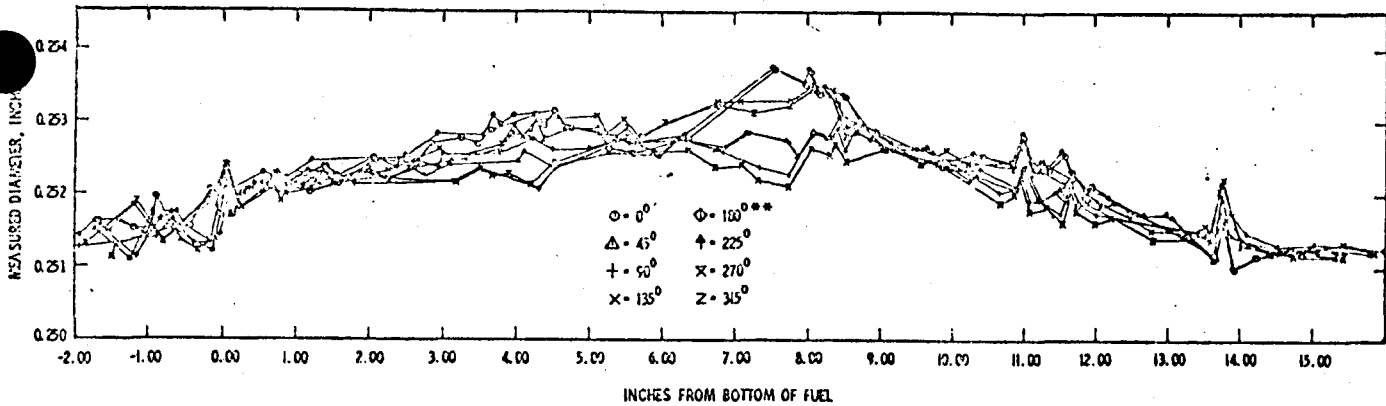
fuel column at all inches from the bottom of the fuel. Localized cladding strain can occur uniformly around the circumference (as in Figure 1) or predominately in a single angular orientation.

Examinations of fuel pin radiographs indicate that concentrations of cesium have an effect on both the fuel and insulator pellets. Large concentrations of cesium activity are associated with fractures within the insulator pellets (details A and C in Figure 1). These fractures may be caused by a volume increase associated with the formation of Cs_2UO_4 .⁽⁸⁾ In addition, it appears that local concentrations of cesium activity are often associated with constrictions in the central void (detail B in Figure 1) of the fuel column. Microprobe examination of sections taken from the UO_2 insulator region indicates that the cesium is distributed in a pattern similar to that described by Neimark, et al.⁽³⁾

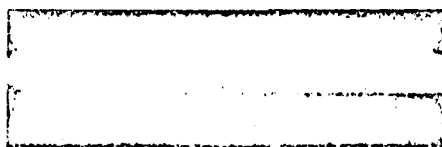
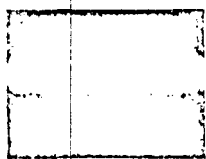
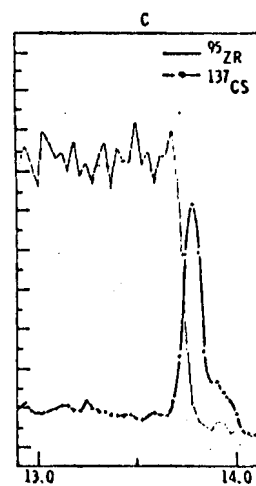
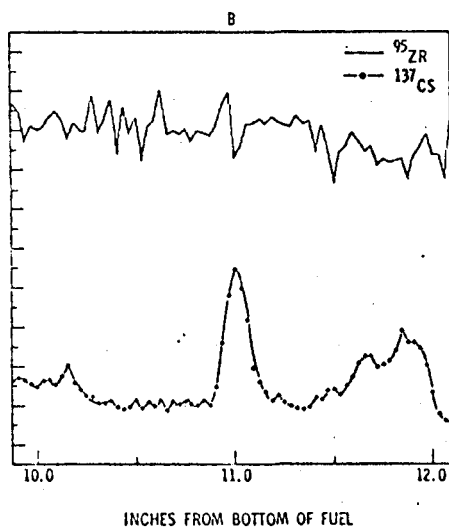
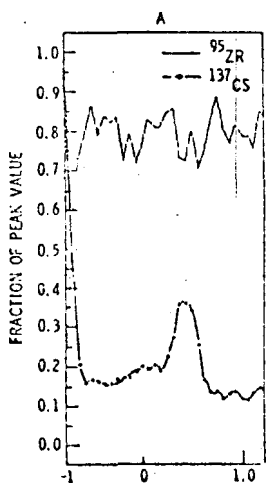
Even though cesium migration occurs in mixed-oxide fuel pins and can lead to localized fuel, insulator, and cladding deformation the effects have not been severe enough to prevent achieving goal burnups above 80 MWd/Kg in the EBR-II with fuel pins clad with annealed type 304 and 316 stainless steel. Furthermore, irradiation beyond the goal burnup⁽⁹⁾ of 80 MWd/Kg did not result in a cladding breach associated with the localized cesium effects. Study of the phenomenon is continuing with fuel pins clad with 20% CW type 316 SS to provide a basis for accounting for these effects in the design of fuel pins for the larger LMFBR systems, and the attainment of higher goal burnups.

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** MEASURED COUNTERCLOCKWISE FROM IDENTIFICATION FLAT ON BOTTOM END CAP



β-RADIOGRAPH

CESIUM MIGRATION IN MIXED-OXIDE FUEL PINS

RA KARNESKY, RD LEGGETT, JW WEBER, AND SA CHASTAIN

THIS MORNING I WILL DESCRIBE SOME OBSERVATIONS OF CESIUM MIGRATION IN MIXED-OXIDE FUEL PINS THAT WERE IRRADIATED IN EBR-II. THESE OBSERVATIONS ARE BASED PRIMARILY ON THE RESULTS OF POSTIRRADIATION EXAMINATIONS CONDUCTED ON PINS IRRADIATED, IN THE PNL-5 AND PNL-8 EXPERIMENTS, AS PART OF THE HEDL FUELS DEVELOPMENT PROGRAM FOR THE FFTF AND ADVANCED LMFBR'S.

SLIDE 1.

FABRICATION DETAILS OF THESE PINS ARE SHOWN IN THIS FIRST SLIDE. THE PINS IRRADIATED IN THESE SUBASSEMBLIES WERE CLAD WITH QUARTER INCH DIAMETER, SIXTEEN MIL THICK SOLUTION-ANNEALED TYPE 304 AND TYPE 316 STAINLESS STEEL, RESPECTIVELY. THE FUEL PINS IN THESE EXPERIMENTS CONTAINED THIRTEEN AND ONE HALF INCH LONG FUEL COLUMNS OF MIXED-OXIDE FUEL PELLETS, WITH A COMPOSITION OF 75 PERCENT UO_2 AND 25 PERCENT PuO_2 . PINS IN THESE SUBASSEMBLIES OPERATED WITH PEAK PIN POWERS OF ~ 12 KW/FT AND PEAK CLADDING TEMPERATURES OF $\sim 1000^\circ F$ IN PNL-5 AND $\sim 1060^\circ F$ IN PNL-8.

SLIDE 2.

IN EVALUATING THE EXTENT OF CESIUM MIGRATION GAMMA SCAN DATA ARE USED TO COMPARE THE RELATIVE CESIUM-137 ACTIVITY PROFILE WITH THAT OF THE ZIRCONIUM-95 PROFILE. THE ZIRCONIUM IS NOT USUALLY OBSERVED TO MIGRATE DURING NORMAL STEADY STATE OPERATIONS AND AS SUCH HAS A DISTRIBUTION THAT IS INDICATIVE OF THE FUEL PIN BURNUP PROFILE AND FUEL COLUMN LENGTH, AS SHOWN IN THIS COMPUTER PRODUCED PLOT OF THE ZIRCONIUM-95 ACTIVITY. THE ENDS OF THE FUEL COLUMN ARE DEFINED BY THE HALF-HEIGHT OF THE ZIRCONIUM-95 ACTIVITY.

SLIDE 3.

IN THE PNL-8 AND PNL-5 SUBASSEMBLIES, SIGNIFICANT AMOUNTS OF CESIUM MIGRATION WERE FIRST OBSERVED AT BURNUPS OF APPROXIMATELY 5 AT. %. THE MIGRATION OF CESIUM IS INDICATED BY HIGH LOCAL CONCENTRATIONS, OR PEAKS, IN THE

SLIDE 4. CESIUM-137 GAMMA ACTIVITY, AS SHOWN IN THIS SLIDE. THE NORMALIZED CESIUM-137 ACTIVITY, SHOWN IN YELLOW, IS COMPARED WITH THAT OF THE NORMALIZED ZIRCONIUM-95. THE PRESENCE OF A LARGE CONCENTRATION OF CESIUM AT THE BOTTOM OF THE FUEL COLUMN IS CLEARLY EVIDENT. AS BURNUP INCREASED, THE AMOUNT OF MIGRATION, AS INDICATED BY LARGE ACTIVITY PEAKS, BECAME MORE PRONOUNCED. IN THIS CASE CESIUM HAS MIGRATED BEYOND THE ENDS OF THE FUEL COLUMN TO THE INSULATOR REGIONS AS WELL AS TO VARIOUS POINTS WITHIN THE FUEL COLUMN AS INDICATED BY THE LARGE ACTIVITY PEAKS. EXAMINATION OF PROFILOMETRY DATA INDICATED THAT THE AREAS OF LARGE CESIUM ACTIVITY PEAKS IN THE INSULATOR REGIONS AND IN THE FUEL COLUMN ARE OFTEN ASSOCIATED WITH LOCAL DIAMETER INCREASES, SUGGESTING THE PRESENCE OF CLADDING STRAIN, AS SHOWN IN THIS SLIDE. DETAILED EXAMINATION BY TWO-DIMENSIONAL GAMMA SCANNING AND ROTATIONAL PROFILOMETRY INDICATES THAT THE ORIENTATION IN WHICH THE MAXIMUM CESIUM ACTIVITY OCCURS AT IS IN THE SAME PLANE AS THAT OF THE MAXIMUM CLADDING STRAIN.

SLIDE 5. EXAMINATION OF POSTIRRADIATION RADIOGRAPHY INDICATES THAT IN ADDITION TO AREAS OF CLADDING STRAIN, HIGH CONCENTRATIONS OF CESIUM-137 ACTIVITY ARE ASSOCIATED WITH DISCONTINUITIES WITHIN THE FUEL AND INSULATOR PELLETS THEMSELVES. IN THE INSULATOR REGIONS LARGE CONCENTRATIONS OF CESIUM ARE FOUND TO BE ASSOCIATED WITH FRAGMENTATION OF THE INSULATOR PELLETS, AS SHOWN IN THIS SLIDE. IN THIS EXAMPLE, THE FUEL PIN RADIOGRAPHY FROM THE TOP AND BOTTOM OF THE FUEL COLUMN ARE SHOWN ALONG WITH THE GAMMA SCAN DATA. THE FRACTURES ARE CLEARLY VISIBLE IN THE INSULATOR PELLETS. A LONGITUDINAL SECTION PREPARED FROM A PNL-5 PIN SHOWS THIS FRAGMENTATION EVEN MORE CLEARLY. WHILE THE MAJORITY OF THE CESIUM IS IN THE FUEL-TO-CLADDING GAP, MICROPROBE MAPPING OF UNFRACTURED INSULATOR PELLETS HAS INDICATED THAT AN AREA OF HIGH CESIUM CONCENTRATION EXISTS AT ABOUT THE SAME POINT AT WHICH

INSULATOR PELLET FRAGMENTATION OCCURS AT HIGHER BURNUPS.

SLIDE 8.

WITHIN THE FUEL COLUMN, AREAS OF HIGH CESIUM CONCENTRATION ARE OFTEN FOUND TO BE ASSOCIATED WITH RESTRICTIONS OR CLOSURES IN THE CENTRAL VOID, AS SHOWN IN THIS SLIDE WHICH SHOWS THE GAMMA SCAN DATA AND RADIOGRAPH FROM A SEGMENT OF THE FUEL COLUMN OF A PNL-8 PIN. THE CLOSURE OF THE CENTRAL VOID IS CLEARLY VISIBLE IN THE RADIOGRAPHY. A MORE DETAILED VIEW OF

SLIDE 9.

THIS PHENOMENON IS SHOWN IN THIS SLIDE, WHICH SHOWS A LONGITUDINAL SECTION FROM THE FUEL COLUMN OF A PNL-5 PIN. THE RESTRICTION IN THE CENTRAL VOID IS CLEARLY EVIDENT AS WELL AS THE PRESENCE OF A CESIUM CONCENTRATION IN THE FUEL CLADDING GAP, WHICH IS INDICATED BY THE DARKLY COLORED AREA.

DETAILED EXAMINATION OF GAMMA SCAN DATA FROM THE PNL-8 EXPERIMENT HAS INDICATED SOME SIGNIFICANT TRENDS IN THE BEHAVIOR OF CESIUM DURING IRRADIATION. INTERIOR AND EXTERIOR PINS WERE FOUND TO SHOW DIFFERENT TRENDS IN THE LOCATION AND MAGNITUDE OF MAJOR CESIUM ACTIVITY PEAKS. THOSE PINS ADJACENT TO THE DUCT WALL WERE FOUND TO HAVE SMALLER ACTIVITY PEAKS THAN THE INTERIOR PINS, AND RARELY HAD LARGE PEAKS AT THE BOTTOM OF THE FUEL COLUMN. IN INTERIOR PINS LARGE ACTIVITY PEAKS OCCURRED AT THE BOTTOM OF THE FUEL IN ALL CASES, AND IN MOST CASES THE LARGEST PEAK OCCURRED AT THE BOTTOM OF THE FUEL COLUMN, AS SHOWN IN THIS SLIDE.

SLIDE 10.

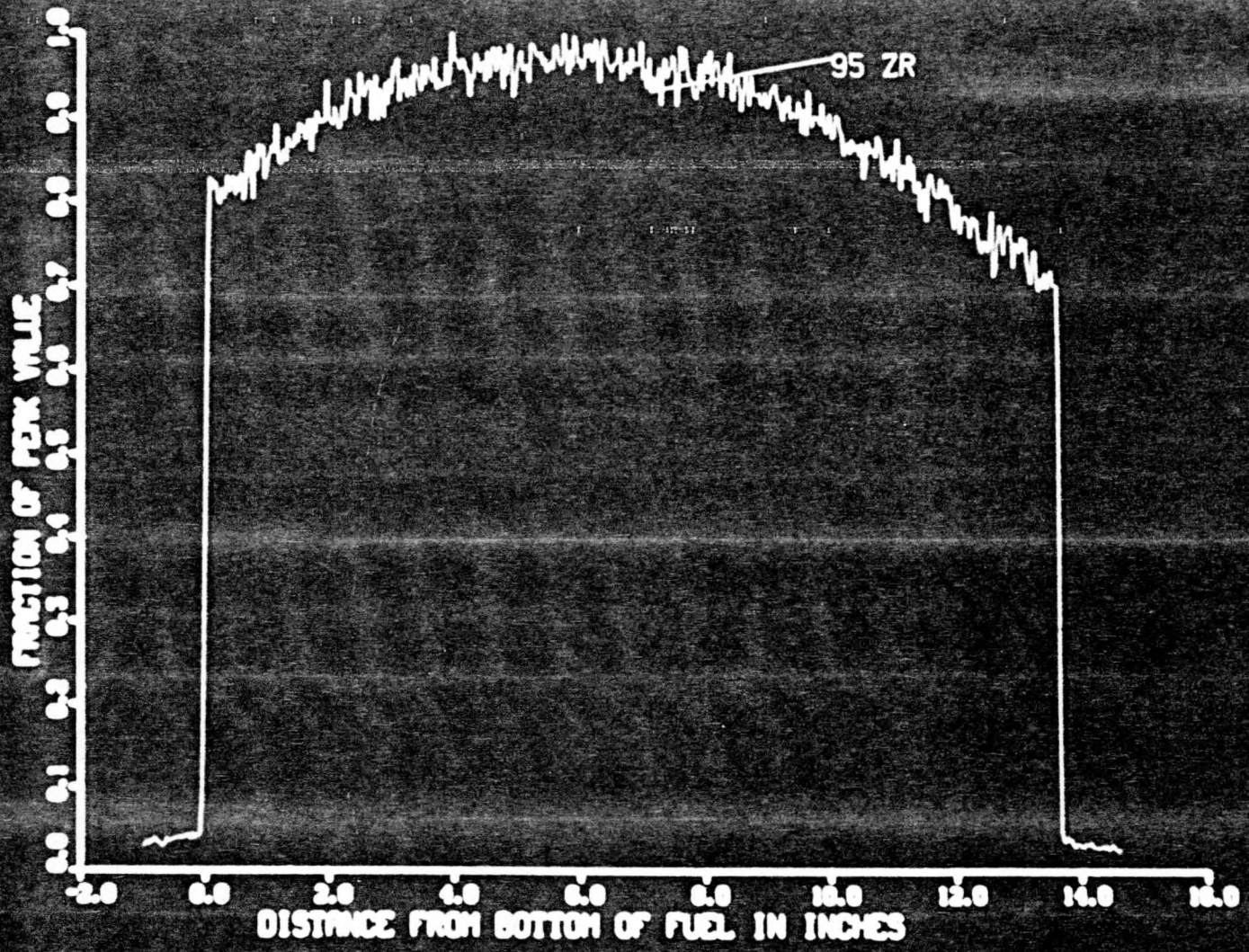
THE DIFFERENCE IN BEHAVIOR BETWEEN INTERIOR AND EXTERIOR PINS IS BELIEVED TO BE DUE TO THERMAL EFFECTS; POSSIBLY AXIAL THERMAL GRADIENT. AS SUGGESTED BY THIS SLIDE, WHICH SHOWS THE MAGNITUDE AND LOCATION OF THE PEAK CESIUM ACTIVITY CONCENTRATIONS IN 30 PINS FROM THE PNL-8 EXPERIMENT, OF A TREND TOWARD LARGER PEAKS IN PINS WITH HIGH AXIAL THERMAL GRADIENTS IS CLEARLY SEEN.

SLIDE 11.

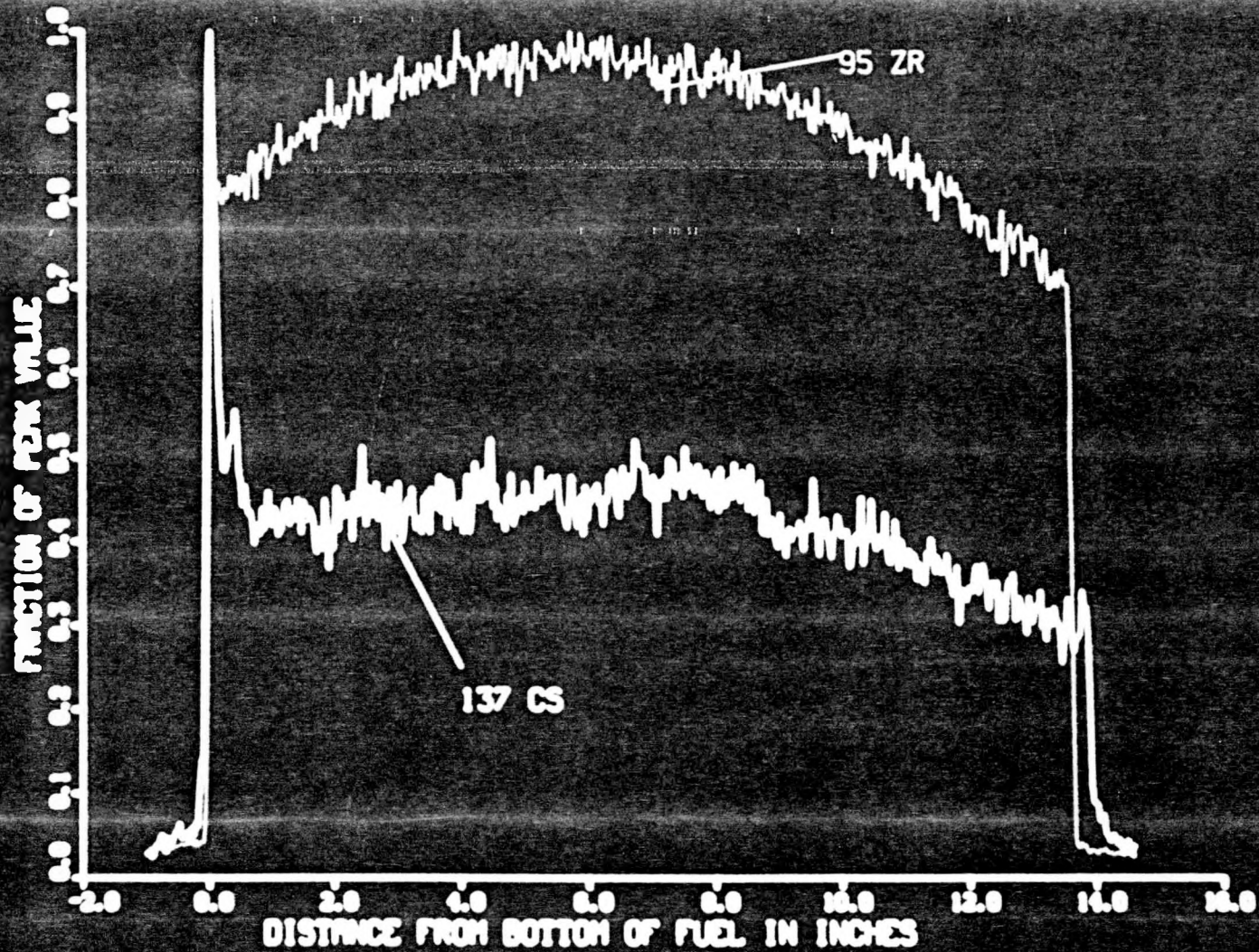
TO SUMMARIZE, THERMAL EFFECTS WERE FOUND TO HAVE A STRONG INFLUENCE ON CESIUM MIGRATION, WITH CLADDING TEMPERATURE

SLIDE 12. OR AXIAL THERMAL GRADIENT INFLUENCING BOTH THE LOCATION AND MAGNITUDE OF CESIUM CONCENTRATIONS. LARGE LOCAL CONCENTRATIONS OF CESIUM WERE FOUND TO BE ASSOCIATED WITH AREAS OF LOCAL CLADDING STRAIN, FRAGMENTATION OF INSULATOR PELLETS, AND RESTRICTIONS IN THE CENTRAL VOID. HOWEVER, THESE EFFECTS HAVE NOT BEEN SEVERE ENOUGH TO PREVENT ACHIEVING GOAL BURNUPS IN EXCESS OF 8 AT. IN EBR-II WITH MIXED-OXIDE FUEL PINS. FURTHERMORE, IRRADIATION BEYOND 8 AT. % HAS NOT RESULTED IN A CLADDING BREACH ASSOCIATED WITH THE EFFECTS OF LOCAL CESIUM CONCENTRATIONS. STUDY OF THESE PHENOMENA IS CONTINUING, WITH THE EXAMINATION OF FUEL PINS CLAD WITH 20% CW TYPE 3L6 STAINLESS STEEL WHICH WILL PROVIDE A BASES FOR EVALUATION OF THESE EFFECTS IN THE DESIGN OF LARGER LMFBR SYSTEMS.

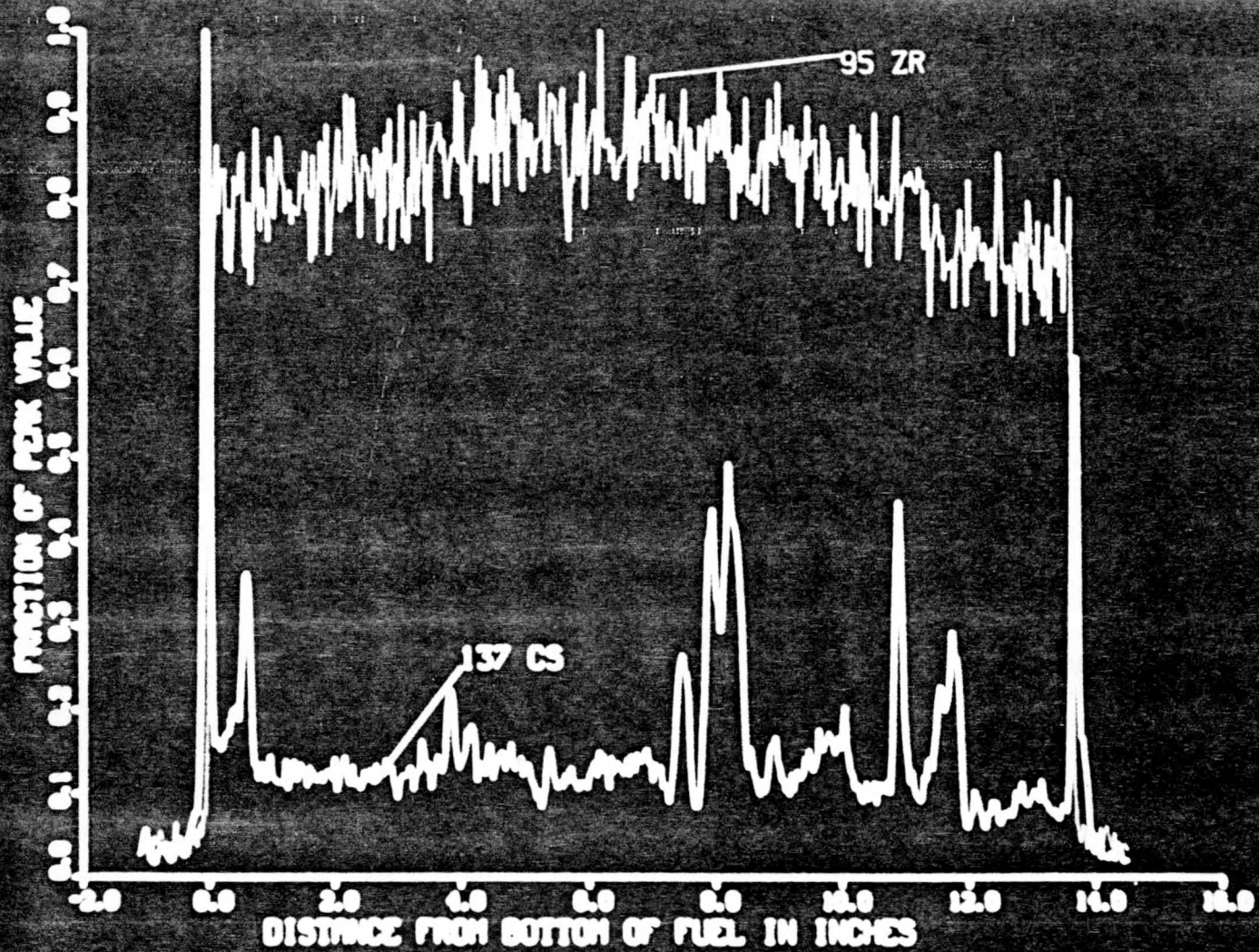
GAMMA SCAN AT 5 AT. PCT. BU.



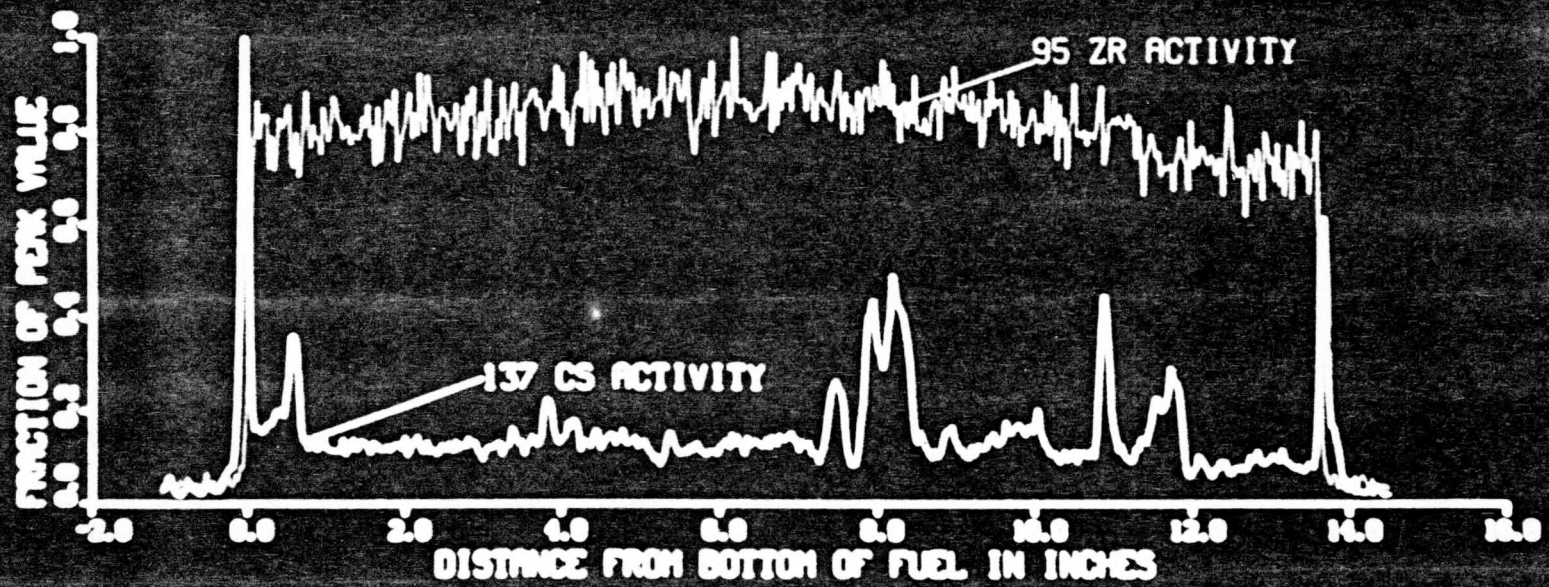
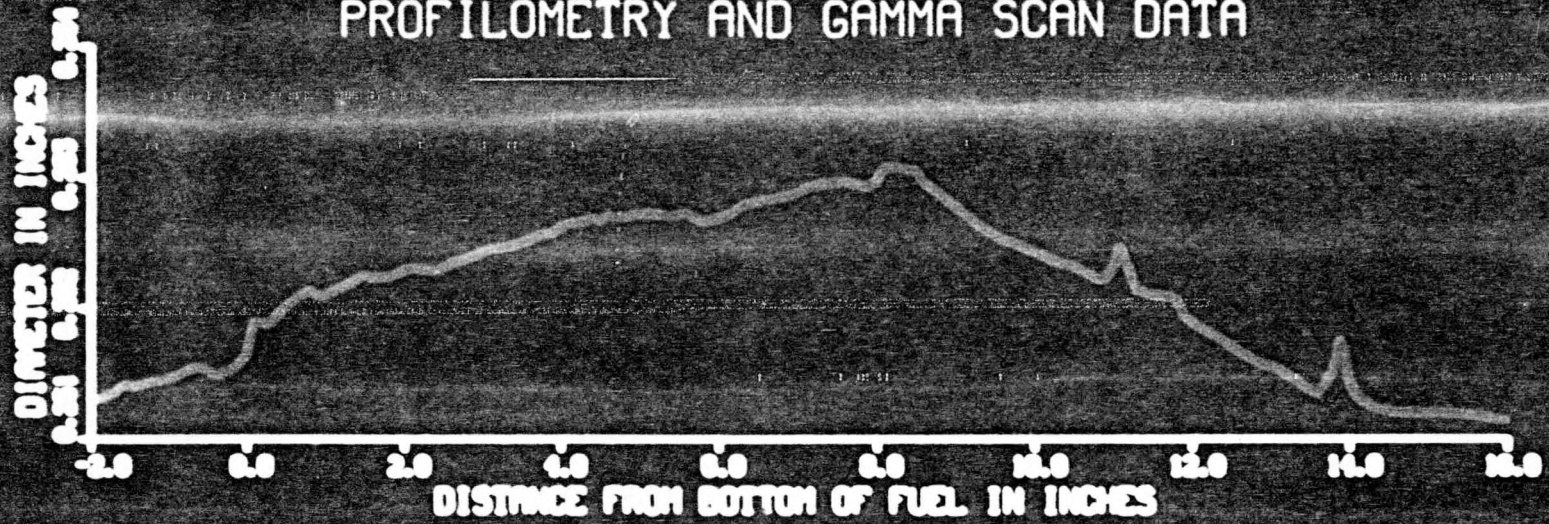
GAMMA SCAN AT 5 AT. PCT. BU.



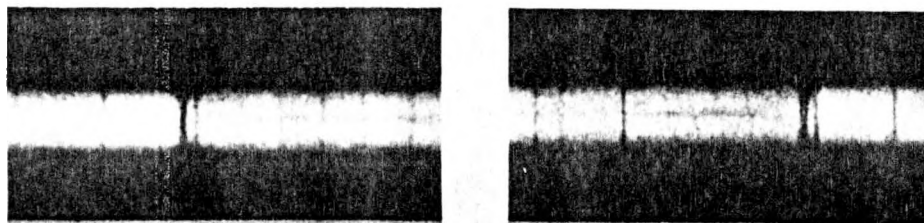
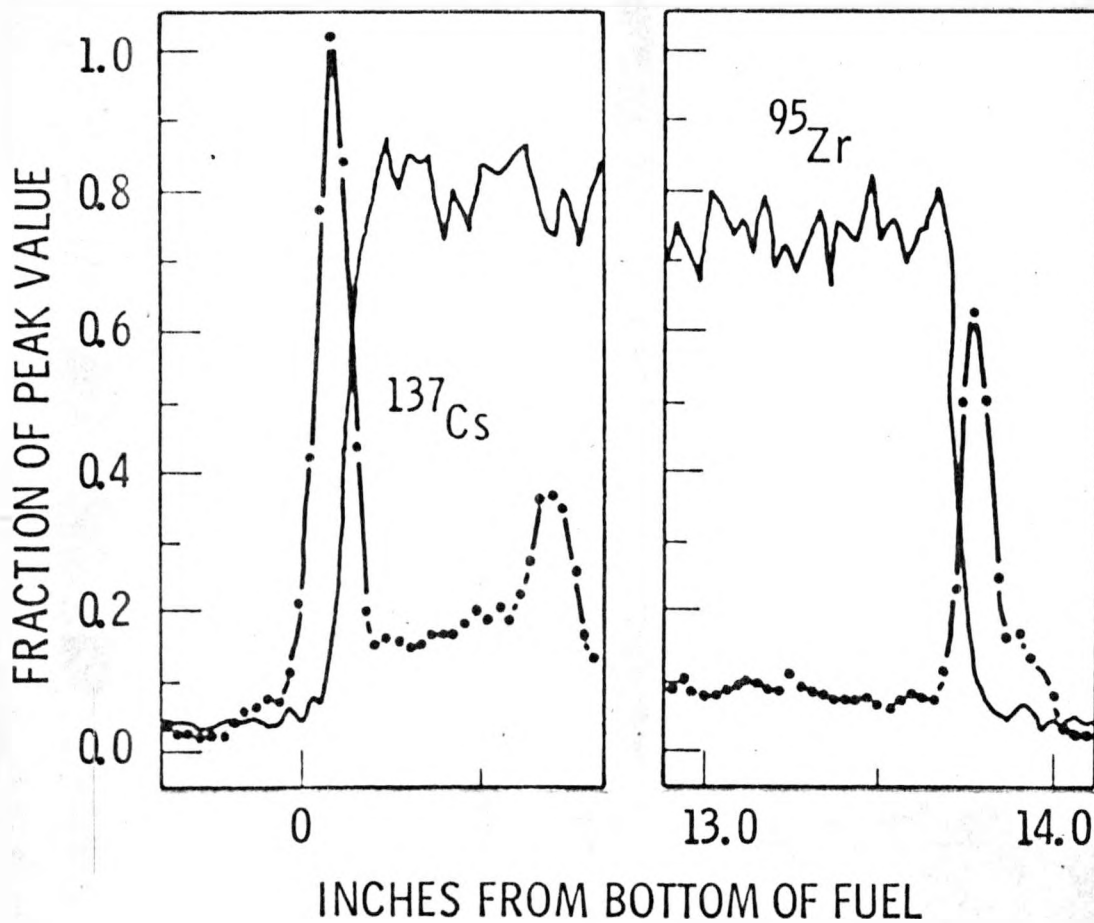
GAMMA SCAN AT 8 AT. PCT. BU.



PROFILOMETRY AND GAMMA SCAN DATA



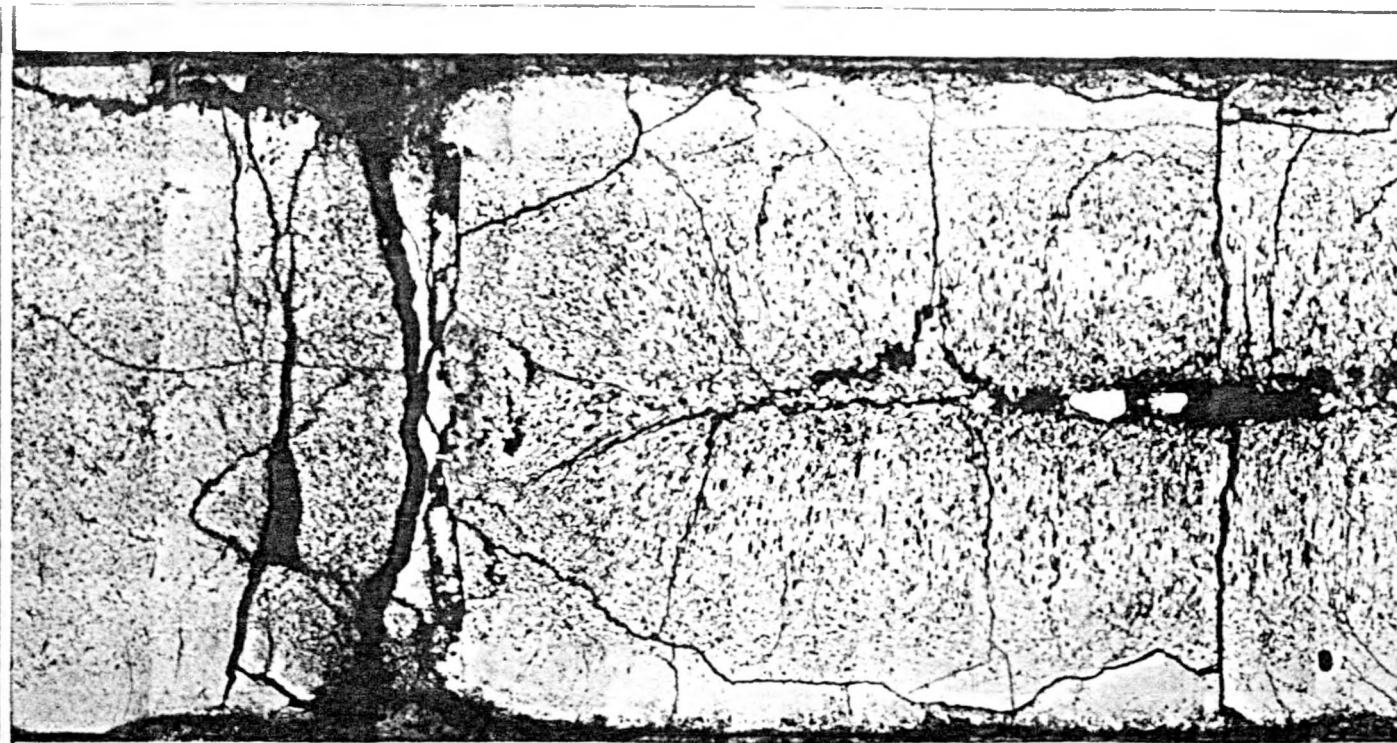
FRAGMENTATION OF INSULATOR PELLETS AT CESIUM CONCENTRATIONS




β -RADIOGRAPH

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FRAGMENTATION OF BOTTOM INSULATOR IN PNL-5-25 AT 6AT%BU



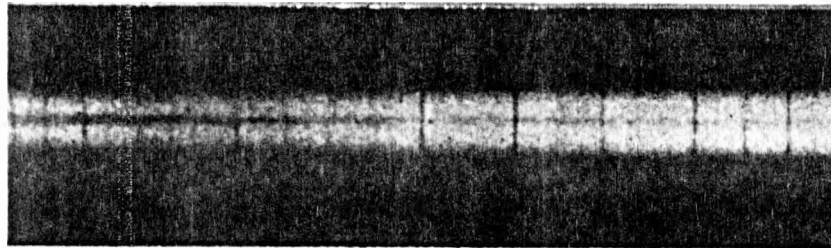
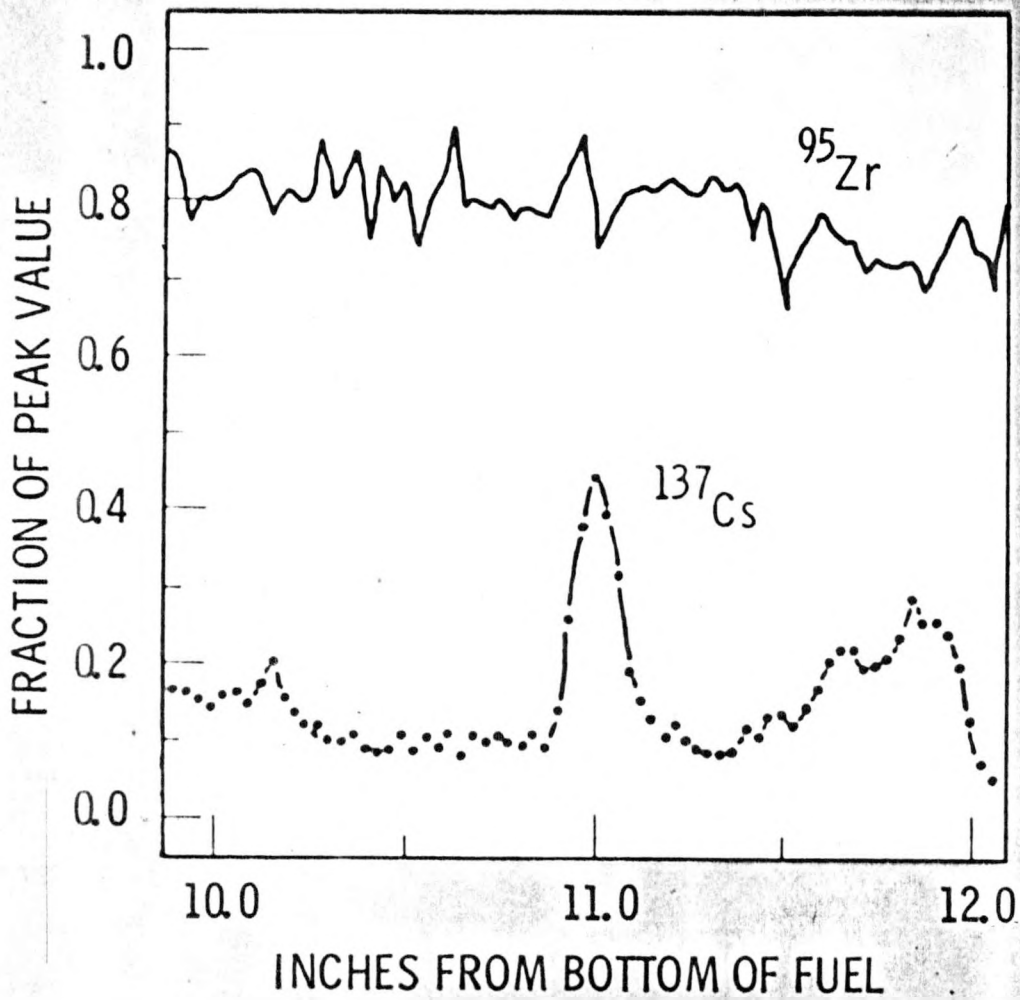
1mm


UO₂ INSULATOR

MIXED OXIDE FUEL

HEDL 7510-255.4

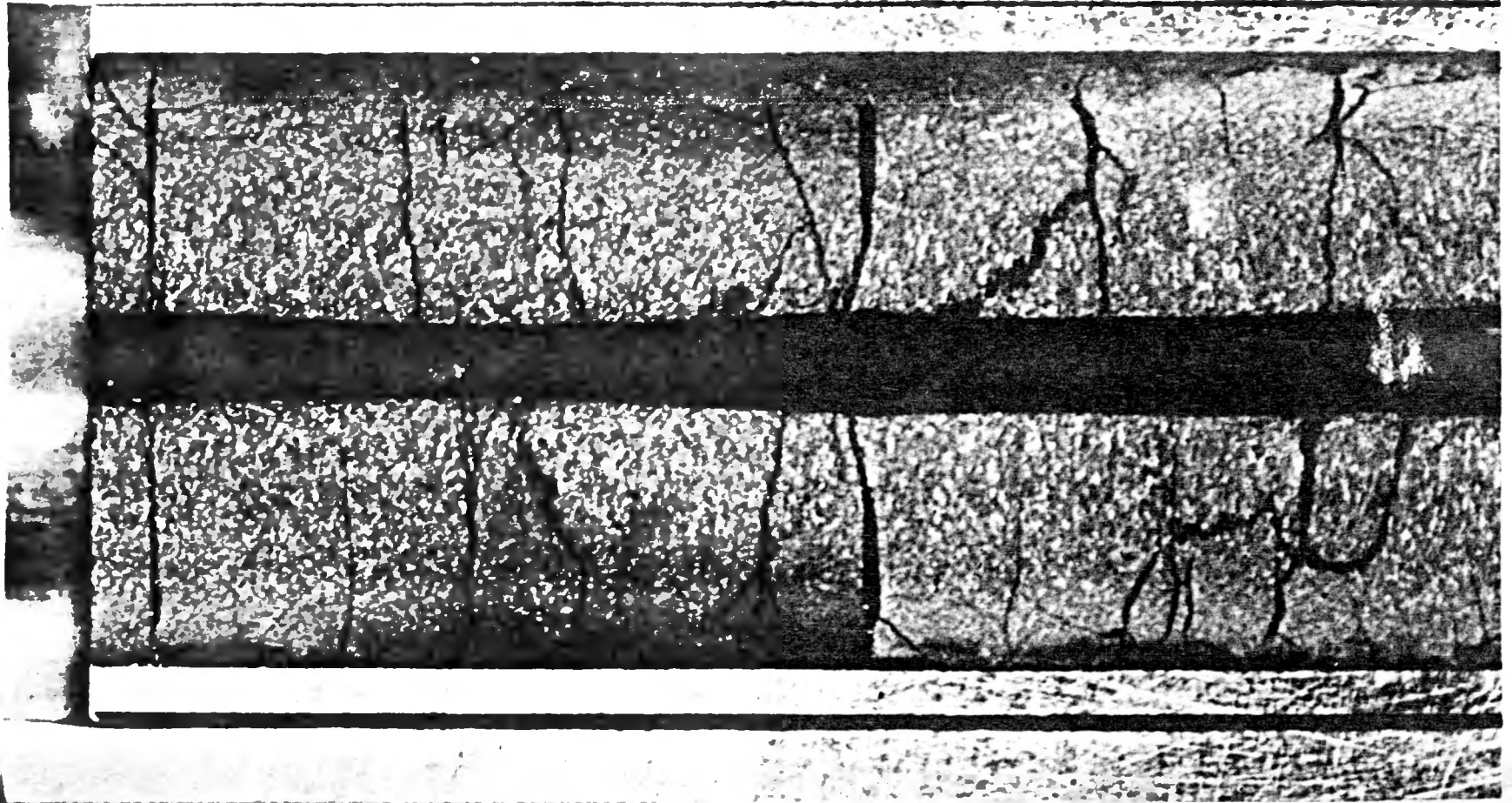
CLOSURE IN CENTRAL VOID ASSOCIATED WITH CESIUM CONCENTRATION (PNL-8-24)



β -RADIOGRAPH

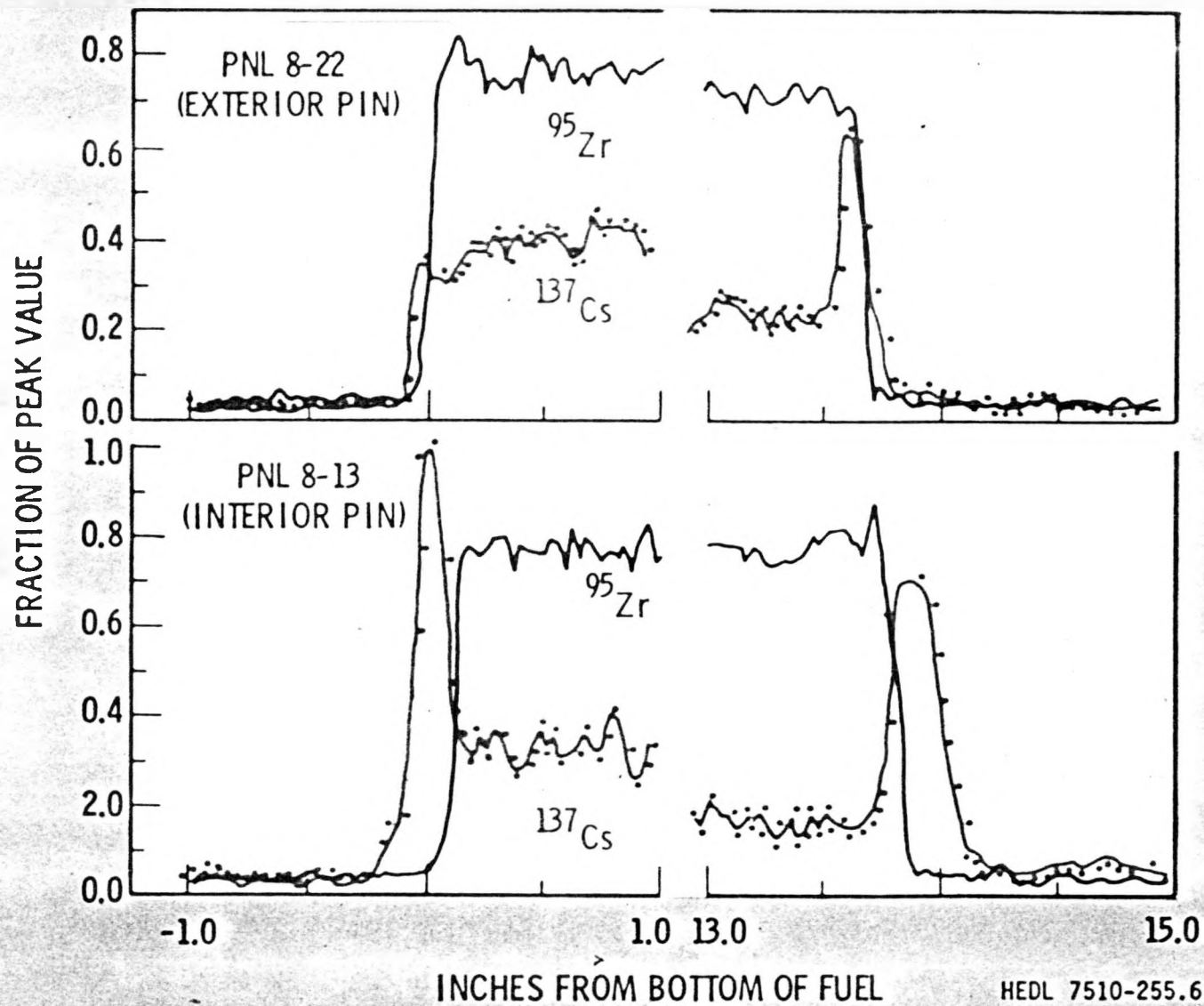
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RESTRICTION IN FUEL COLUMN OF PNL-5-22 AT 6AT% BU

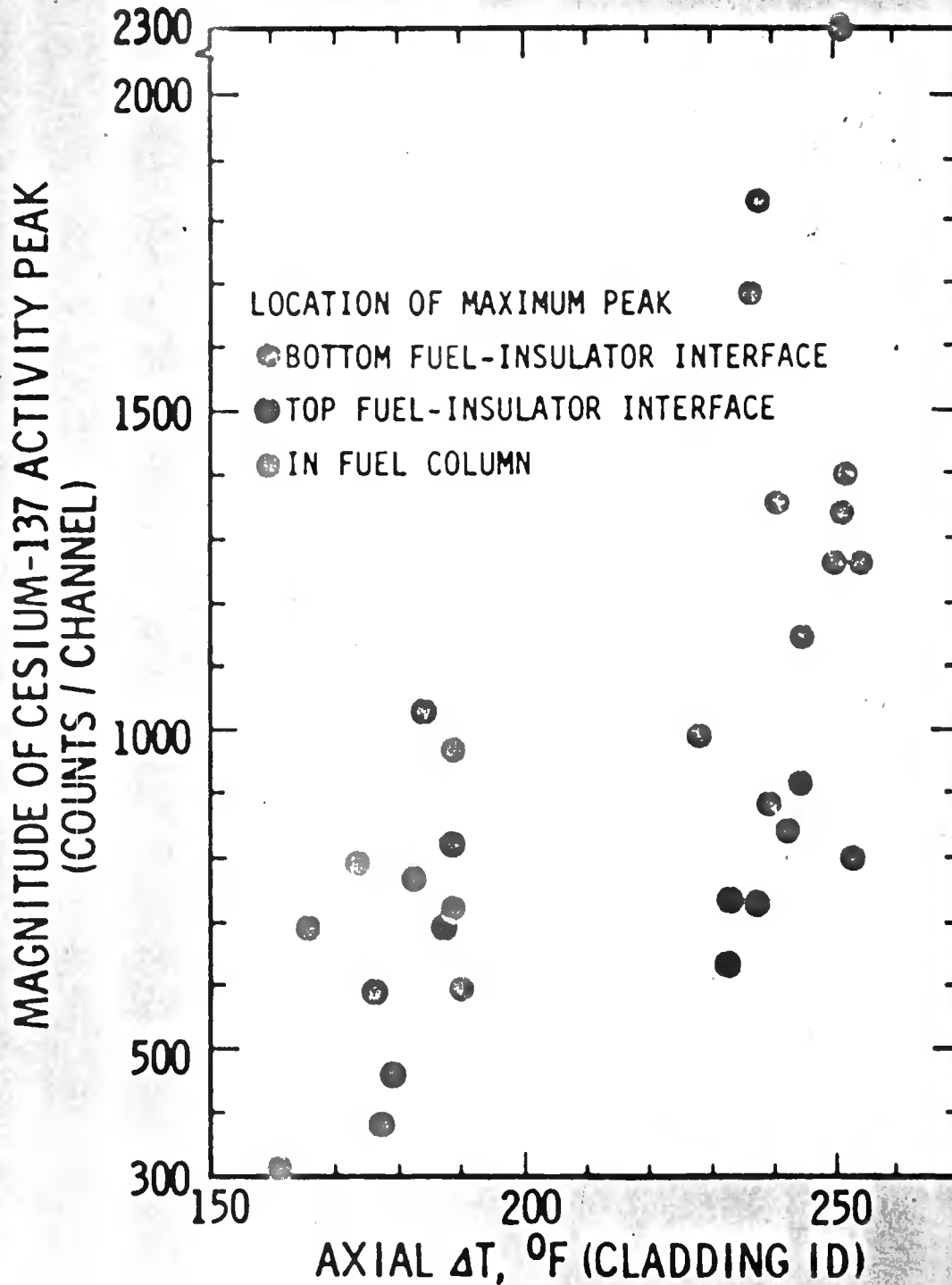


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CESIUM MIGRATION IN PNL-8 FUEL PIN (8AT%BU)



EFFECT OF THERMAL GRADIENT ON CESIUM MIGRATION



CESIUM CONCENTRATIONS

WERE FOUND TO BE ASSOCIATED WITH

- **AREAS OF LOCAL CLADDING STRAIN BOTH IN THE FUEL COLUMN AND AT THE ENDS OF THE FUEL COLUMN**
- **FRAGMENTATION OF INSULATOR PELLETS**
- **RESTRICTIONS IN THE CENTRAL VOID**