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E. I. du Pont de Nemours and Co.
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CONTENTS

SECTION I

PHYSICS EXPERIMENTS WITH FUEL ASSEMBLIES SIMULATING BURNED-UP FUEL

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INTRODUCTION

A series of experiments are scheduled for the Process Development Pile (PDP) and Subcritical Experiment (SE) facilities at the Savannah River Laboratory to investigate the physics behavior of burned-up fuel in the CANDU and similar heavy-water power reactors. These experiments are to make use of specially fabricated fuel assemblies containing plutonium and uranium in approximately the isotopic compositions expected for a fuel irradiation of 5000 MWD/ton.

SUMMARY

All the simulated burned-up fuel rods have been received from Nuclear Fuel Services, and all modifications to the rods to be used for activation measurements have been made at SRL. Results of chemical analyses are available for Type A rods, one of the three types of plutonium-containing fuel. (See DPST-66-83-3 for complete description of the fuel rods.) Analyses on the other two types will probably not be available until after June 1, 1966. The major activation measurements were completed during April and auxiliary experiments were begun to determine assay of materials in foils (see DPST-66-83-3) and to examine the effect of gaps adjacent to the foils. The Type B fuel is being reassembled to make temperature coefficient measurements in the Subcritical Experiment (SE).

The buckling substitution measurements being carried out in the PDP have gone as scheduled. Work with the 19-rod clusters was completed during April and the pile is being reloaded for a new host lattice of 31-rod clusters. Preliminary analyses of results indicate that precisions will be about what was expected.

DISCUSSION

Reduction of the data for fast fission and resonance capture is almost complete. The remaining data are dependent on assays of individual foils containing mixtures of elements. This assay will be accomplished by neutron activation in standard uniform fluxes. These measurements should be completed during May 1966.

Auxiliary experiments have begun to determine the effect of the "gap" formed by the end caps of the plutonium-bearing assemblies. The first of these experiments involves single columns of natural uranium oxide (Type E) fuel which are irradiated in a special holder at the center of the SP reactor. The dominant effects are expected to be in ^{238}U resonance capture and in thermal flux peaking at the foil.

SE buckling measurements on the Type B fuel are being initiated. These measurements are for the purpose of determining the overall temperature coefficient of the plutonium-bearing lattices. The lattices are 19-rod D_2O-cooled (i.e., no housing tube) clusters at triangular pitches of 9.33 inches and 12.12 inches. These measurements will also permit a comparison of buckling values with PDP results.

Samples of all three types of plutonium-containing fuel have been submitted to the Analytical Chemistry Division. Results are now available on the Type A fuel and show excellent agreement between assay of plutonium as determined by alpha counting and as determined by the scanning coulometric method which will be used as the standard method for the other types. The analytical work on Types B and C fuel has been delayed because of the requirements of other programs, and results on these two types will not be available until June.

Buckling measurements by the substitution technique in the PDP have been completed for the 19-rod cluster fuel. Of the 19-rod cluster measurements, originally scheduled and described in DPST-66-83-2, all were completed except for measurements with seven assemblies of depleted uranium. The reactivities in these cases were so low that the pile could not be brought critical. Measurements made with smaller quantities (1 and 3 assemblies) of this material were made, however, and are expected to give almost equivalent precision. The three types of fuel containing plutonium have bucklings in the same general range as the bucklings of the host lattice and buckling mismatch problems are therefore not expected for these types of fuel. A running preliminary analysis is being made of the PDP measurements to detect bad measurements at a time when they can easily be repeated. No such bad points have been found thus far and no remeasurements have been required. The PDP is being reloaded to contain a host lattice of 85 assemblies of rod clusters containing 31 rods each. The triangular lattice pitch will be 12.12 inches and the usual poison rod boundary will be used. No further program interferences between use of the test fuel in the SE and the PDP is expected. Remaining work in the PDP is expected to run through the end of June.

SECTION II

HYDRIDE ORIENTATION AND MECHANICAL PROPERTIES OF THIN-WALLED ZIRCALOY TUBING

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INTRODUCTION

Factors that influence the orientation of zirconium hydride platelets in thin-walled Zircaloy tubing are being investigated at the Savannah River Laboratory. These studies will define the relationship of fabrication techniques and associated Zircaloy structures to susceptibility of tubing to preferred hydride orientations. The work will also assess the effects of various aspects of hydride morphology, orientation, platelet size, and cluster size on the mechanical behavior of tubing.

SUMMARY

The final sections of specially fabricated Zircaloy tubing were prepared by the vendor during April 1966. This completed the fabrication phase of tests to determine how well the SRL-developed "directional-strain" parameter describes the relationship of hydride orientation to fabrication history. Samples of the tubing were received at SRL. Fourteen different kinds of tubing were produced by various specified routes using the combined processes of mandrel drawing, tube reducing, and swaging. Forty samples of tubing were taken to monitor the changes in hydride orientation throughout the tubing history. Approximately 3/4 of these samples have been hydrogenated and experimentally analyzed for hydride orientation, including separate analysis of intergranular and grain boundary hydride platelets.

DISCUSSION

The concept of how to use fabrication history to control hydride orientation has been developed in past monthly reports in this series. This concept will be summarized here as preparation for the presentation and discussion of the results of the special fabrication test next month.

DEVELOPMENT OF DIRECTIONAL STRAIN CONCEPT

The comparison of hydride orientations to fabrication history was based on the relationship between zirconium strain (deformation) and the orientation of subsequently formed hydride platelets. Since little quantitative information about strain-orientation of hydride platelets had been published, the relationship between strain and hydride orientation was assumed to be linear and was developed as follows.

Both the Chalk River and Savannah River work showed that a positive strain (elongation) in a direction caused a higher fraction of subsequently formed hydride platelets to be parallel to the strain direction than before straining. Since a correlation of strain with the fraction of perpendicular platelets was desired,

$$+ {}_x\epsilon \longrightarrow - \Delta_x f_N \qquad (1)$$

where $+_x\epsilon$ = a positive strain (elongation) in direction x.

$-_x\epsilon$ = a negative strain (contraction) in direction x.

$\Delta_x f_N$ = change in fraction of hydride platelets oriented perpendicular to reference direction x.

Conversely, a negative strain (contraction) in a direction, x, caused a higher fraction of platelets to be perpendicular to the strain direction,

$$-_x\epsilon \longrightarrow + \Delta_x f_N \text{ in direction x.} \qquad (2)$$

For tubing fabrication, relationships (1) and (2) indicated the hydride orientation in each major tubing plane should be related to the dimensional changes in that plane. Thus,

Transverse Tubing Plane	Longitudinal Tubing Plane
$\pm \Delta f_N$ = function $(\mp \Delta\bar{D})$ (3)	$\pm \Delta f_N$ = function $(\mp \Delta L)$ (5)
$\pm \Delta f_N$ = function $(\pm \Delta W)$ (4)	$\pm \Delta f_N$ = function $(\pm \Delta W)$ (6)

where:

$\Delta\bar{D}$ = change in average diameter

ΔW = change in wall thickness

ΔL = change in length

Relationship (3) indicated that larger fractions of radially oriented hydrides, higher f_N, should be associated with larger decreases in tube diameter. Relationship (4) indicated the effect of diameter reductions would be diluted by reductions in wall thickness. For normal tube fabrication, i.e., $-\Delta D$ and $-\Delta W$, higher fractions of radially oriented platelets should be associated with comparatively smaller wall reductions, i.e., less dilution of the $-\Delta D$ effect. A scan of tube histories showed this to be true.

A similar check of the sense of the directional strains for the longitudinal plane of the tubes also indicated qualitative agreement with the preferred hydride orientation.

Since each set of hydride orientations in a plane was the result of two major strains in that plane, the sense and amount of each strain in the plane was combined into a single parameter. For the transverse and longitudinal tubing planes the strain parameter for comparison with hydride orientation was termed the "Directional Strain Parameter," (DϵP), and defined as follows:

Tubing Plane	Reference Direction	Directional Strain Parameter (DϵP)
Transverse	Circumferential	$[\Delta\bar{D} - \Delta W]$ (5)
Longitudinal	Longitudinal	$[\Delta L - \Delta W]$ (6)

Comparison of Directional Strain with Hydride Orientation

With the sense of the directional strain parameter-hydride orientation relationship correctly defined, the fabrication history of each tube was analyzed. The directional strain parameter, DϵP, for each deformation process was calculated from the best information available on the in-process dimensional changes of the tubing.

Excellent agreement was observed between the hydride orientation and the directional strain history of the tubes. The hydride orientation distribution was described mathematically using the "f_{48}" notation, which expressed the fraction of platelets oriented between 48° and 90° to the reference axis. Comparisons of hydride orientation, "f_{48}", to the DϵP of the last forming step are shown in Figure 1. Lower fractions of perpendicularly oriented hydride platelets were associated with large positive values of DϵP, i.e., high net elongations. Conversely, high fractions of perpendicularly oriented platelets were associated with small net, positive values of DϵP that resulted in the transverse tubing plane from high diameter reductions and comparatively low reductions in wall thickness.

Three tests of the DϵP parameter were performed by drawing and swaging in the SRL Fabrication Laboratory. First, a section of sheathing was given "free sinking" operations to measure the effect of such metal flow on the hydride orientation distribution. The tubing was dimensionally measured and annealed after each sinking pass and sampled for hydride orientation after the anneals. Since the fabrication history prior to the SRL sinking tests was not known, these data were added to Figure 1 by fitting the pre-sinking hydride orientation (FS_o) to the line and then adding the post-sink DϵP-f_{48} data, (FS_1 and FS_2). The sinking operations increased the radial hydrides significantly. The fit of the sinking data to the last step DϵP correlations, Figure 1, was good.

For the next two tests, sections of the "F" and "E" tubing used in the development of the DϵP parameter were each swaged at SRL through a sequence of diameter and wall reductions, for example, F → IIa → IIϕ → IIb → IIc and E → Ia → Iϕ → Ib → Ic. The hydride orientation distribution was determined after each cycle of swaging, dimensional measurements, annealing, and sampling. The history of the specimens and the resulting values of DεP and f48 are given in Table I. The hydride orientation data, f48, for the two base tubes and the changes induced by the swaging are shown in Figure 1. The arrows shown are for the reader's convenience in following each tubing through its reduction sequence.

In conclusion, the directional-strain parameter (DεP) as presently formulated appears to be a good description of the structural factors controlling hydride orientation. Several possible refinements are being examined.

TABLE I

DIRECTIONAL STRAIN AND HYDRIDE ORIENTATION DATA FOR SWAGED TUBING

Specimen	Average Diameter D, in	Wall W, in	Change in Average Diameter ΔD, %	Change in Wall ΔW, %	Directional Strain Parameter [ΔD - ΔW]	Hydride Orientation f_{48}
E	2.180	.033	-9.1	-17	+8	54
Ia	2.146	.034	-1.6	0	-1.6	55
Iϕ	2.121	.032	-1.2	-3.0	+1.8	52
Ib	2.111	.031	-0.5	-3.1	+2.6	60
Ic	2.108		-0.1	-8.1	+8.0	53
F	2.493	.037	-3.1	-30	+27	38
IIa	2.328	.038	-6.6	+3.5	-10	55
IIϕ	2.142	.040	-4.3	+8.1	-12	73
IIb	2.122	$.038_5$	-0.9	-3.8	+2.9	66
IIc	2.116	$.036_5$	-0.3	-5.2	+4.9	61

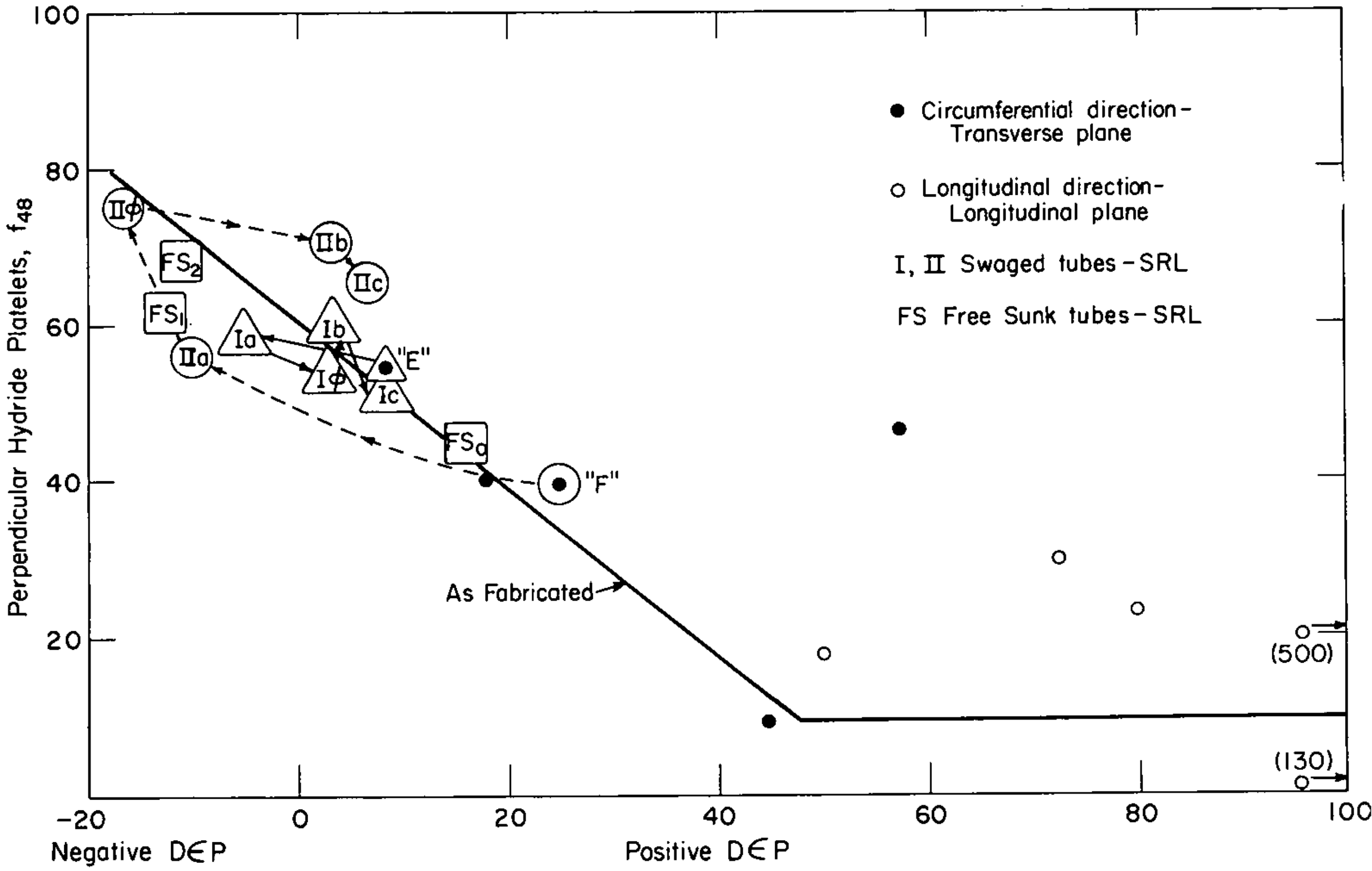

FIG. 1 HYDRIDE ORIENTATION COMPARED TO DIRECTIONAL STRAIN OF LAST DEFORMATION PROCESS

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