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Preliminary Analysis of Surface Displacement Results in the Creepdown Irradiation Experiment HOBBIE-1

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PRELIMINARY ANALYSIS OF SURFACE DISPLACEMENT RESULTS IN THE CREEPDOWN IRRADIATION EXPERIMENT HOBBIE-1

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PRELIMINARY ANALYSIS OF SURFACE DISPLACEMENT RESULTS IN THE CREEPDOWN IRRADIATION EXPERIMENT HOBBIE-1

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ABSTRACT

This report presents the results of the eddy-current surface displacement measurements of Zircaloy cladding obtained during the HOBBIE-1 irradiation experiment in the HFR at ECN-Petten, the Netherlands. Raw creepdown data from the test were corrected through the use of reference coils incorporated in the eddy-current coil block in the experiment capsule. The corrected displacement results are compared with out-of-reactor results obtained under nominally identical conditions of pressure and temperature.

Experiment HOBBIE-1 was run at 371°C and 13.1 MPa specimen external pressure for a total time of approximately 950 h. No gross cladding ovalization was obtained. This result differed from the relatively simple ovality found in the out-of-reactor test. Contact with the internal mandrel occurred between 400 and 500 h, compared with 375 h for a comparable out-of-reactor test. Average diameter decreases for both tests were similar. These results are discussed in detail.

INTRODUCTION

The Zircaloy Fuel Cladding Creepdown Studies Program, sponsored by the U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, is being conducted at Oak Ridge National Laboratory (ORNL). A joint program is presently under way with Stichting Energieonderzoek Centrum Nederland (ECN), the Netherlands, to perform irradiation testing of the Zircaloy cladding. The experiment capsules are assembled and calibrated at ORNL and shipped to ECN for installation in the High Flux Reactor (HFR). The Dutch have responsibility for running the equipment and for subsequent hot cell examination during disassembly. Details of the conduct of the experiment will be available in a later report.

The purpose of the HOBBIE experiments is to study the creepdown (a coined word denoting the inward movement of the cladding under the influence of external pressure) of Zircaloy fuel cladding as a function

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of temperature, external pressure, and neutron flux. The HOBBIE-1 experiment is the first of approximately eight such tests scheduled under the joint program.

Fast neutron flux can affect Zircaloy creep behavior at temperatures below those at which thermally activated creep is significant.[1,2] Fidleris[1] states "Around 350°C there is a change in the slope of the inverse temperature vs creep rate plot." This is shown in Fig. 1, redrawn from Piercy's plot[2] of Fidleris' uniaxial data. There

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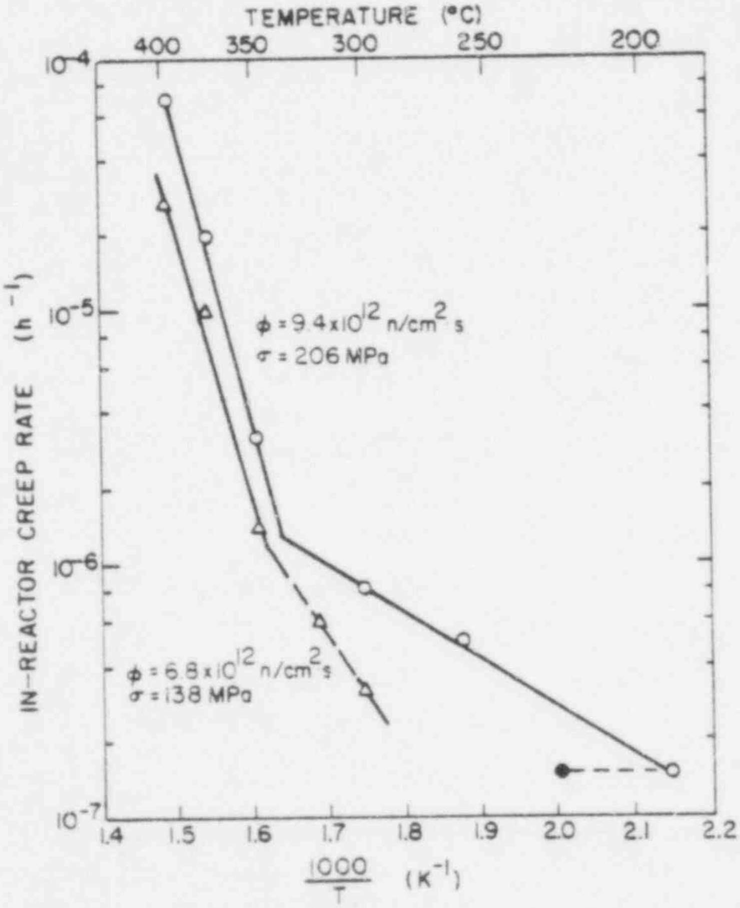

Fig. 1. Temperature Dependence of the In-Reactor Creep Rate of Cold-Worked Zircaloy. (Piercy's[2] plot of Fidleris'[1] data.) The closed circle is our plot of the datum taken directly from Fidleris' report.[1] The open circle is shown as plotted by Piercy.[2]

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is some confusion about the low-temperature data point in the 206 MPa test. Piercy apparently has the point misplotted, possibly because of an incorrect temperature scale on the drawing. Conversion of the 220°C test temperature gives a value for $1000/T$ of 2.03, and the datum has been replotted at that coordinate as a filled point. If a straight line is now drawn from the filled point to the 350°C point, passing between the 260 and 300°C points, better agreement is obtained between the curves for the two tests. Then the breaks occur at almost the same temperature and the slopes of the low-temperature portions of the curves are closer.

Unfortunately, the breaks in the Arrhenius plots occur very near the temperatures of interest for reactor fuel element cladding: 340 to 370°C (650–700°F). If one assumes that the creep is primarily thermally activated above approximately 350°C, then observable fast flux effects should be found predominately below that temperature. Such effects were reported by Ibrahim[3] and are shown in Figs. 2 and 3 for internally pressurized Zircaloy-2 tubing specimens tested at 263 and 297°C, both in and out of an average fast neutron flux of 3.0×10^{17} n/m^2 s.

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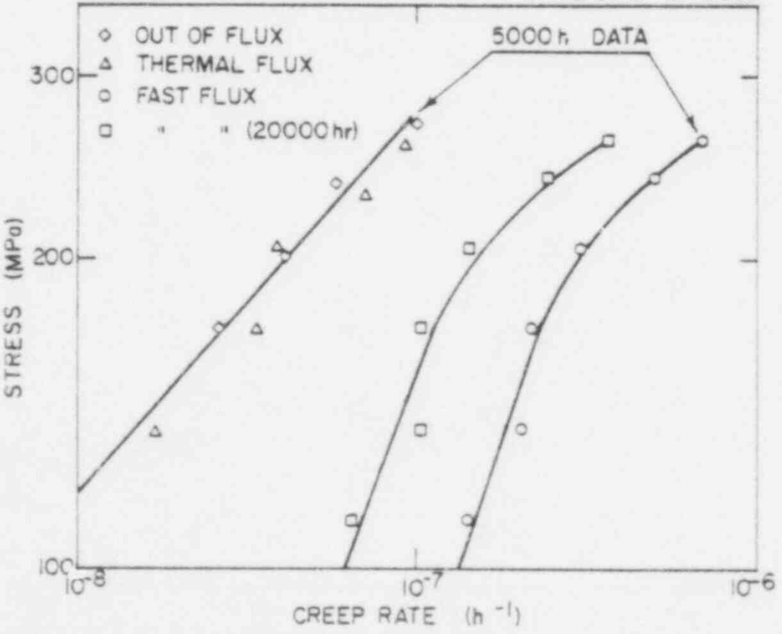

Fig. 2. Creep Rate Results for 20%-Cold-Drawn Zircaloy-2 Tubes Tested at 263°C, Both In and Out of Neutron Fluxes. Based on Ibrahim.[3]

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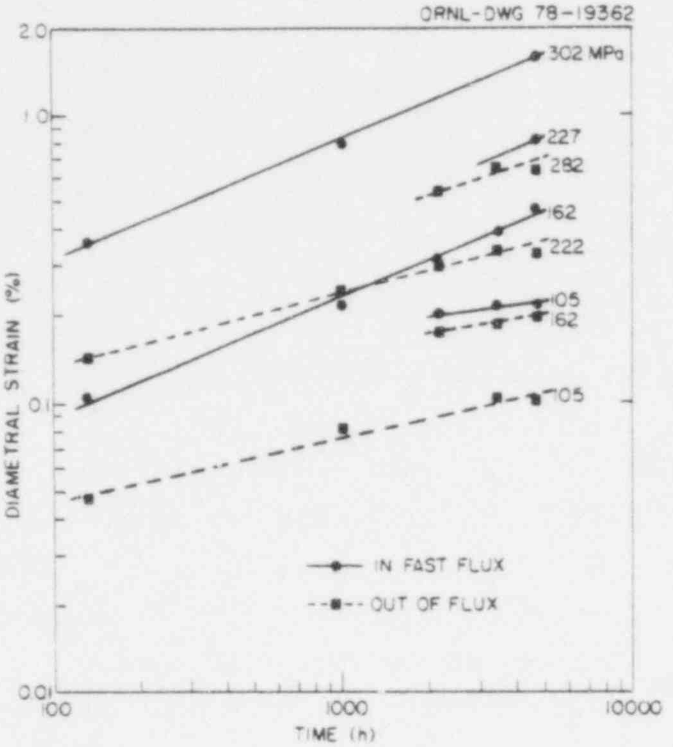

Fig. 3. Diametral Creep Strain as a Function of Stress and Time for 70%-Tube-Reduced and Stress-Relieved Zircaloy-2, Tested at 297°C, Both In and Out of a Fast Neutron Flux of 3.0×10^{17} n/m^2 s. Based on Ibrahim.[3]

Both Figs. 2 and 3 show a definite flux effect: an order of magnitude in creep rate at the lower stresses in Fig. 2 and a factor of 5 in diametral strain in Fig. 3. The HOBBIE-1 test results to be described in this report were obtained at 370°C in the high-temperature creep range reported by Piercy.[2] The fast flux for the HOBBIE-1 test averaged approximately 5.4×10^{17} n/m^2 s, which is comparable to the fluxes reported by Ibrahim.[3]

EXPERIMENTAL PROCEDURE

Details of the eddy-current test method for measuring surface displacements have been given in other reports.[4,5] The HOBBIE irradiation test itself is described generically in a design and safety report.[6]

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Briefly, the eddy-current method uses a microcomputer-controlled instrument to supply a 2-MHz signal to flat-wound coils of anodized aluminum ribbon. These coils are positioned close to the tops of flatheaded, spring-loaded probes whose points contact the surface of the Zircaloy cladding specimens at chosen positions. Twenty working probe assemblies are arrayed in a double helix over a 50-mm gage length of the specimen. Two reference coils and two zero coils complete the eddy-current system.

When a coil is brought near a conductor, the alternating electromagnetic field induces eddy currents in the conductor, which in turn modify the field, causing the resistive component of the coil impedance to increase and the reactive component to decrease. With the coil in an impedance bridge, a change is produced in the voltage out (V_0) as the impedance of the test coil varies with respect to the reference coil. The output voltages, through appropriate calibration of each probe assembly, are proportional to the coil-to-probe head distance, or lift-off. The microcomputer, with the coil calibrations stored in memory, systematically scans each coil in turn, calculates the lift-off for each probe, compares this with the initial lift-off, and outputs the difference. This difference is the amount of radial displacement undergone by the particular point on the cladding surface since the beginning of the test. Instrument drift that occurs in the measurement system can be corrected by use of the reference lift-off and zero reference coils that are included in the coil holder block. These corrections will be discussed later.

The HOBBIE experiment capsules are described in detail.[6] They are placed in the H8 corner core position of the HFR in an independently water-cooled thimble provided by ECN. Each test irradiates a Zircaloy tube test specimen 10.92 mm OD by 0.64 mm wall by 1524 mm long. The test specimen is welded to a Zircaloy reducer tube, which in turn is welded to a Zircaloy-to-stainless-steel transition joint. This is a commercially obtained tandem-extruded joint, allowing the use of an inner stainless steel bulkhead through which the heater and internal thermocouples can be brazed.

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The pressure vessel of the capsule is type 316 stainless steel 55.12 mm OD, 44.95 mm ID, and 560 mm long. To reduce mechanical and thermal stresses, the bottom part of the pressure vessel is provided with a hemispherical head. The penetration of instrumentation lead wires and gas lines precluded an identical geometry at the top of the pressure vessel. Therefore, a flat plate bulkhead has been designed into which the lead wires and gas lines have been furnace brazed with Nicrobraz 50 at a temperature of 1010°C.

Along with the aluminum deformation monitoring device and the specimen with transition tube, there are two aluminum blocks, one above and one below the deformation monitoring device. This obtains the correct thermal characteristics of the capsule while keeping the volume of high-pressure gas as small as possible. Detailed assembly drawings including parts lists and material specifications are given in ORNL drawings X8E11762-100 et seq., available from the author.

Temperature and pressure data for the test are shown in Figs. 4 and 5, respectively. Examination of the temperature data shows that three scrams occurred during the test — at approximately 50, 110, and 480 h — and that a scheduled two-day reactor shutdown took place at approximately 560 h. The temperature data also point out a problem encountered in the test. There was a 25°C axial temperature differential over the 50-mm gage length of the specimen. This is thought to be due to thermal convection cells being formed in the helium pressurizing gas surrounding the specimen. Changes are being made in experiment design to alleviate this problem. As will be pointed out later, this temperature differential may have influenced the deformation mode of the cladding specimen.

The HOBBIE-1 experiment is the first pressurized test in this series. An unpressurized mockup capsule was previously installed in the HFR to test heat transfer calculations and eddy-current coil behavior in a neutron flux. Reference 6 describes the pressurization system for the HOBBIE experiments and, in particular, the pressure regulation and equalization components. The pressure data in Fig. 5 indicate a sawtooth variation in pressure with time. This has been interpreted as a malfunctioning of the pressure equalization cylinder, which, instead of

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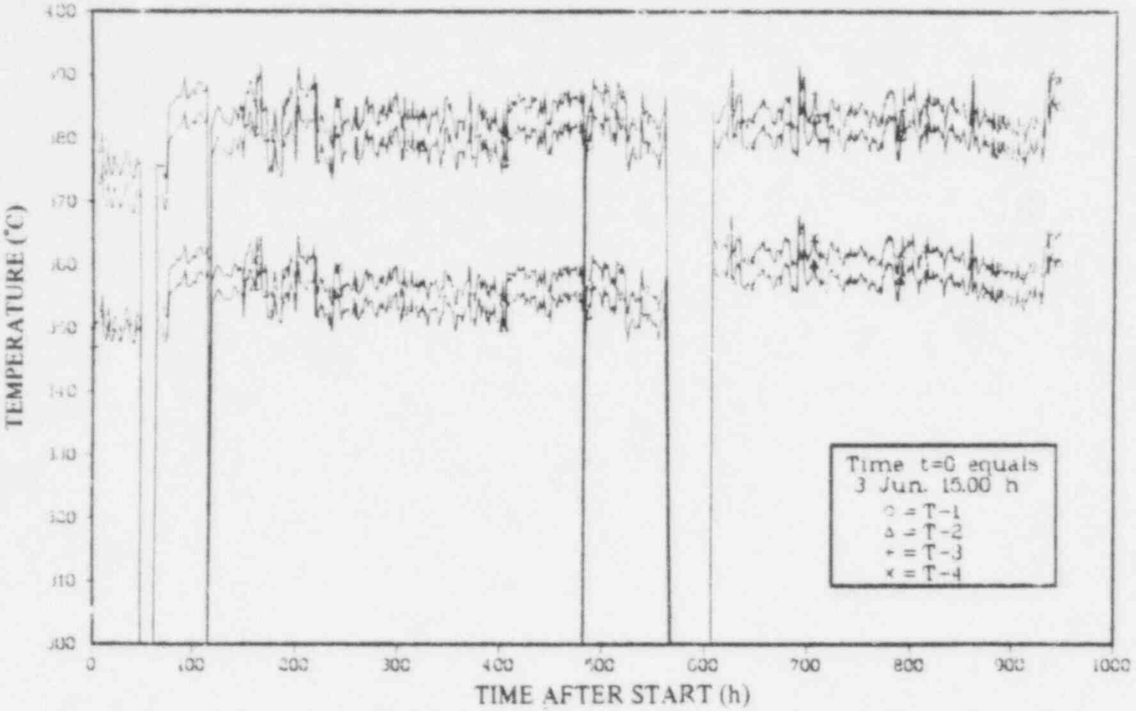

Fig. 4. Temperature History of HOBBIE-1, as Supplied by ECN-Petten The sudden drops at approximately 50, 115, and 480 h represent reactor scrams. The extended drop beginning at approximately 570 h was a scheduled reactor shutdown.

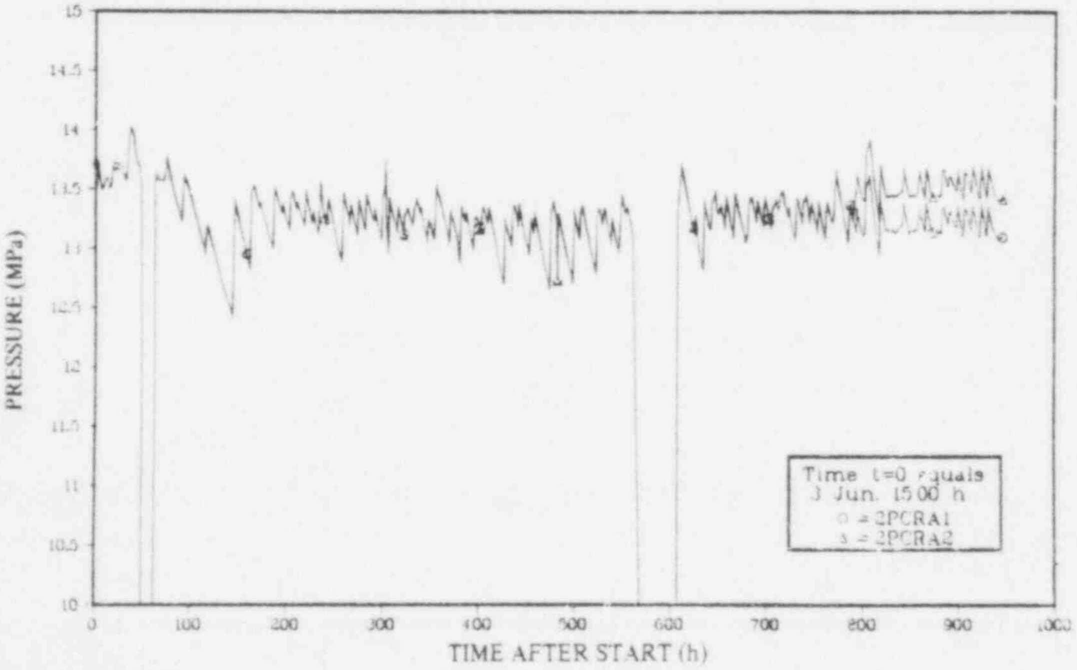

Fig. 5. Pressure History of HOBBIE-1, as Supplied by ECN-Petten.

maintaining a relatively constant pressure over the length of its stroke, refused to cycle. As a result, the pressure alternated between the lower and upper regulator settings for the experiment. The vertical portions of the curves represent pressurization and the decreasing portions represent leakdown. The apparent leak rate is 80 Pa/s (30 kPa/h or 4.5 psi/h).

The effects of these variations on the creepdown behavior cannot be quantified at this time. This will be discussed later.

RESULTS

Raw Data

Experimental creep data were obtained during the irradiation test as punched paper tape output from the data acquisition system. A copy of this tape was mailed to ORNL from ECN for evaluation and processing.

The HOBBIE-1 raw lift-off data are shown in Figs. 6 through 15, first as line plots supplied by ECN and then as computer point plots done at ORNL. The data obviously show a large amount of variation with time. Figures 6 through 10, the Dutch line plots, emphasize a 24-h periodicity in the lift-off data that is probably due to ambient temperature fluctuations in the air in the reactor containment building. This periodicity is particularly evident in Fig. 10 with coil 12 (a reference lift-off coil) and coil 18 (an alternate zero reference coil). Data for these two coils and from coil 6 (another reference lift-off coil) furnished the information needed for correcting the raw data from HOBBIE-1 for the fluctuations discussed above and for instrument drift with time.

The raw data indicate that small amounts of surface displacement took place during the first few hundred hours, substantial movement occurred between approximately 300 and 500 h, and that mandrel-cladding contact occurred between approximately 400 and 500 h.

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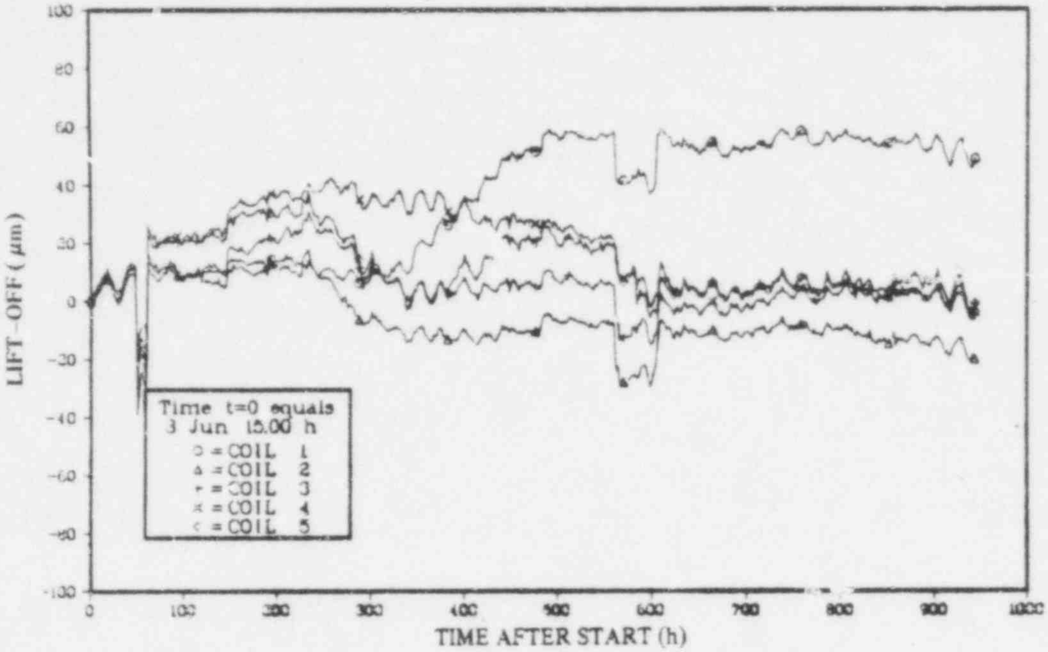

Fig. 6. Lift-Off History of HOBBIE-1, as Supplied by ECN-Petten. Data for coils 1 through 5.

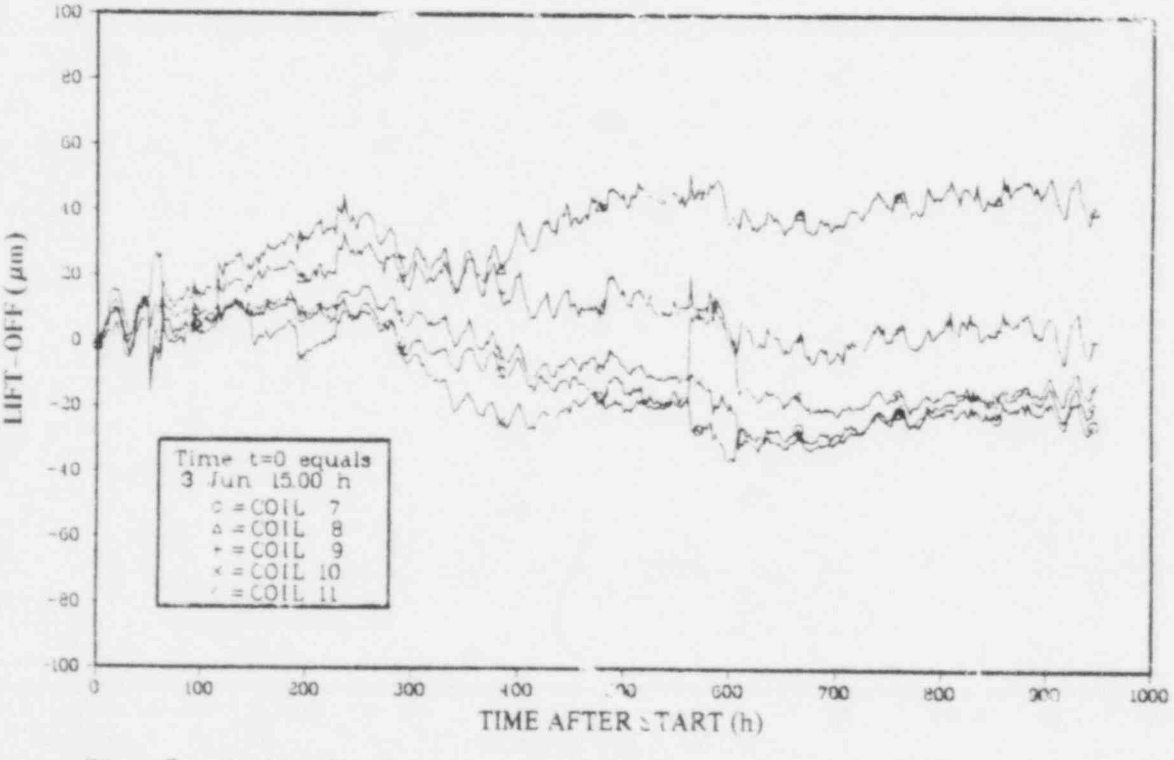

Fig. 7. Lift-off History of HOBBIE-1 as Supplied by ECN-Petten. Data for coils 7 through 11.

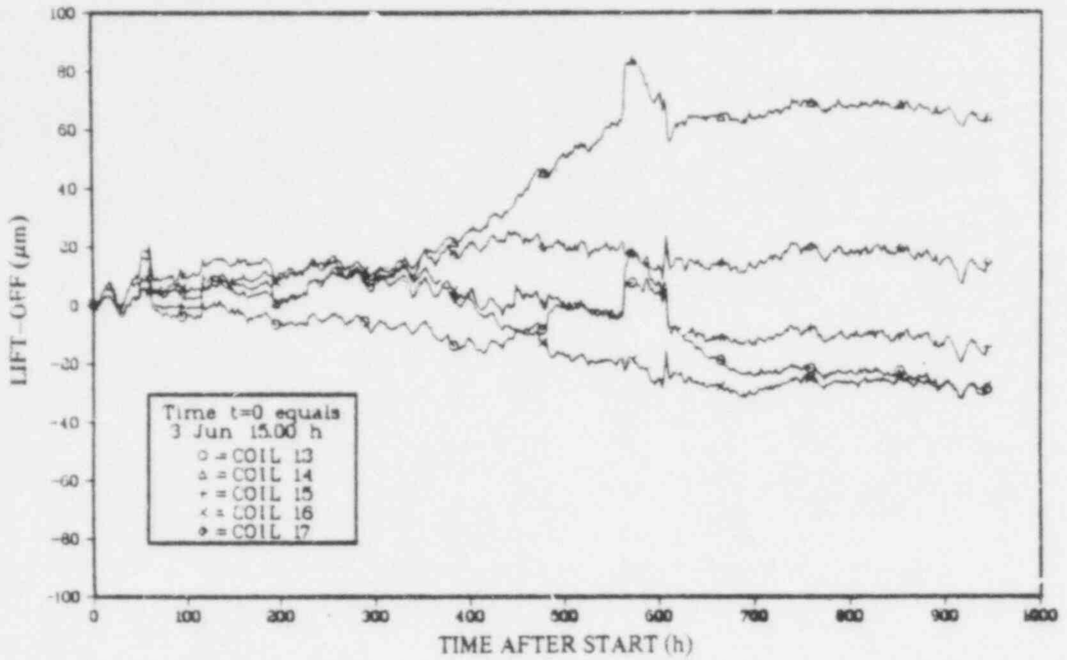

Fig. 8. Lift-Off History of HOBBIE-1, as Supplied by ECN-Petten. Data for coils 13 through 17.

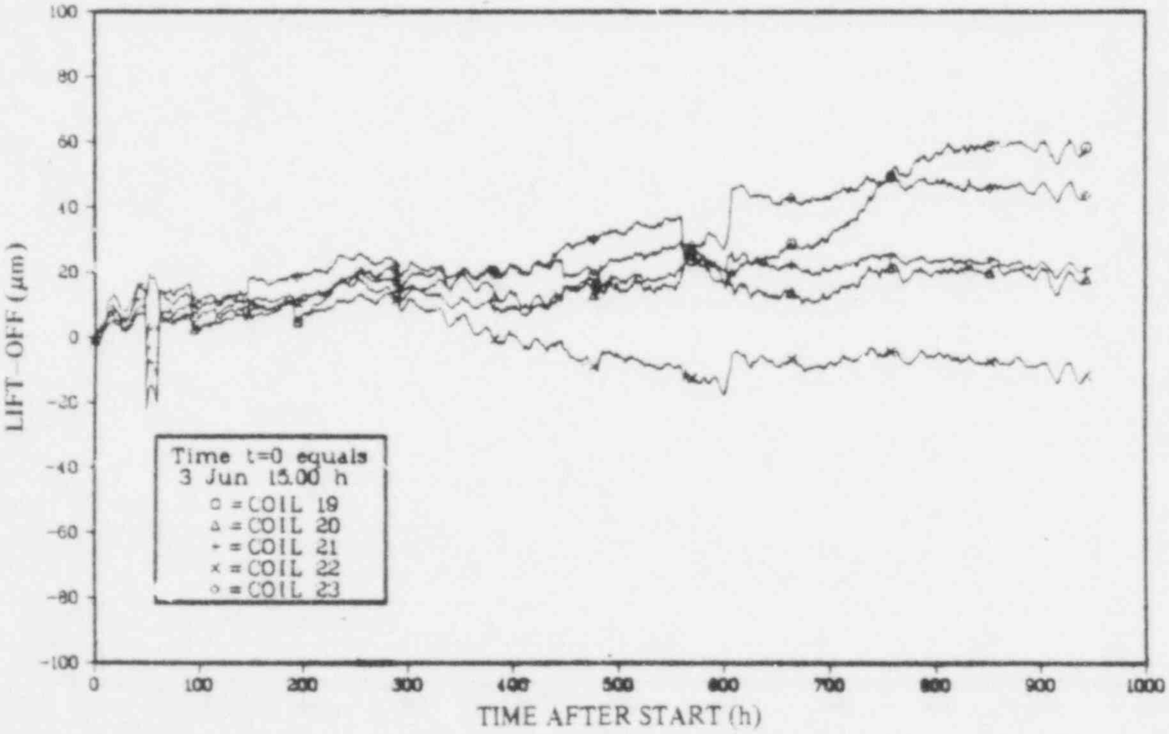

Fig. 9. Lift-Off History of HOBBIE-1, as Supplied by ECN-Petten. Data for coils 19 through 23.

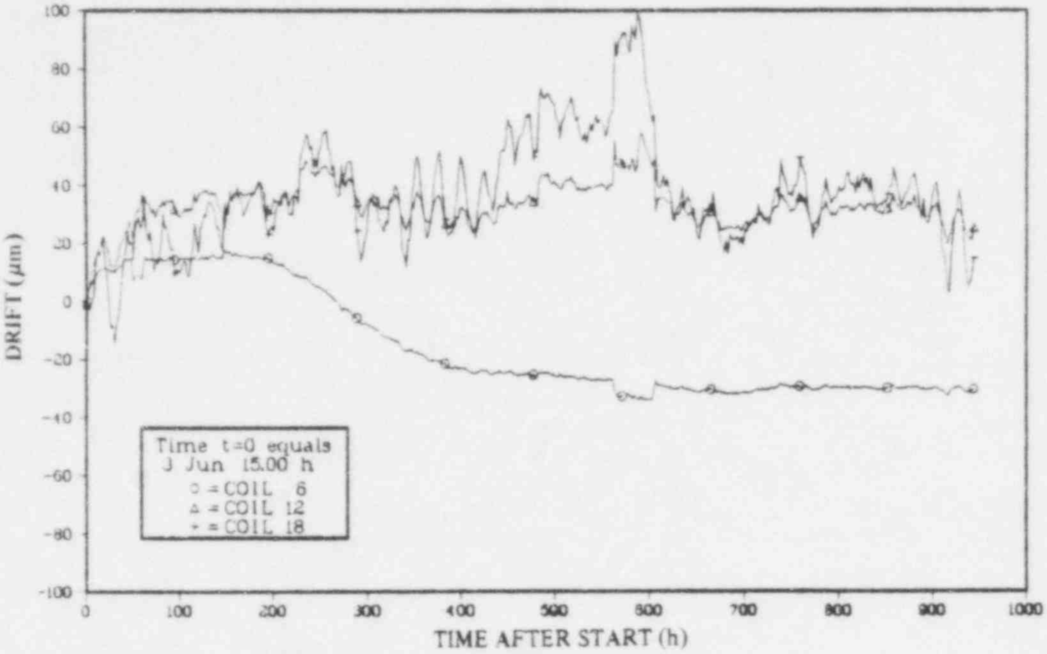

Fig. 10. Lift-Off History of HOBBIE-1, as Supplied by ECN-Petten. Data for reference coils 6, 12, and 18.

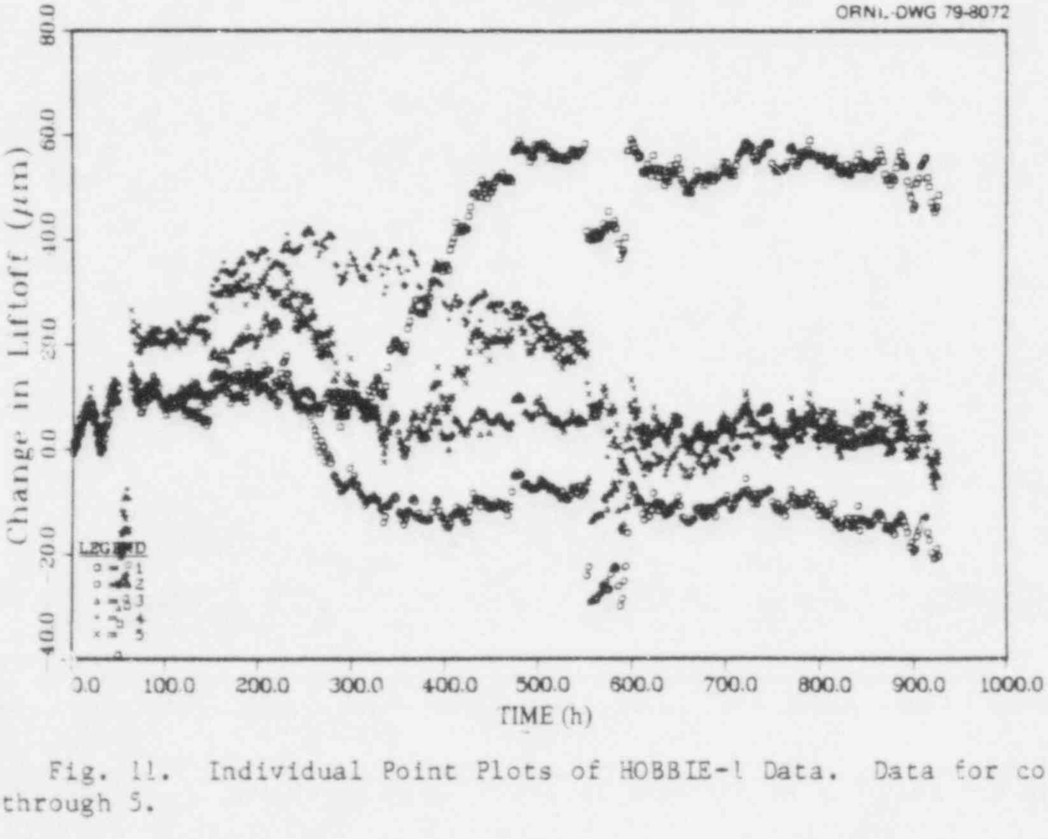

Fig. 11. Individual Point Plots of HOBBIE-1 Data. Data for coils 1 through 5.

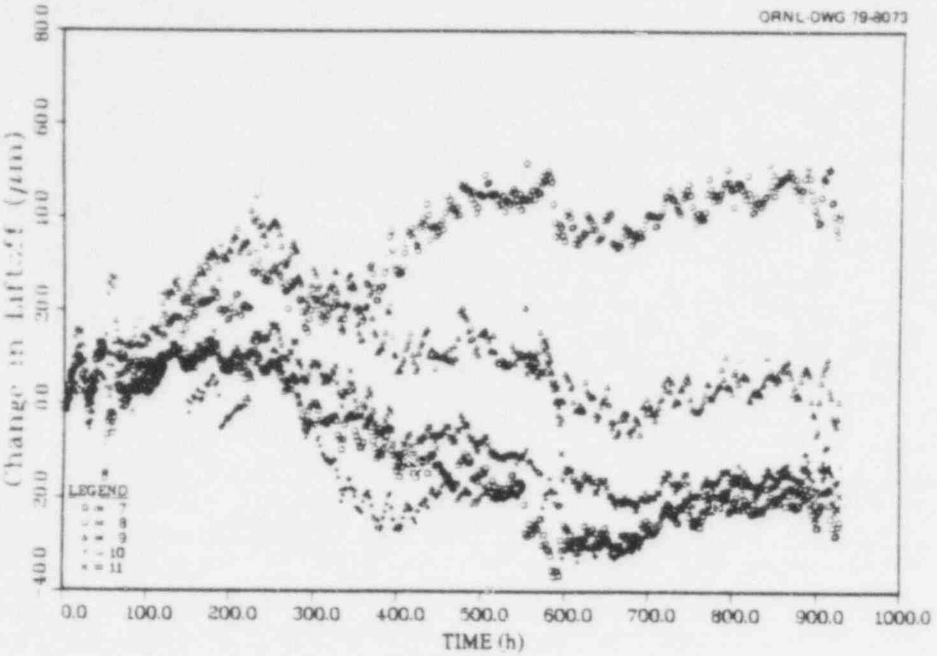

Fig. 12. Individual Point Plots of HOBBIE-1 Data. Data for coils 7 through 11.

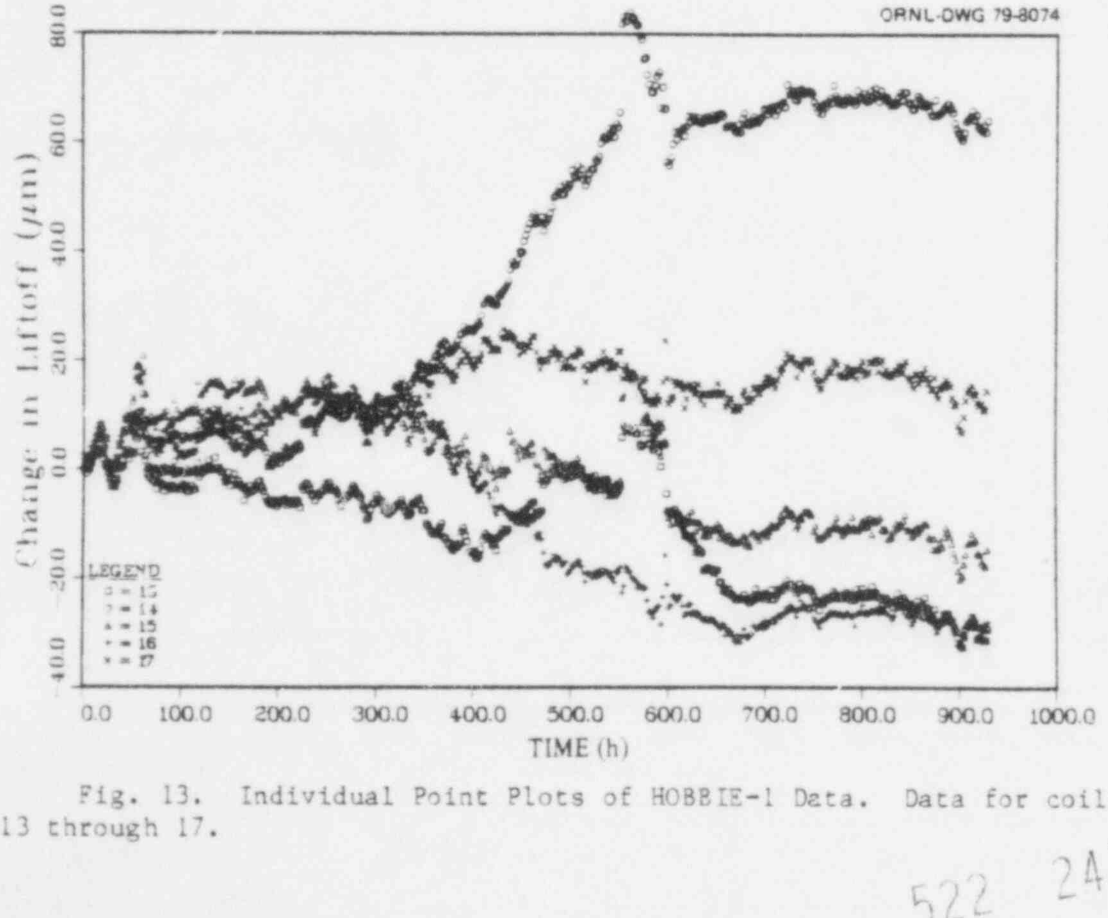

Fig. 13. Individual Point Plots of HOBBIE-1 Data. Data for coils 13 through 17.

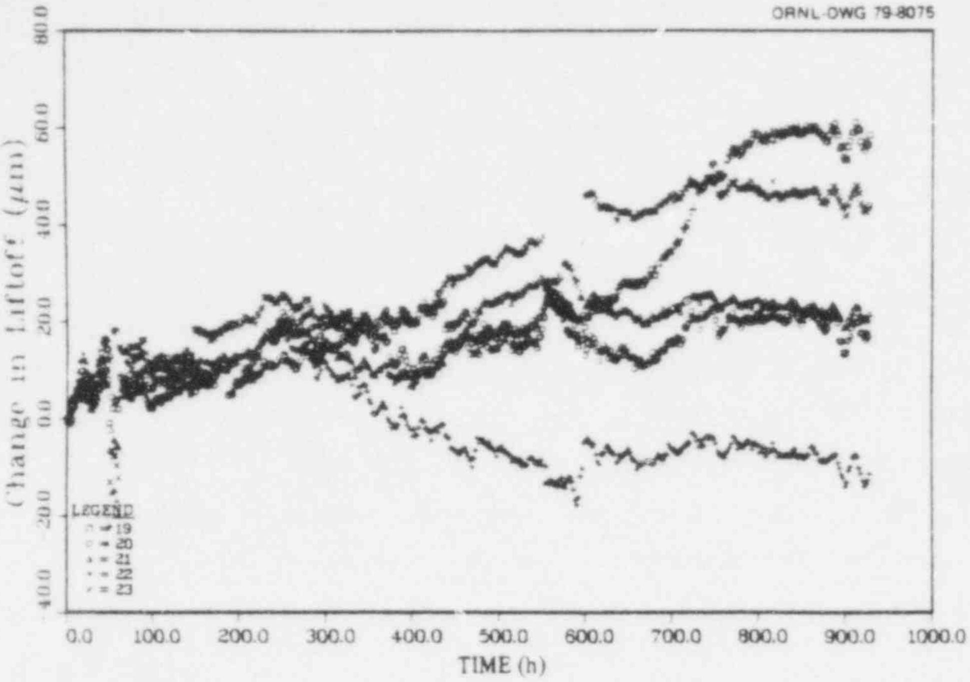

Fig. 14. Individual Point Plots of HOBBIE-1 Data. Data for coils 19 through 23.

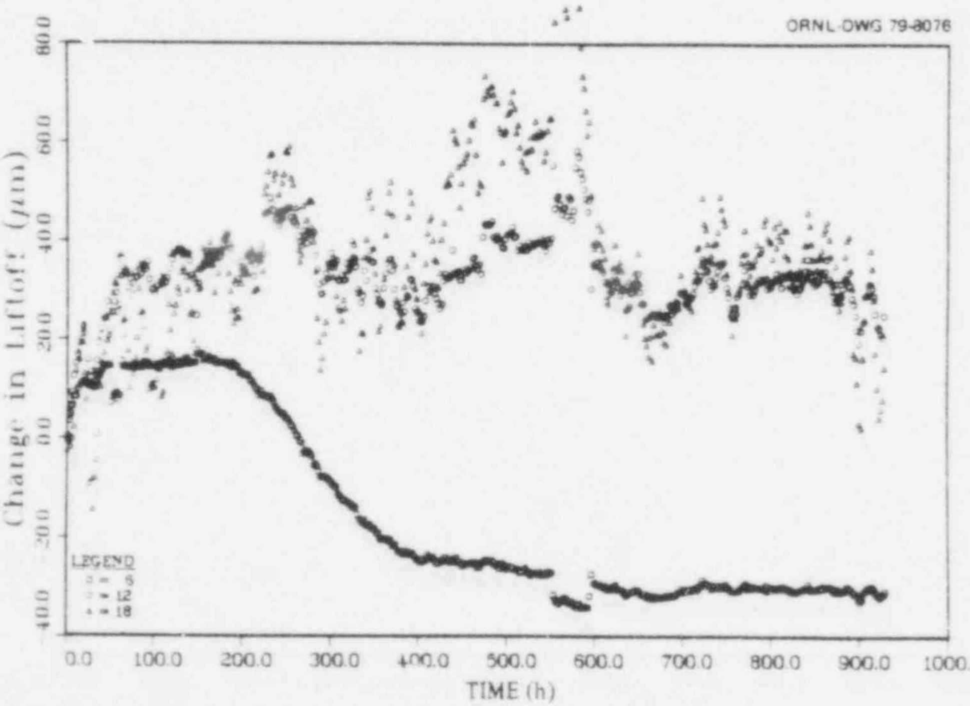

Fig. 15. Individual Point Plots of HOBBIE-1 Data. Data for reference coils 6, 12, and 18.

Data Correction Method

Reference coils are included in the creepdown-monitoring equipment to indicate the amount of instrument drift and to provide a means for quantitatively correcting the data for that drift. Coils 6 and 12 were preset to constant lift-off values of 402 and 794 µm, respectively, before the test. Ideally, if no drift occurred during the test no change in lift-off should occur for those coils. Coil 18 was used as a backup zero reference coil to be used if coil 24, the regular zero reference coil, was lost. Its data were recorded as analogue-to-digital (A/D) output readings, and these are plotted on the same scale as coils 6 and 12 in Figs. 10 and 15, but are not in the same units. The A/D readings are digitized representations of the voltage differences generated by the eddy-current coils. The coil 18 data would have been uniformly zero with time if coil 18 had been identical in electrical characteristics with coil 24. In reality, the A/D readings represent the differences between coils 18 and 24, where coil 24 is defined as having a constant A/D reading of zero. An average of the absolute values of coils 18 and 24 with time (one half the A/D value for coil 18 at each data acquisition interval) was subtracted to correct the data for drift in the instrument zero value.

Data acquisition intervals of 2 h were used in the test, with 23 pieces of information being acquired at the end of each interval. These 23 data consisted of information from the 20 working coils, 2 reference lift-off coils, and the backup zero reference coil. The eddy-current instrumentation, described in ref. 4, contains a microcomputer, which stored the calibration constants for each of the eddy-current coils. These constants were used in a simple polynomial in the natural logarithm of the A/D readings to calculate the lift-off. The form of the equation is

$$\text{lift-off} = C_0 + C_1[\ln(\text{A/D})] + C_2[\ln(\text{A/D})]^2 \ ,$$

and with it and the quadratic formula one could also obtain the A/D value from the lift-off value. At the beginning of the test, the eddy-current instrumentation was zeroed and a set of 20 absolute

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lift-off readings was obtained. These values were stored in computer memory, and all subsequent data sets were compared with them. The differences constituted the output data.

The following scheme illustrates the correction method for the HOBBIE-1 data. For clarity only one datum, for one coil and one time step, will be discussed. It should be understood that the actual correction was done by computer on each of the approximately 9500 data points for the test.

Assume the data point for coil 8 at 500 h is to be corrected. The initial absolute lift-off for this coil was 763 μm. The change in lift-off after 500 h was +45 μm, so that the actual lift-off was 808 μm. This value was converted to its equivalent A/D value with the appropriate polynomial to obtain a value of 940. Coil 18, the alternate zero reference coil, produced a value of 68 for the 500 h time step. This value was directly in A/D output units and represented drift relative to the zero reference coil — the one being used by the instrument as a baseline. As discussed earlier, an appropriate correction for this drift would be to average the two zero reference readings. This produced an A/D value of 34 since the zero reference coil was zero by definition. This value was subtracted from the coil 8 reading to give an A/D value of 906, which converted to a lift-off of 824 μm. Subtraction of the initial absolute lift-off left a change-in-lift-off value of 62 μm. This completed the correction based on the zero reference coils.

Coils 6 and 12 were preset to constant lift-off values before startup of HOBBIE-1. If the measuring system had performed with no drift these two coils would have shown no change in lift-off during the test. Since they did vary with time, it was necessary to apply a correction based on those variations. The initial lift-off values for coils 6 and 12 were 402 and 794 μm, respectively. The average initial lift-off for the 20 working coils was 662 μm. The difference between the average value and the coil 12 value is one-half the difference between the average and the coil 6 values. Therefore, a weighting procedure was used wherein the changes in apparent lift-off in coils 6 and 12 were used to make a final correction in the data. This correction was of the form

$$(\text{Correction})_{6,\ 12} = [2(\Delta LO)_{12} + (\Delta LO)_6]/3 \ ,$$

and was subtracted, at each time step, from each of the 20 working coil lift-off values. The rationale used for this weighting was that coil 12 was closer to the average lift-off values of the working coils and should better represent the drift behavior of those coils.

Corrected Data

The results of the preceding correction are shown in Figs. 16 through 20 and are best seen in a comparison of Fig. 15 with Fig. 20. These are the raw and the corrected reference lift-off data, respectively. The differences between the raw coil 6 and 12 data and the corrected coil 6 and 12 data reflect the weighting used in the correction. Note that the curves for coils 6 and 12 are essentially mirror images in shape but are displaced from the zero lift-off line distances by amounts inversely proportional to their weighting. If the curves were averaged according to their weighting, that average would fall close to the zero line. The coil 18 data, which are not lift-off data, are uncorrected and are identical in the two figures.

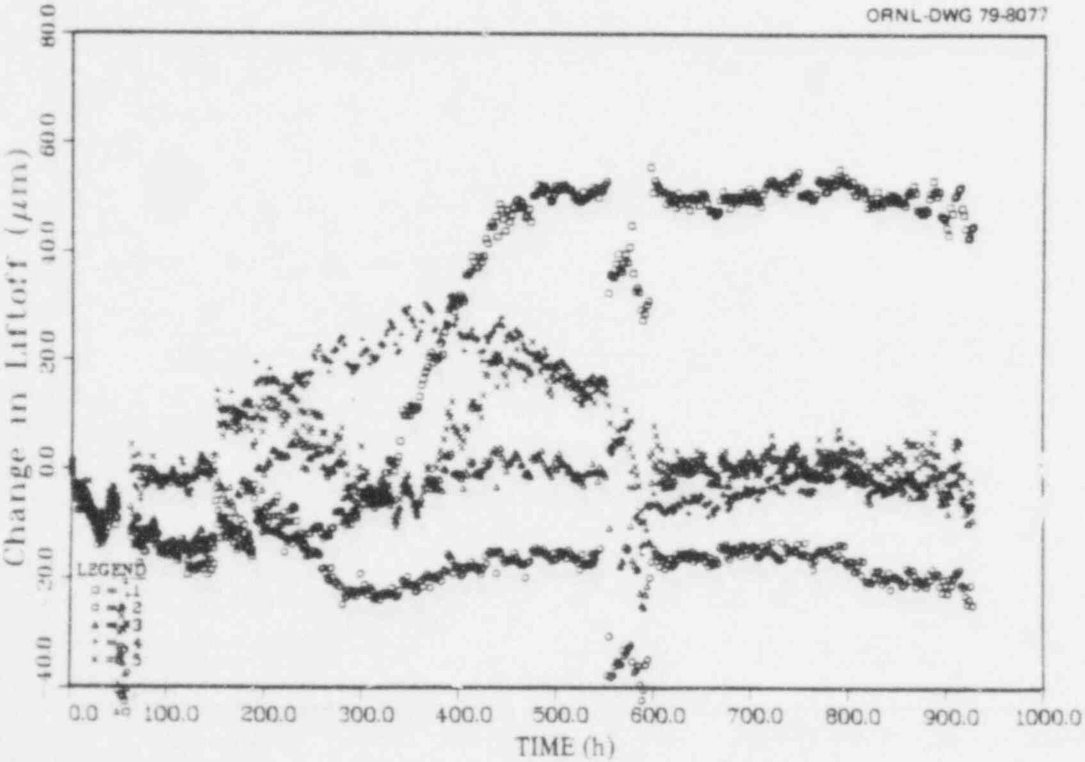

Fig. 16. Corrected Individual Point Data for HOBBIE-1, Coils 1 through 5.

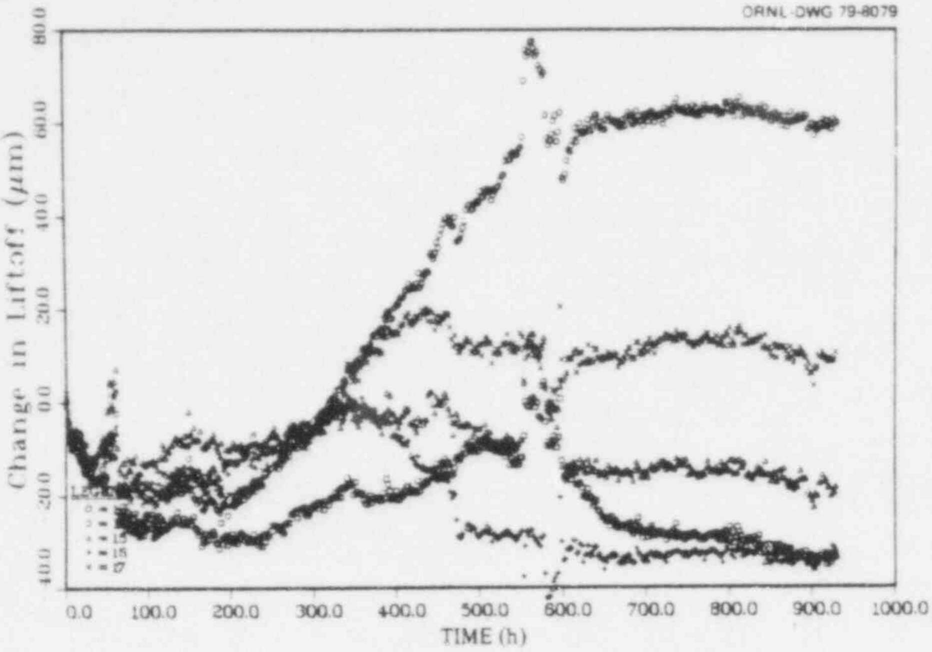

Fig. 17. Corrected Individual Point Data for HOBBIE-1, Coils 7 through 11.

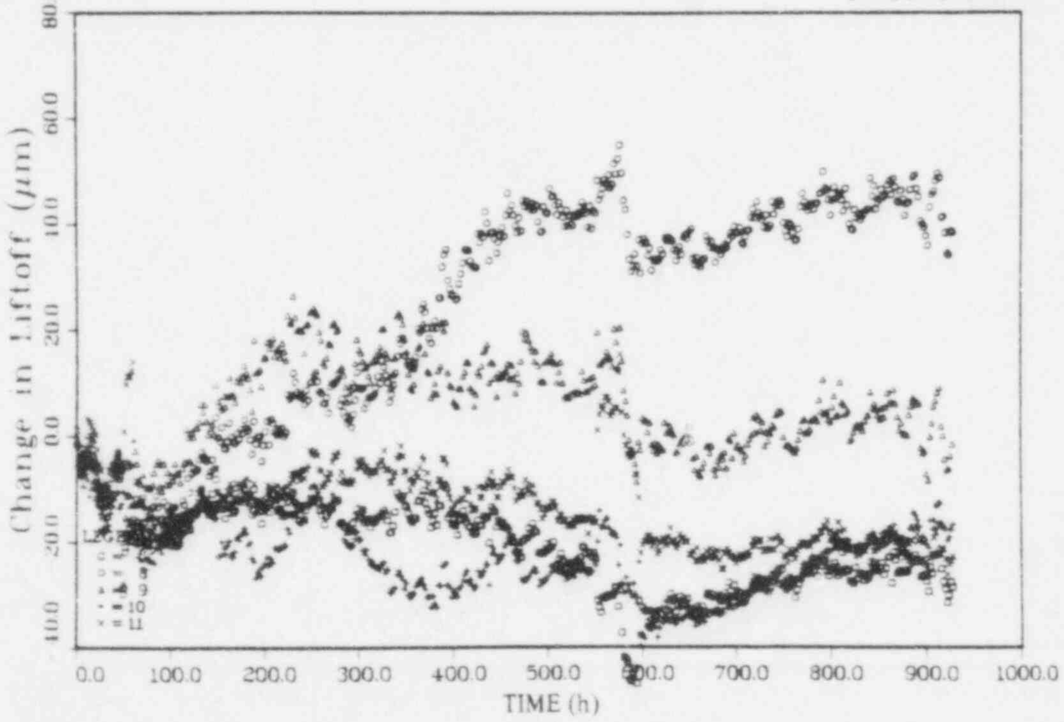

Fig. 18. Corrected Individual Point Data for HOBBIE-1, Coils 13 through 17.

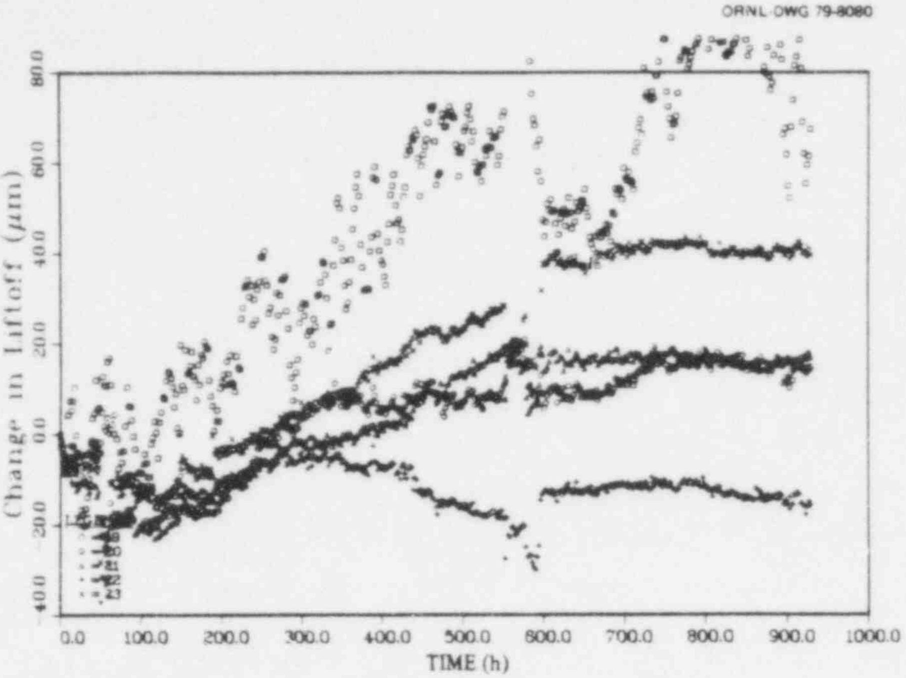

Fig. 19. Corrected Individual Point Data for HOBBIE-1, Coils 19 through 23.

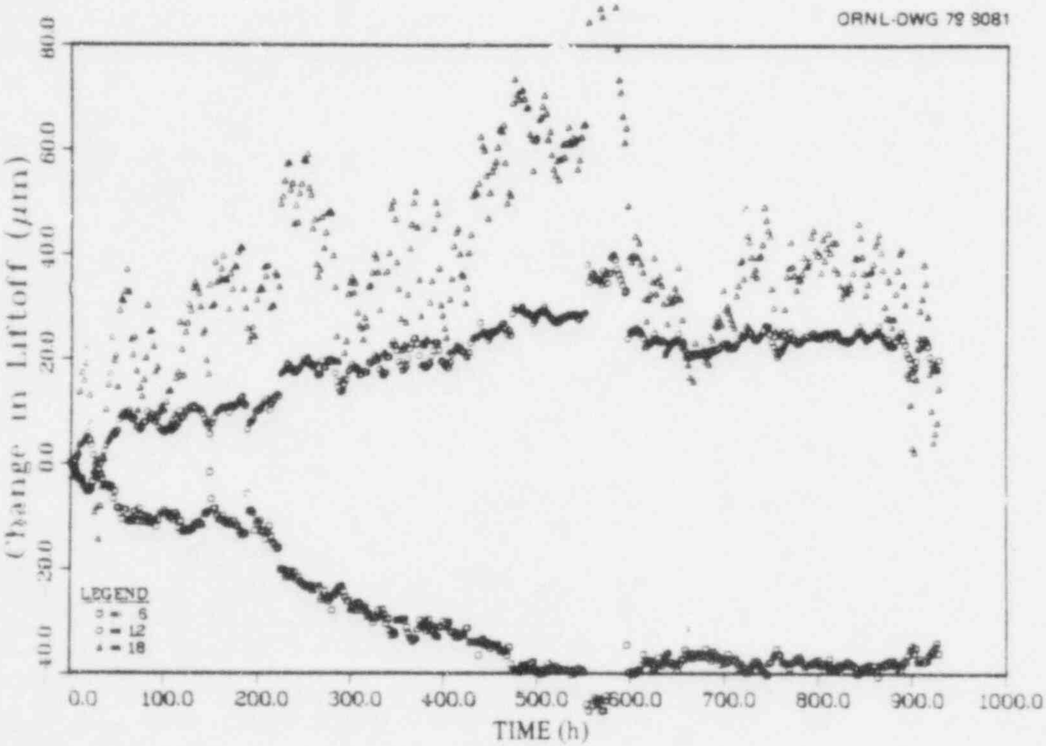

Fig. 20. Corrected Individual Point Data for HOBBIE-1, Reference coils 6, 12, and 18.

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Figures 16 through 20 show that even though the data corrections eliminated part of the scatter in the HOBBIE-1 results, there was still a fine structure related to the 24-h periodic variation discussed earlier. This was eliminated by averaging the corrected data for each coil over a 24-h time period. The results are shown in Figs. 21 through 24.

Finally, one area of data correction was not implemented in this experiment. The computer-controlled clock gained approximately 1 min/d. Also, several reactor scrams during the experiment introduced some uncertainty in the exact time of the test. The data were collected at 2-h intervals during the test, and the actual test times were estimated. The data reported herein are based on a best estimate of the correct test times but may be off by a few hours. This is not considered important in the analysis of the HOBBIE-1 data.

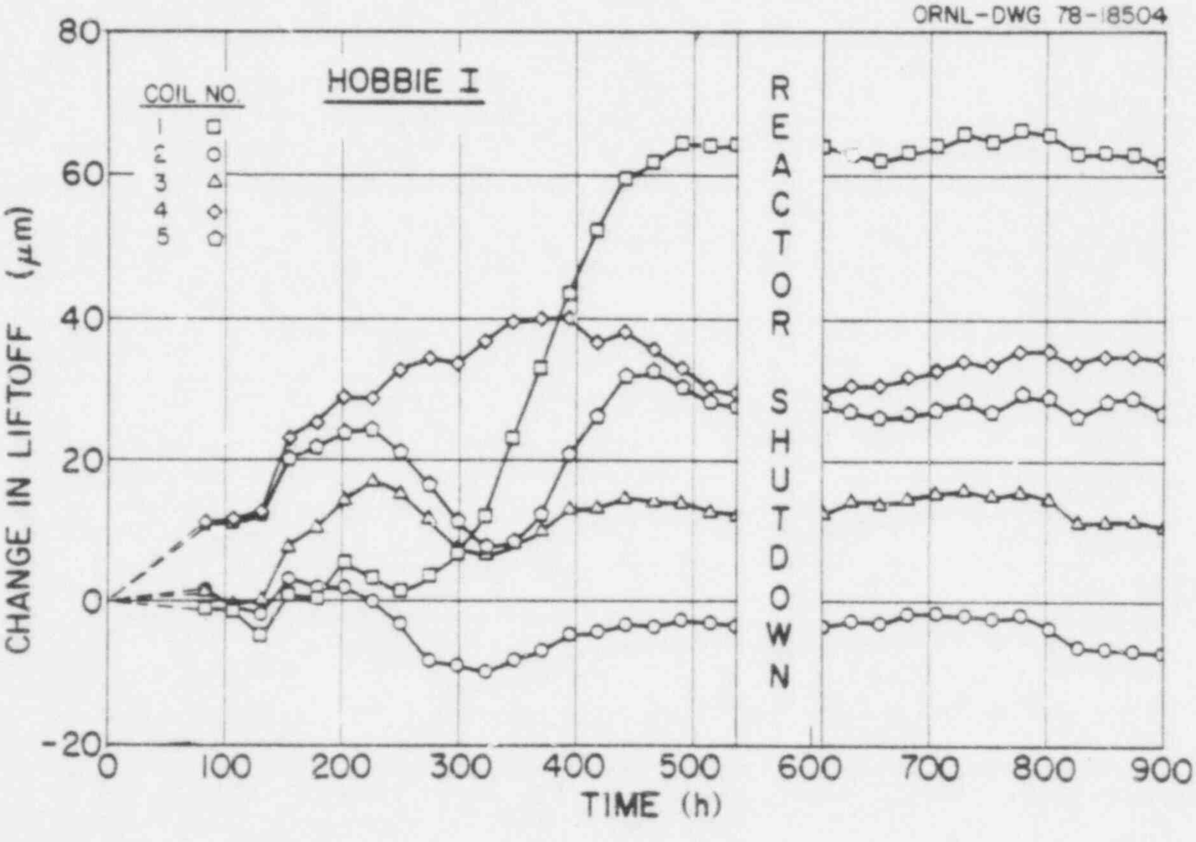

Fig. 21. Corrected and Averaged Data for HOBBIE-1, Coils 1 through 5.

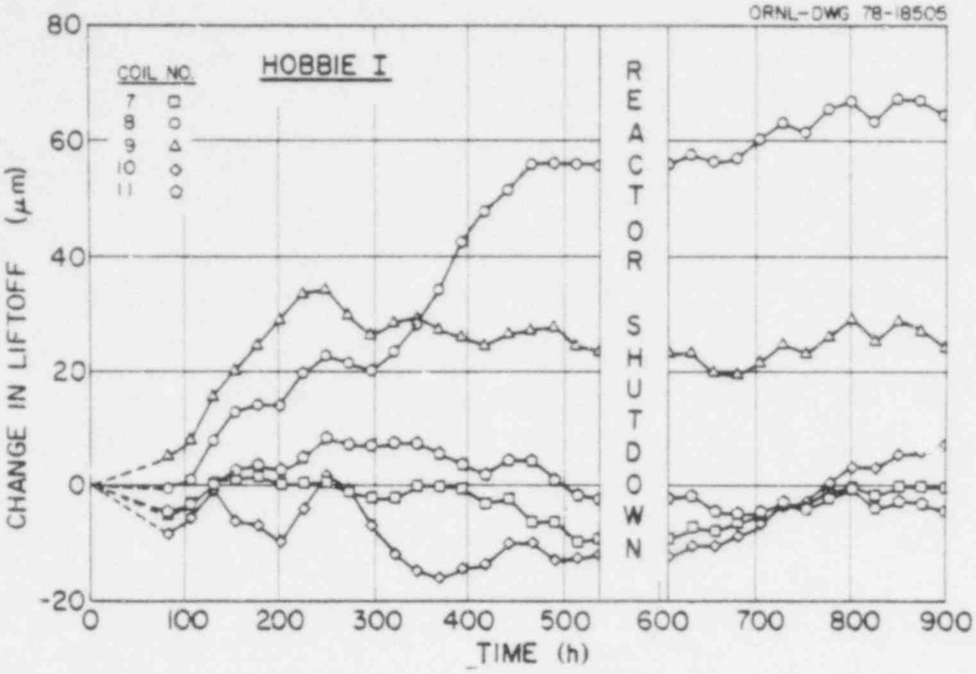

Fig. 22. Corrected and Averaged Data for HOBBIE-1, Coils 7 through 11.

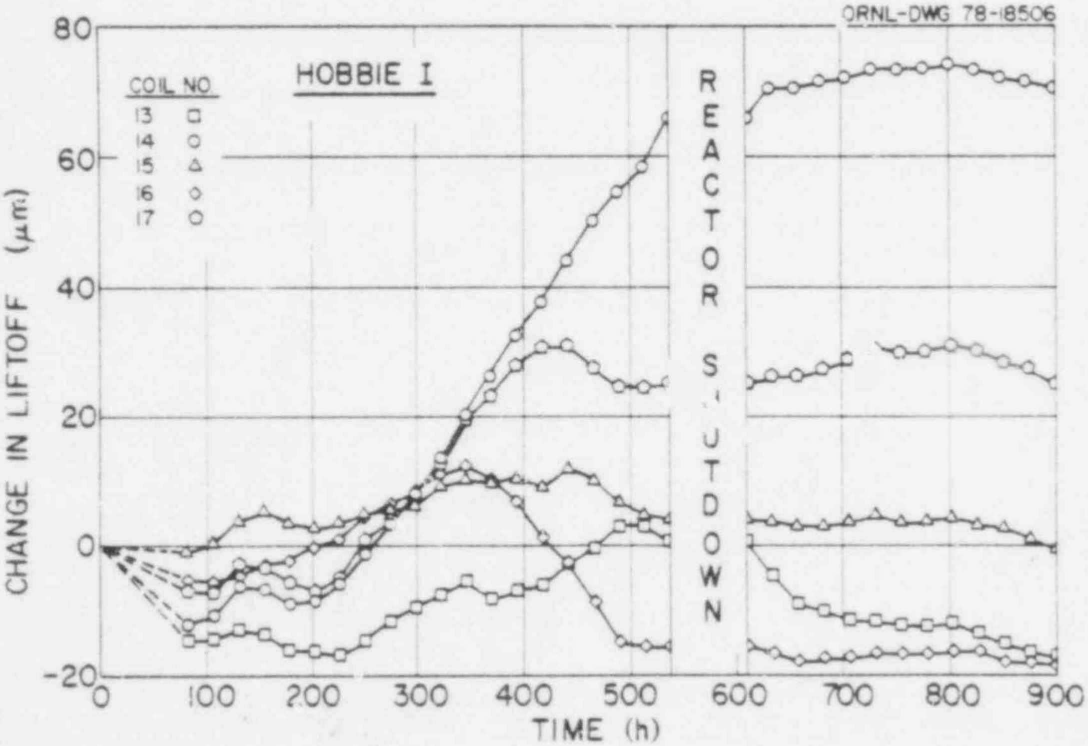

Fig. 23. Corrected and Averaged Data for HOBBIE-1, Coils 13 through 17.

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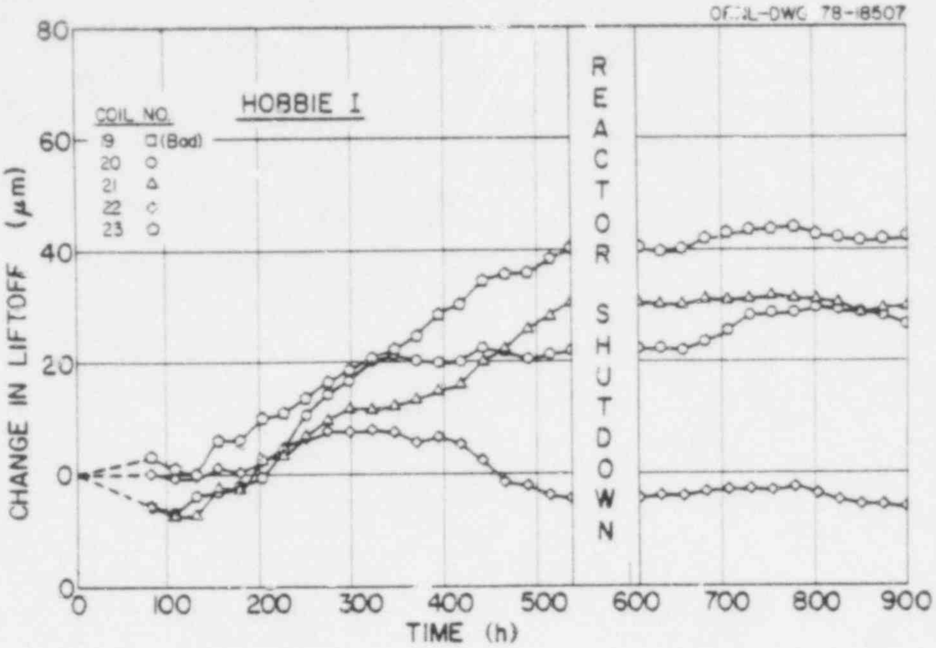

Fig. 24. Corrected and Averaged Data for HOBBIE-1, Coils 19 through 23.

DISCUSSION OF RESULTS

Prior out-of-reactor tests showed that the Zircaloy cladding deformed by two general modes — ovalization and diameter decrease. Both modes could be recognized easily from the data. Ovalization produced increasing lift-off in sets of coils on opposite sides of the specimen and decreasing lift-off in coils at right angles to those sets. Diametral or circumferential strain could be detected by a general trend in the data toward increased lift-off. The HOBBIE-1 results do not show the smooth ovalization found in out-of-reactor tests. It is not known at present whether this is typical of in-reactor behavior or is due to the axial temperature gradient that existed in the specimen. Further testing, in which the gradient is eliminated by experiment redesign, should answer that question.

Average diameter changes occured in HOBBIE-1 in a relatively smooth manner, as shown in Fig. 25, as a function of test time. The uncertainty in the data for the first 100 h of test time is due to a trend in

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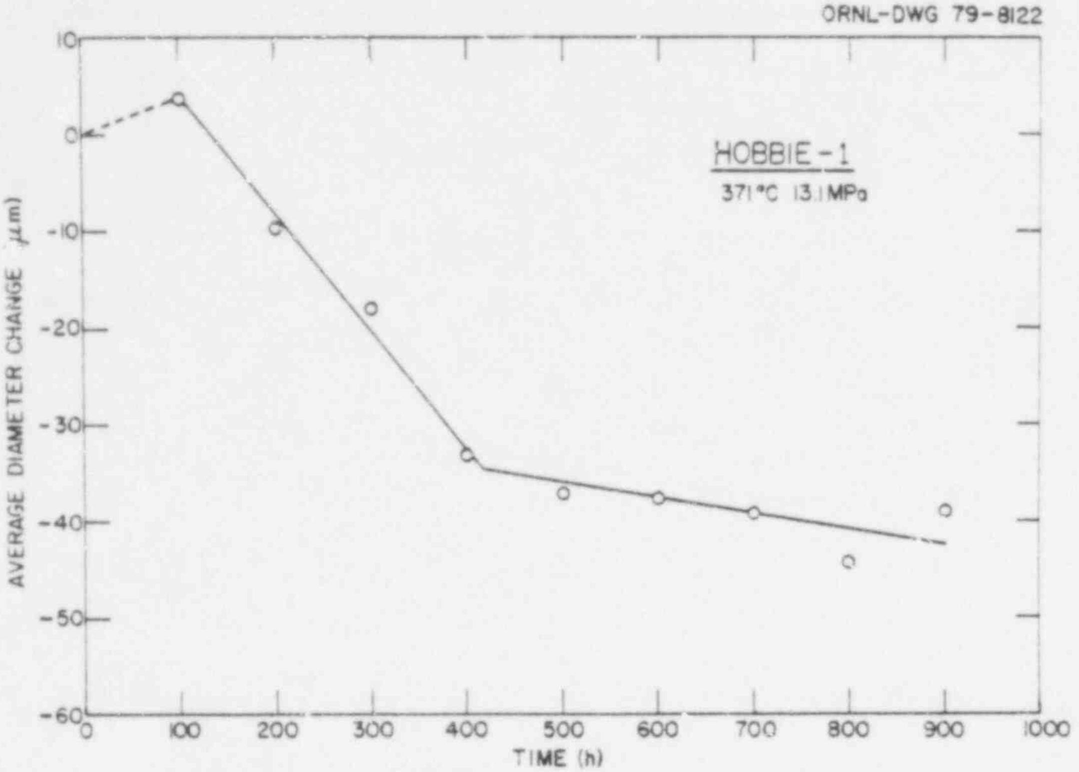

Fig. 25. Average Specimen Diameter Change as a Function of Time. The slope change between 400 and 500 h represents the time of mandrel contact by the specimen. The dashed line between 0 and 100 h represents the uncertainty in the absolute lift-off measurements caused by the reactor scram.

the data toward decreasing lift-off — this indicates a diameter increase — and to a reactor scram. This all occurred during the first 60 h of testing. Indications from the corrected reference coil data, Fig. 20, were that this trend was not due to instrument drift since such drift presumably was taken care of by the corrections. The data probably had not been corrected to completely eliminate the effects of the scram that occurred at approximately 50 h after the start of testing. These uncertainties led to a decision to "float" the data, starting at 100 h. The loss of the zero position during this time span and the uncertainty in the absolute lift-off values are not of great importance to the present interpretation of creepdown in HOBBIE-1. Hot-cell examination of the test specimen will give values of total plastic strain that will allow back calculation of lift-off.

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The total average diametral decrease from 100 to 900 h was about 46 μm. This represents a circumferential compressive strain of approximately 0.42% or an average strain rate of approximately 5.3×10^{-6}/h. The specimen contacted the internal mandrel between approximately 400 and 500 h, compared with 375 h for a comparable out-of-reactor test,[5] and an apparent change in rate can be seen in Fig. 25. The rate of average circumferential strain between 100 and 400 h was approximately 1.1×10^{-5}/h. This rate is higher than reported[1,2] for uniaxial creep, but the test condition differences preclude meaningful comparisons. Future tests will allow a better comparison with published data.

CONCLUSIONS

This report has presented the creepdown data from HOBBIE-1, the first of a series of externally pressurized Zircaloy-4 fuel cladding creepdown tests. The results are reported together with the procedures used to correct the data for instrument drift and the effects of reactor scrams.

The following conclusions have been reached:

The eddy-current deformation-monitoring system worked well for the approximately 1000-h lifetime of the experiment.

Instrument drift can be corrected through the use of the reference lift-off coils and the zero-balance coil. The correction method does not eliminate completely the scatter in the data but it does provide a rational method for quantitatively adjusting the lift-off readings according to variations in the reference coils.

No simple pattern of ovalization of the specimen was found in the HOBBIE-1 test. We do not know yet whether this was due to testing in-reactor or to influence of the axial temperature gradients in the specimen.

Specimen-to-mandrel contact was made between 400 and 500 h.

The rate of average diameter decrease, or circumferential strain, was approximately 1.1×10^{-5}/h between 100 h and the time of first mandrel contact.

Future tests will be run at lower temperatures (340–345°C) to try to separate the fast flux contribution from the thermal contribution to the creepdown rate.

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REFERENCES

1. V. Fidleris, "Uniaxial In-Reactor Creep of Zirconium Alloys," *J. Nucl. Mater.* 26: 51–76 (1968).
2. G. R. Piercy, "Mechanisms for the In-Reactor Creep of Zirconium Alloys," *J. Nucl. Mater.* 26: 18–50 (1968).
3. E. F. Ibrahim, "In-Reactor Tubular Creep of Zircaloy-2 at 260 to 300°C," *J. Nucl. Mater.* 46: 169–82 (1973).
4. D. O. Hobson and C. V. Dodd, *Interim Report on the Creepdown of Zircaloy Fuel Cladding* ORNL/NUREG/TM-103 (May 1977).
5. D. O. Hobson, *Creepdown of Zircaloy Fuel Cladding – Initial Tests*, ORNL/NUREG/TM-181 (April 1978).
6. K. R. Thoms and T. van der Kaa, *Design and Safety Report for HOBBIE Capsules*, ORNL/NUREG/TM-167 (December 1977).

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