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CEND-3336-251

(EURAC-1510)

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ATOMIC ENERGY COMMISSION
RESEARCH AND DEVELOPMENT PROGRAM

PROGRESS REPORT

DEVELOPMENT AND TESTING OF A TEMPERATURE
TRANSIENT METHOD FOR PERFORMING
IN-PILE THERMAL CONDUCTANCE TESTING

For Period
July 1 to September 30, 1965

RELEASED FOR ANNOUNCEMENT

IN NUCLEAR SCIENCE ABSTRACTS

Issued October 1965

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UC-25 Metals, Ceramics
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TID-4500, 45th Edition

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For Period
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Prepared by:

C. E. Burdg
S. S. Christopher

Contract AT(30-1)-3336
U. S. Atomic Energy Commission

Issued October 1965

Unclassified
Classification

Approved by:

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DEVELOPMENT AND TESTING OF A TEMPERATURE
TRANSIENT METHOD FOR PERFORMING
IN-PILE THERMAL CONDUCTANCE TESTING

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DEVELOPMENT AND TESTING OF A TEMPERATURE
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PREFACE

The United States and The European Atomic Energy Community (EURATOM) on May 29 and June 18, 1958, signed an agreement which provides a basis for cooperation in programs for the advancement of the peaceful applications of atomic energy. This agreement, in part, provides for the establishment of a Joint U.S. -EURATOM research and development program which is aimed at reactors to be constructed in Europe under the Joint Program.

The work described in this report represents the Joint U.S. -EURATOM effort which is in keeping with the spirit of cooperation in contributing to the common good by the sharing of scientific and technical information and minimizing the duplication of effort by the limited pool of technical talent available in Western Europe and the United States.

DEVELOPMENT AND TESTING OF A TEMPERATURE
TRANSIENT METHOD FOR PERFORMING
IN-PILE THERMAL CONDUCTANCE TESTING

By

C. E. Burdg and S. S. Christopher

ABSTRACT

The concept now being investigated is one whereby measurement of the transient temperature response at the surface of an operating fuel element, following a reactor power change, will yield thermal conductance values. This two-phase investigation consists first of out-of-pile demonstrations of feasibility followed by in-pile confirmation of the method. Concurrent mathematical analyses of the thermal model will provide the bases for data interpretation, as well as guides for the design of the experimental portions of the program.

Installation of a lowpass filter in the cladding thermocouple signal path has resulted in significant improvement in the signal/noise ratio. Tests of a ZrO_2 element, using square wave cyclic input, have yielded anomalous results. The phase shift of the cladding temperature response with regard to the input signal appears to be different at different locations along the length of the element, by an amount not fully explained by recognizable uncertainties in measurement. However, the fuel was of low density (72% of theoretical) and inhomogeneities or cracks may be responsible for this anomalous behavior.

I. SUMMARY

During this reporting period a lowpass electronic filter was received and placed in the system. This equipment is used to attenuate the high frequency noise components present in the thermocouple signal so that measurements of the cladding temperature phase shift can be made. Operation of this filter in the lowpass mode, in the thermocouple signal path, has resulted in a marked improvement in the signal/noise ratio.

Cyclic input tests were performed on a ZrO_2 -10 wt%-CaO element, designated Z-2. This element contained pellets 1.07 cm OD x 0.224 cm ID x 0.523 cm in height. The pellets had a density of 72 $\pm$ 1% of theoretical with a uniform pore distribution. These tests revealed that the cladding phase lag was not uniform along the axis of the element. Thermocouple readings showed phase shift differences along the axis of the element reaching 27° which corresponds to about 4.3 seconds at the input frequency.

The reason for the phase shift differences along the axis of the element is not known, however it might be attributed to inhomogeneity of the low density pellets, cracking of the pellets during testing or the geometry of the system. All of the above factors are currently being evaluated.

II. INTRODUCTION

The objective of this program is to develop a method of determining the thermal conductance of UO_2 fuel elements while operating in a reactor. Transient response of element surface temperature, following a power change, is the parameter to be utilized.

The present program consists of an out-of-pile and in-pile investigation. The out-of-pile phase is intended to prove the feasibility of the method to be employed in-pile. It is also intended to demonstrate that reliable values for fuel element conductances can be obtained through transient testing techniques. Upon completion of the first phase, a review of the results will be made and concurrence of the Commission obtained prior to initiation of the second phase of the program. This second, or in-pile, phase will utilize the correlations and experience gained during the out-of-pile investigation. The methods and analytical techniques should prove particularly useful.

During the previous reporting period, the mechanical low frequency function generator was constructed. This apparatus, which produces cyclic variations of the power input to the heater of the test element, was used to perform exploratory tests of an element containing ZrO_2 . These tests showed that a high-frequency noise component in the cladding thermocouple signals was large enough to preclude obtaining useful data with the existing system.

During the current reporting period, an ultra-low frequency electronic filter was obtained and placed in the system. Operation of this filter in the lowpass mode, in the thermocouple signal path, has resulted in a very significant improvement in the signal/noise ratio. Further tests with the ZrO_2 element⁽¹⁾ were performed. Three elements containing UO_2 were fabricated during this period and additional ZrO_2 elements are being fabricated.

(1) CEND-3336-241, Burd, C. E. and S. S. Christopher, "Development and Testing of a Temperature Transient Method for Performing In-Pile Thermal Conductance Testing".

III. EXPERIMENTAL STUDIES

During the preceeding reporting period⁽¹⁾ it was found that a high-frequency noise component in the cladding thermocouple signal was large enough to preclude obtaining useful phase shift data with the existing instrumentation system. In an attempt to clean up the signal, an electronic filter was obtained; this filter, a Krohn-Hite Model No. 335 Variable Filter has the capability of being used in lowpass, highpass, bandpass, or band reject modes. It covers a continuously variable frequency range from 0.02 Hz to 20 KHz, in four bands. The attenuation slope outside the pass band is 24 db per octave, with a maximum attenuation greater than 80 db. Inspection of the early recordings indicated that an attenuation of the high frequency components of 30 db would probably be adequate to permit retrieval of the phase shift information. Therefore, the filter appears to have the needed attenuation characteristics.

One almost inescapable characteristic of filters is that amplitude attenuation and filter-caused phase shift are solidly intertwined for any particular ratio of signal frequency to filter "cutoff" frequency. Thus, when used in an application like the present one, the phase shift due to the filter must be determined and considered along with the phase shift of the tested system. Fortunately, this is relatively easy to measure and remains fixed for a given set of operating frequencies. For example, in the lowpass mode this filter has the following approximate phase shifts for a signal frequency (f_s) = 0.0168 Hz:

TABLE I
FILTER PHASE SHIFT

Cutoff Frequency f_c (Hz)	f_s/f_c	ϕ (deg)
.020	.84	150
.084	.20	25
.168	.10	10

Cyclic input tests were performed on an element, designated Z-2, containing ZrO_2 -10 wt% CaO to simulate the fuel. ZrO_2 was selected based on its ability to operate at high temperatures; its crystallographic structure which is similar to UO_2 and its comparable microstructure with UO_2 . The ZrO_2 -10 wt% CaO pellets were sintered in air at 1500°C for 16 hours and slowly cooled. Pellet densities varied from 71 to 73% of theoretical with a uniform pore distribution. The sintered pellets measured approximately 1.57 cm OD x 1.270 cm high. The pellets were subsequently drilled and ground to an inside diameter of 0.224 cm. The final pellet size was: height-0.523 cm; OD-1.07 cm and ID-0.224 cm. The pellets were then slipped over a tungsten-25 rhenium heater rod which acted as the source for the thermal pulse. A slip fit clearance of about 0.005 cm between pellets and cladding was used. The entire assembly^(*) consisting of test element and cooling jacket, was contained in a helium atmosphere.

The tests were performed using the filter in the thermocouple signal path, as shown in the test equipment schematic, Figure 1. Immediately ahead of the filter is a DC amplifier having a gain of 40 db and essentially no phase shift at the frequencies of interest. A "pipper" relay, driven by the mechanical function generator, provides fiducial marks on the temperature vs time recording

* See Appendix A

FIGURE 1
TEST SCHEMATIC

RUN 6
 TEST ELEMENT Z-2
 SIGNAL FREQUENCY .0168 Hz
 CUTOFF FREQUENCY .020 Hz
 200 WATT SQUARE WAVE INPUT
 THERMOCOUPLE #3

FIGURE 2
 CLADDING TEMPERATURE VS. TIME

$$f_s / f_c = 0.84$$

$$f_s / f_c = 0.20$$

so that measurements of the phase shift can be made. At the "increase" corner of the input wave the pip is positive, and at the "decrease" corner the pip is negative. The phase lags of the peak values of the signal trace were measured from the pips, for each half cycle, and the average of seven cycles reported. In all cases, the input signal was a square wave of power at 0.0168 Hz.

Figure 2 is a typical recording for a filter cutoff frequency of 0.020 Hz, or $f_s/f_c = 0.84$. It can be seen that the signal has been shorn of virtually all noise components, leaving only a reasonably accurate sinusoid. In Figure 3, a recording where $f_s/f_c = 0.20$, some distortion appears on the signal as a result of incomplete attenuation of noise. Even so, phase shifts can be measured easily within about 20°; averaging over a number of cycles reduces the errors.

The results of measuring the cladding phase shift for element Z-2 are presented in Table II. This table contains the results for each of the five axial locations, separately for the "increase" and "decrease" halves of the cycles, and are typically averages of 7 cycles. In each case, the measured phase shift has been corrected by the values of Table I to compensate for filter phase shift.

TABLE II
CLADDING PHASE SHIFT FOR ELEMENT Z-2
INPUT FREQUENCY 0.0168 Hz

TC#	Power	$f_s/f_c =$	Phase Shift (degrees)		
			.84	.20	.10
1	+		182	176	203
1	-		169	186	185
2	+		183	176	198
2	-		178	181	184
3	+		161	166	193
3	-		157	174	178
4	+		188	186	211
4	-		182	179	190
5	+		183	196	214
5	-		178	183	183

IV. DISCUSSION

Comparisons of the various values in Table II show that the cladding phase lag of the element was not uniform along the axis of the element. The greatest difference in phase shift appears to be between thermocouples Nos. 3 and 4. For that filter setting where $f_s/f_c = .84$, which results in nearly sinusoidal traces that are easiest to measure accurately, the difference between the two locations is 27° for the positive half cycle, and 25° for the negative half cycle. The average, 26° , corresponds to about 4.3 seconds at this input frequency. As reported previously⁽²⁾, it was determined by computer studies that the cladding time lag for an input frequency close to this encompassed a range from 6 to 12 seconds, over the entire range of effective conductivities of interest. It should be noted that while the computed results are for the reference UO_2 element, a ZrO_2 element should have a time lag on the order of 12 seconds. The observed lag was 28.6 ± 2.5 seconds.

A second observation that can be made from Table II is that the phase shift values for the two halves of the cycle are not identical. Possible reasons for this are non-linearities in the test element, assymetry of the input power variations, or recording interpretation error. Efforts are being made to devise more precise graphical interpretations so as to minimize that source of error and thus determine if the other causes are real.

A final observation is that the phase shift values for various filter settings are not identical, even for the same thermocouple. This can be attributed in part to some inaccuracy in the value used for filter phase shift, and in part to inaccurate graphical interpretation. Effort is being aimed at further definition of these problems and their subsequent solution.

(2) CEND 3336-229, Burdick, C. E., J. R. Parrette, R. I. Brockett, and W. P. Chernock, "Development and Testing of a Temperature Transient Method for Performing In-Pile Thermal Conductance Testing".

V. FUTURE WORK

During the next period the Z-2 element will be removed from the test apparatus and evaluated. The ZrO_2 -10 wt% CaO pellets will be removed from the element and a correlation will be made, if possible, between the location of any cracked pellets in the element and the phase shift results along the axis of the element. Individual pellets from the thermocouple locations will be removed for density and metallographic determinations. This evaluation should determine whether the phase shift values can be attributed to the individual pellets or whether it is due to the system.

A second element fabricated from high density UO_2 (92-93% of theoretical) will be fabricated and tested. It is expected that with the higher density pellets the anomalous behavior of the Z-2 element will be overcome. However, if the UO_2 element shows the same behavior as Z-2 and if local phase shift variations cannot be correlated with pellet crack patterns or other local inhomogeneities, the efficacy of the method will be in sufficient question to warrant consideration of program termination.

If the UO_2 element behaves satisfactorily, a high density ZrO_2 -10 wt% CaO element will be tested to determine if the phase shift anomaly is associated with the ZrO_2 -10 wt% CaO composition. If both the high density UO_2 and ZrO_2 -10 wt% CaO elements verify the predicted computer results, it is proposed that an in-pile effort be undertaken.

A meeting will be held at the Commission on or about the 15th of November to present the results of this study and to make recommendation whether to terminate the program or undertake in-pile studies.

APPENDIX

TEST ELEMENT DATA

All elements have a cladding of 304 stainless steel tubing, nominal 1.27 cm (.500 in.) outside diameter, .051 cm (.020 in.) wall, and 21.6 cm (8.50 in.) long. The inside diameter of each piece was measured; the range of inside diameters for all cladding used so far on this program is from 1.175 cm (.4627 in.) to 1.176 cm (.4630 in.).

The axial heater is tungsten-26% rhenium rod, with a diameter of .238 cm. $\pm$.0002 cm. (.090 in. $\pm$.0001 in.). The rod is full diameter for 21.6 cm (8.5 in.) the effective length of the test specimen; an additional 1.27 cm (.5 in.) at each end is reduced to .190 cm (.075 in.) for clamping in the power terminals. The inside diameter of all test sample pellets is a snug slip fit on the heater estimated to be about .0013 cm (.0005 in.) loose.

Cladding thermocouples are 36 gage, .013 cm (.005 in.) diameter, chromel-alumel wire with Type K calibration. They are individually insulated with "Teflon" * TFE-fluorocarbon resin, and spotwelded directly to the cladding along a single longitudinal line. Their five axial positions are 3.8 cm (1.5 in.) left and right of the center, and 6.3 cm (2.5 in.) left and right of center. Position nomenclature is No. 1 through No. 5, from left to right.

*DuPont registered trademark