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Westinghouse Astronuclear Laboratory

TRANSACTIONS

HELD NOVEMBER 16, 17, 1965 AT WESTINGHOUSE ASTRONUCLEAR LABORATORY

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Westinghouse Astronuclear Laboratory

TRANSACTIONS
OF THE
Non Destructive Testing
SYMPOSIUM

HELD NOVEMBER 16, 17, 1965 AT WESTINGHOUSE ASTRONUCLEAR LABORATORY

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PART 1

WELCOME

N. A. Pollack

I'd like to welcome you gentlemen to Pittsburgh. As you know, this is the second session on non-destructive testing of NERVA and ROVER fuel elements; and the presentations will be made in that vein. We shall present our NDT organization here at Westinghouse and how we operate with Reactor Analysis and Reactor Design personnel; what our requirements are; and how we go about supplying the information. In addition, our statistician will make a presentation on the Application of Non-Destructive Testing.

I sincerely hope this session -- the second of its kind -- will be of interest and will motivate future meetings of this nature. It should also motivate people working together on a day-to-day basis relative to their particular installation and the other two activities. We plan a tour at Cheswick on Thursday. Those of you who are interested in making a tour of our activity here at Large will be pleased to know we plan to do this tomorrow afternoon. We anticipate the session will adjourn at approximately 3:00 P.M.; thus permitting sufficient time for a tour of the Large Site.

Gentlemen, that concludes my opening remarks. I'd like to present Mr. D'Amore, who will chair the meeting for the next two days.

PART 2

APPLICATION OF NON DESTRUCTIVE TESTING TO NERVA FUEL ELEMENTS

W. H. Horton

M. D'Amore, WANL: Thank you, Nick. Most of the Westinghouse presentations are of about 15 minute duration. We've scheduled half an hour for each presentation to permit a short general discussion period to follow each presentation. We're going to have difficulty in adhering to the schedule, and during the course of the meeting, I may cut off some of the discussion. In that case, those of you who have questions that are unanswered may see the speaker this evening at the meal. If you don't have that opportunity, give us the question in writing and we'll see that you get an answer to it. First on our agenda is Bill Horton who will present "Application of Non-Destructive Testing to NERVA Fuel Elements". This will be the Westinghouse keynote address. Bill is a statistician reporting to our Reliability Section. He has been assisting the Astrofuel Quality Engineering Activity on experiment planning and statistical evaluation of the non-destructive test data for approximately 6 to 8 months. He is now located at Astrofuel on a temporary assignment of several months duration to permit an expansion of our statistical evaluations.

Classically, non-destructive testing refers to the techniques developed as a replacement for methods of testing which lead to the loss of the product being evaluated, or destructive testing. Practically, any test in which the product being evaluated is not affected by the test itself can be considered as falling in the non-destructive testing area, e.g.: dimensional and weight measurements, visual inspections, and "go - no go" gauging. However, none of these conform to the classical definition nor do these conform to the later definition of non-destructive testing as that area in which the test method involves the application of a test medium to the object being evaluated, the modification of the test medium in some manner by flaws or material variations, and a mean for detection of these changes.

In the evolution of non-destructive testing, a field some 25 years young, the early applications were primarily for detecting discontinuities or defects in materials. As a result, the early methods were fairly simple and, though limited in their use, were quite effective. As examples, the use of dye penetrants and penetrating oils which reflected defects in the surfaces of castings required no unusual equipment or unusual interpretation. However, these tests were restricted to the evaluation of surface discontinuities only. With the need for evaluating possible internal defects came the need for more complex equipment and, as a consequence, greater difficulty as to the interpretation of the resulting data. In almost all cases, these tests were performed for quality control evaluation or to satisfy inspection requirements. In addition, the data generated were to be as good as, or better than, existing destructive analyses that could be made.

Today, non-destructive testing makes use of even more complex equipment, more complex because of the test mediums being applied and more complex because of the automated features that have been incorporated to remove the human element from the data generation. The progress made is truly significant and, as may be surmised, the emphasis no longer is on replacement (in fact, some tests have no destructive counterparts). In spite of the application of sophisticated test mediums and the incorporation of automated data generation, two factors still detract from the general acceptance of non-destructive testing:

- 1) Non-destructive testing has been used primarily for inspection purposes or, at best, for quality control evaluation, and
- 2) Requirements imposed on non-destructive tests have been more stringent, for the most part, than those for destructive counterparts.

The non-destructive testing of NERVA and ROVER fuel elements seems to follow the experiences encountered in the field of non-destructive testing in general. In particular, the history of non-destructive testing of NERVA fuel elements at Westinghouse can serve

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as an example. Eddy current and gamma scan test data have been obtained on almost all fuel elements produced at the Astrofuel Facility. These tests were to evaluate the structural integrity and uranium loading of the fuel element respectively and, as such, were replacement tests for destructive analyses by metallography and chemistry. Some beta backscatter data as a replacement for niobium carbide thickness per metallography was obtained on NRX-A2 candidate fuel elements. For NRX-A3 candidate fuel elements, the use of beta backscatter test data completely replaced the acceptance of fuel elements per metallographic examination. As may be noted, all three of these non-destructive tests serve as replacements for destructive tests and fortunately so, considering the cost of a single element. In addition, all three use rather sophisticated test mediums with the resulting data being a function of the changes introduced in the test medium by the variations existing in the fuel element.

Prior to NRX-A4 candidate fuel elements, those beta backscatter data obtained were derived from a manually-operated equipment set-up. For NRX-A4 elements, automated beta backscatter equipment similar to that designed by the Oak Ridge Laboratory, Section Y-12, was installed and made operational. While termed automated, this equipment is really semi-automated with the automated portion primarily associated with the traverse of the beta probe and the recording of the count data by means of an IBM card punch. Eddy current tests on fuel elements are similarly semi-automated while gamma scan tests remain manual. If these tests are to parallel the developments made in the field of non-destructive testing, beta probe and eddy current tests will become more fully automated and gamma scan tests will make the transition from a manual to a semi-automated to a fully automated equipment set-up.

Again following the evolution of non-destructive testing, the non-destructive tests made on NERVA fuel elements have been for satisfying inspection requirements, with the acceptance or rejection of the fuel element being that of greatest interest. There is no doubt that this will continue to be the case however, as more and more information is generated, more and

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more emphasis is being placed on the use of this data for other purposes. In essence, the acceptance of these data for other than inspection requirements is gradually taking place and already there are indications that, perhaps, the requirements "wished for" with respect to these data are more exacting than those needed for quality certification.

To continue the review of non-destructive testing of NERVA and ROVER fuel elements, highly significant accomplishments have been made at Westinghouse and its counterparts at Oak Ridge and Los Alamos. Some of these are apparent in the minutes of the symposium held at Los Alamos in April. Other accomplishments will be discussed in this second symposium. All participants seem to have common goals with an exchange of information relative to progress as well as to problem areas readily taking place. In addition to these symposia, fuel elements and data taken on these elements at all three locations have been exchanged. The status of this program will be presented later in this symposium. Briefly, this status will indicate that there are areas requiring some resolution to the disagreements found among the data, areas in which the agreement among participants is excellent, and plans for continuing such an exchange so as to take advantage of all the "know-how" of all concerned. One general statement should be made at this point. The non-destructive testing techniques associated with eddy current, gamma scan, and beta probe evaluations are well established and well proven at all three locations. The interest is now being centered in subtle refinements to the collection of data and additional use of the data being generated.

Returning to the non-destructive testing of NERVA fuel elements at Westinghouse, and perhaps this is typical of the other two locations, the amount of data being generated is voluminous. To process this information as needed has required the installation of a rather complex, completely integrated, data retrieval system. This system will be discussed in some detail in a later presentation. As will be noted in this presentation all inspection plus some process control data is treated by this system. Indications are that this system will continue to grow and naturally become more vital to the evaluation of fuel elements.

In the next two presentations information contained in the data system will be shown to be of primary interest. Astrofuel's Process Engineering is continuing to make more and better use of all inspection data. As discussed in that presentation, its needs center around rapid turnaround in so far as the processing of the data is concerned. In addition, if inspection data could be logically created at other stages in the fuel element process, then even more extensive process control measures could be enforced.

Astronuclear's Reactor Analysis well defines its needs and indicates that these are:

1) byproducts of the data system to serve as inputs to the nuclear calculations made for each reactor, and 2) data essentially as definitive as possible for pre-test design and post-test evaluation.

As stated earlier, general acceptance of non-destructive testing seems to be affected by the stringent requirements placed upon this field. A critical examination of the data resulting from eddy current testing leaves little to be desired in so far as accuracy and precision are concerned. (Accuracy is defined as the degree of agreement between the measured value and the "true" value, and precision is defined as the degree of agreement among repeated measurements for the same "true" value.) Most of the problems associated with the eddy current test are found in the interpretation of the data obtained. If anything, the eddy current test may be too sensitive; thus, data interpretation becomes cloudy since the destructive counterpart is not easily visualized.

Data resulting from the beta probe also is well defined. First, the precision of this equipment is certainly equal and probably better than its metallographic counterpart. If greater precision were required, this could be easily accomplished by several means, e.g., more data per element, longer counting periods, better calibration data, and smaller counting intervals. Second, the accuracy of the beta backscatter data is that of its metallographic counterpart in that indicated thicknesses per beta determinations are adjusted by an empirical relationship to yield directly comparable thicknesses.

Gamma scan data are those that suffer most when compared to the destructive data. First, these non-destructive data are more critically reviewed and evaluated than most of the measurements taken on a fuel element. Second, the agreement between destructive and non-destructive data is not well founded. In general, the precision of most chemical analyses is very good but not as good as the chemist is prone to quote and certainly not as good as most engineers and scientists seem to think. As with the beta probe test, the precision of the gamma scan can be as good as desired, though perhaps somewhat costly from the standpoint of time required for a set of measurements. Of greater significance to the user of the gamma scan data is the accuracy of the reported loadings. Up to the present, standards for which chemical analyses have been obtained have been accepted as having very small inaccuracies or biases. Some of the data given in a later presentation seem to indicate that this may not be the situation at all. In addition, data from two different programs associated with uranium loading values (analyses from these data will be available in the near future) also point to the presence of rather serious biases in data of this type. Certainly, continuing effort will be spent on the gamma scan equipment, first to automate this equipment which should improve its precision and second to obtain better correlation between gamma scan and chemistry.

In summary, non-destructive testing of NERVA and ROVER fuel elements parallels the developments found in the field of non-destructive testing in general with the accomplishments in the fuel element tests quite remarkable when the time element is considered. At Westinghouse, eddy current, beta probe, and gamma scan test data have proven very effective as inspection and quality control reference data. Additional use of these data and additional refinements to the equipment and data generation have been implied in the use of these data by Astrofuel Process Engineering and Astronuclear Reactor Analysis. Their requirements also imply more extensive and critical use of the rather complex data retrieval system. Finally, these interests, as well as the interests of all participants in this symposium, can only serve to stimulate the growth of non-destructive testing of fuel elements and to maintain the dynamic characteristics seen in the past.

PART 3

UTILIZATION OF NDT RESULTS

BY REACTOR ANALYSIS

R. A. Doncals

M. D'Amore, WANL: The objective of this session of non-destructive testing is to review the application of NDT data. The first symposium held at Los Alamos in early April of this year, had as its primary objective the establishment of better communications between the three activities involved in non-destructive testing, Y-12, Los Alamos and Westinghouse. The second objective of that conference was to discuss the techniques, the equipment and the philosophies involved between the three organizations in order to establish a uniform report. During the period since the first non-destructive test symposium, Westinghouse installed the automatic equipment that was produced for us by Y-12 and has generated a wealth of production data from that equipment. The turn around time for quality information feedback, particularly to Process Engineering, has been significantly better, primarily because of the automation. We can turn out more results faster and of higher quality. We find that there are three principal users of the non-destructive test information that we generate. Process Engineering uses them to control the process. Reactor Analysis uses our results for their core predictions and, of course, we use our results ourselves. One of our primary uses of the non-destructive information and the need for rapid turnaround of this information in our own activity is for control of the automated equipment. The other principal use within the Quality Control activity is for the release and certification of an element to design and specification requirements. We've asked Reactor Analysis to give a short discussion of their use of our data and their needs for the precision and accuracies required for prediction of the parameters involved in the NERVA reactor system. Richard Doncals of our Reactor Analysis section is the next speaker on the agenda. His presentation will be "Utilization of NDT Results by Reactor Analysis".

The subject of my talk will be the utilization of non-destructive fuel element data by Reactor Analysis. Described will be the method by which non-destructive data is transmitted

FLOW CHART FOR DATA TRANSMISSION

Slide 3-1

to Reactor Analysis, its use in pre-test predictions, the effects of errors in non-destructive testing on the performance of the reactor, and a comparison of the analytical predictions with post-operative measurements.

Slide 3-1 shows the flow chart for data transmission from the fuel element supplier to the Nuclear and Thermal Design groups of Reactor Analysis. Two sets of IBM data cards and a printed data package which contains the complete inspection data on each fuel element either accompany or precede delivery of the fuel element to WANL. Reactor Analysis uses the data package only when an Engineering Review Board action is required, such as when element weights or dimensions exceed specifications.

The set of IBM cards transmitted to the Nuclear Design Group contains the element serial numbers, weights, and niobium profiles. These element cards are used in the Automated Materials Data System Program (AMDS) which tabulates the core composition weights by loading code and manufacturer and also estimates the excess reactivity of the reactor.

The core weights calculated in the AMDS program, in conjunction with lateral support and reflector weights, are used to derive atom densities for the various reactor regions. These atom densities are used in two-dimensional nuclear codes to determine approximately 30,000 coolant channel power factors. A channel power factor is defined as the ratio of the power produced in an individual coolant channel relative to the average power produced in all the coolant channels. The Core Thermal Design Group uses these channel power factors together with a second set of data cards which contains the element serial number, uranium weights, and air impedance to determine the proper element placement in the core and the orifice sizes which should be used in the individual coolant channels. The temperatures of the core material and the propellant are then predicted from this orificed flow distribution.

The reactivity of a NERVA reactor is based on the measured critical drum position and material inventory of a previous reactor. Slide 3-2 develops the mass and reactivity differences

NRX-A3 AND NRX-A2 MASS AND REACTIVITY COMPARISON

Material	NRX-A3 Mass, kg	NRX-A2 Mass, kg	Mass Difference, kg.	Reactivity Coefficient, ρ /kg	Reactivity Change, ρ
Fuel					
Carbon	859.9	855.5	4.4	5.6	24.6
Uranium	172.2	173.6	1.4	13.3	18.6
Niobium	72.5	72.9	-0.4	-5.5	2.2
Sub Total					45.4
Non-Fuel					42.6
TOTAL					88.0

Slide 3-2

MASS AND REACTIVITY EFFECTS OF ERRORS IN NON-DESTRUCTIVE
FUEL TESTING

TYPE OF ERROR	Reported Code 9 Final Element Loading, gm			Error in Calculated Reactivity, cents			TOTAL REACTIVITY Error, Cents	
							Individual Reactor	Maximum Diff. Between Reactors
	<u>U</u>	<u>Nb</u>	<u>C</u>	<u>U</u>	<u>Nb</u>	<u>C</u>		
1. Actual final loading	123	41	529	0	0	0	0	0
2. Final γ scan $\pm 1\%$	124	40	529	± 27	± 10	0	± 37	± 74
3. Pre-coat γ scan $\pm 1\%$	123	42	528	0	-10	-10	± 20	± 40
4. Both γ scans $\pm 1\%$	124	41	528	± 27	0	-10	± 17	± 34
$U = (U_{\text{final } \gamma})^{\text{apparent}} \times (K_{\text{factor correction}})$								
$N_b = (Wt)_{\text{final}} - (Wt)_{\text{as-leached}} + (U_{\text{as-leached } \gamma} - U_{\text{final } \gamma})$								
$C = (Wt)_{\text{final}} - U - Nb$								

Slide 3-3

between the NRX-A3 and NRX-A2 reactors. The masses of carbon, uranium, and niobium in each fuel element determined by non-destructive testing are summed to determine the complete core inventory in each reactor. Since the bore niobium is not uniformly distributed axially, the niobium profile reported by beta backscatter is used to determine for each fuel element an axially uniform mass of niobium which is equivalent in reactivity. This effective niobium mass is then used in the reactivity calculations.

The reactivity difference between the NRX-A3 and NRX-A2 reactors is taken to be the product of the mass differences of each chemical element and an experimentally determined coefficient which is the change in reactivity per unit mass. It is of interest to note that approximately half of the reactivity change between the NRX-A3 and NRX-A2 reactors is based on non-destructive fuel element data.

After the total reactivity difference between NRX-A3 and NRX-A2 reactors was determined, it was converted into an equivalent amount of control drum motion. This drum motion, coupled with the measured critical drum position of the NRX-A2 reactor, determined the predicted critical drum position of the NRX-A3 reactor. This predicted critical drum position was adjusted, or shimmed, by the addition to the reactor of a prescribed number of tantalum carbide unfueled elements.

Because of the large number of elements involved, the reactivity comparison is not affected by individual random errors, but only by an overall bias. Slide 3-3 shows three possible errors in the non-destructive data and their corresponding effect on core reactivity. Since the reported mass of uranium, carbon, and niobium all depend directly upon the final and as-leached gamma scans, and upon the element weight change during niobium coating, errors in these must be treated collectively.

Slide 3-4

The first line of slide 3-3 shows the actual content of a tabulated code 9 element. The succeeding lines show errors in reactivity resulting from possible errors in the final gamma scans, the precoat gamma scan and for the combination of the two scans for all the Code 9 elements in the reactor. The reported Code 9 final element loadings are shown only for a positive one percent error in the gamma scans. The error in calculated reactivity will either be plus or minus depending on the sign of the error in the gamma scan measurement. Since the reactivity comparison is based on a difference in core inventories of two reactors, it is possible to have a maximum error of twice that of an individual reactor.

The effects of ambient reactivity errors will now be related to the performance of the reactor. The NRX-A4 orifice angle is the drum angle for which the corresponding power distribution is assumed in orificing propellant flow, was chosen to be 115 degrees. The factors which influenced this selection were the cold-to-hot reactivity swing, drum runout during operation, safeguards implications and thermal considerations. Slide 3-4 shows the effect of the start of life, orificed, and end of life control drum angles on the radial maximum fuel element temperature. The relative position of the orifice angle during the predicted drum rollout was defined by setting the increase in temperature at the core center at start of life equal to that at the periphery for end of life. Based on this criterion the expected maximum fuel temperature rise above the orificed condition is only 60 degrees R. Any deviations in the predicted cold critical drum angle will displace the start of life and end of life drum angles from their predicted positions. The severity of this change will depend on any additional corrosion that may result due to the higher operating temperatures.

To expedite the NERVA test schedule it has been the practice to assemble, shim, and ship the reactor to the test site without performing a critical experiment at WANL. Therefore, if the cold critical drum position obtained at the Nevada Site is not compatible with the test, the reactor must be shipped back to WANL, disassembled, and reshimmed. This

CRITICAL ANGLE PREDICTION EXPERIENCE TO DATE

REACTOR	PREDICTED CRITICAL DRUM ANGLE	MEASURED CRITICAL DRUM ANGLE	DRUM ANGLE ERROR	REACTIVITY ERROR
NRX-A2	91.6°	97°	5.4°	41%
NRX-A3	92.6°	89.1°	3.3°	25%

Slide 3-5

would cause several months delay in the test schedule. It is therefore imperative that no serious bias be developed in the core weights determined by non-destructive testing.

Slide 3-5 shows the critical angle prediction experience to date for the NRX-A2 and NRX-A3 reactors. The difference in the predicted and measured critical angles was only 5.4 degrees and 3.3 degrees for the NRX-A2 and NRX-A3 reactors, respectively. The corresponding reactivity errors were 41 and 25 cents. This comparison implies that on a core-to-core basis the effects of the non-destructive errors have been small.

One of the objectives of Reactor Analysis is the development of the technology required to predict the power distribution in the flight engine to a high degree of precision. This is essentially an iterative process, involving the application of increasingly refined methods to successive NERVA reactors and carefully analyzing the results to continuously reduce the error in predictions. The need for extreme accuracy is inherent in the high performance of a nuclear rocket. In order to achieve high specific impulse, the hydrogen propellant leaving each fuel channel must be uniformly heated to the highest temperature compatible with the properties of the fuel. In the NERVA I reactor the exit gas temperature is about 4100 degrees R. At the same time, the power density in the fuel is unprecedentedly high, producing over 1120 MW in the relatively small core. It will be shown in the subsequent discussion that random errors in the non-destructive fuel element data directly effect this aspect of the reactor design.

Slide 3-6, which shows the calculated radial variation in the fission rate per unit mass of uranium-235 in the NERVA reactor, can be used as a basis for understanding the problem of accurately predicting and flattening the power in the NERVA reactor. The gross ion measurements shown on this slide will be discussed later. For about 70 percent of the distance from the centerline to the core edge, the fission rate follows a normal mode which arises primarily from epithermal fissions. Near the core edge, however, thermal neutrons returning

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COMPARISON OF THE NRX-A3 MEASURED AND PREDICTED POWER DISTRIBUTIONS THROUGH TRAVERSE 008 TO J8D, FISSIONS PER GRAM

Slide 3-6

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3-10

from the reflector produce the severe spiking shown. In a uniformly loaded core, the power would follow this shape and consequently the power density at the core edge, would be approximately 2-1/2 times that at the centerline of the reactor. In order to avoid the extremely high pressure drop across the core that would be required to cool the edge elements, the uranium loading per element is gradually reduced toward the edge of the core. Because it is impractical to provide an effectively continuous fuel distribution, propellant flow orificing is also employed to flatten the radial temperature distribution.

Based on similar calculated fission distributions and nominal fuel element loadings, power factors for different control drum positions are generated for each coolant channel in the reactor. Slide 3-7 shows a radial plot of these channel power factors for the 90 degree drum position. The discontinuities in the power distribution are the result of the different uranium loadings in the reactor.

Slide 3-8 shows the method by which these nominal power factors are adjusted by non-destructive data to give those used in orificing. The actual to nominal uranium ratio corrects the power factors for the measured uranium in an individual element; this correction is directly influenced by the random errors in the non-destructive uranium weights. The nominal to as-built core uranium mass ratio is necessary to insure that the average channel power factor in the core remains very close to unity. This correction, based on extrapolating to the total core uranium inventory, is necessary since orificing is started prior to release of all the fuel elements.

An orifice jet is selected for each channel on the basis of these channel power factors and the measured flow impedance of the channel to achieve a uniform core exit gas temperature. The core pressure drop is determined by the channel which, because of its power factor and measured channel diameter, presents the largest flow impedance.

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Slide 3-7

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USE OF NON-DESTRUCTIVE FUEL TESTING DATA IN GENERATING CHANNEL POWER FACTORS

$$\begin{array}{l} \text{POWER FACTOR USED IN} \\ \text{ORIFICING FLOW CHANNEL} \end{array} = \begin{array}{l} \text{POWER FACTOR BASED ON} \\ \text{NOMINAL URANIUM LOADING} \end{array} \times \frac{(\text{ACTUAL ELEMENT URANIUM LOADING})}{(\text{NOMINAL ELEMENT URANIUM LOADING})} \times \frac{(\text{NOMINAL CORE URANIUM MASS})}{(\text{AS-BUILT CORE URANIUM MASS})}$$

Slide 3-8

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COMPARISON OF THE MEASURED AND THE PREDICTED RADIAL
TEMPERATURE DISTRIBUTIONS

Slide 3-9

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The following summarizes our experience to date in predicting the power and temperature distributions in the NERVA reactor. Slide 3-6 shows a comparison of the measured and predicted radial power distributions for the NRX-A3 hot test. The gross ion measurements are a measure of the total activity of the fission products in a fuel element. This activity is related to the total power generated in the element during the entire test. The calculated fission distribution is based on a control drum angle which is obtained by power weighting the drum angle over the entire test. This comparison indicates that the maximum error in the central core region due errors in both the analytical method, and the non-destructive uranium estimate is at most only 2 to 3 percent. The larger peripheral error is primarily due to the analytical method used in predicting the power distribution.

Slide 3-9 shows a comparison of the measured and predicted radial temperature distributions for the NRX-A3 hot test. Shown are the start and end-of-life predictions and the thermal capsule measurements. These measurements represent the highest temperatures reached at a particular core location during the test. All except one measurement fell within a two standard deviation of plus or minus 173 degrees which encompassed both the start and end of life predictions.

These power and temperature comparisons, in addition to our critical angle prediction experience to date, indicate that the errors in the pre-test predictions are small due to the use of non-destructive fuel element data.

DISCUSSION

W. Scheib, SNPO-W: One of the things that you had mentioned was that the drum angle is also affected by the amount of boron you have in the plates. Does this challenge the non-destructive testing or is this well in hand?

R. A. Doncals, WANL: Well, in our calculations, we actually know the boron content of the boron plates so that when we calculate our power distribution, we do know what the manufacturer is supplying with in a given tolerance. We do this by chopping off samples and by chemical analysis.

N. A. Pollack, WANL: Walt, actually the boron plates are not even received into the assembly area without a certification by chemical certification.

W. Scheib, SNPO-W: On your NRX-A2 and NRX-A3 predicted versus actual errors, you had a 5.4 for NRX-A2 and 3.3 for NRX-A3. Was there any particular area in which that improvement took place?

R. A. Doncals, WANL: No, we used the same method and the same approach to predict in both reactors.

N. Thielke, SNPO-C: On the same subject, one error appeared to be positive, the other negative.

R. A. Doncals, WANL: I also looked at that before the meeting and we're anxiously awaiting to see what NRX-A4 will show to see if this is the randomness of our error or what.

E. Price, Y-12: On one slide, you gave the relative reactivity for carbon, uranium and niobium or equivalent reactivity I should call it. The niobium measurement in thickness is still a way you want this measured?

R. A. Doncals, WANL: I didn't go into detail on how we used the beta backscatter information. We only use the physical weight or the weight gain which is measured. In other words, as you code the probe channel, we know the weight gain and calculate the niobium mass. The profile that we obtain we effectively $\sin^2$ weight this. That's all we do with this

profile. This gives us an effective factor that we can multiply times the physical mass to get a mass that can be used in the reactivity calculations. If the mass of this uranium were either a straight linear function or even flat along the channels, we wouldn't have to go through this extra process of sine² weighting it. But it's just a means that we use to get an effective mass of niobium so we do like to see the physical thickness of it. In other words, we just used the thicknesses as a means of obtaining a weighting function, that we multiply times the true mass.

E. Price, Y-12: Would the difference between the physical thickness and the mass per unit area not cause errors in your calculations?

R. A. Doncals, WANL: No, because I believe they're used separately by us.

I don't care if the distribution is normalized to the real mass. In other words, all I need is a relative distribution. It can be up or down. Sometimes in our calculations we'll take their true mass and assume some kind of a density form, as you're pointing out, and normalize a shape to it. But in our reactivity calculations we don't do that. So we just use these two things separately, the mass separately and also, the profile separately.

B. Blanks, Los Alamos: I noticed in your purposes of the load measurement, you didn't mention your use of uranium loading in the reflector.

R. A. Doncals, WANL: You mean in the life of the reactor?

B. Blanks, Los Alamos: Well, in the post mortem examination of an element, how do you determine uranium chemistry?

R. A. Doncals, WANL: We do not use that in our comparison. We use the values that were determined previously in non-destructive data. In other words, at the test site they take the element for us and put them in a gross ion chamber and measure the activity and get a term which is representative of the total fissions which actually occurred in that element. They then divide this by the non-destructive element weight to get a fission per gram distribution. We don't use a radiochemistry value. They also perform radiochemistry on selected numbers to show if there were any bias in the distributions. Now, to date, we have not seen

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any bias.

N. Pollack, WANL: Bruce, are you concerned about total reactivity loss during any run on a reactor?

B. Blanks, Los Alamos: Yes, we are.

N. Pollack, WANL: Aren't you rather more interested in corrosion than in reactivity loss?

B. Blanks, Los Alamos: We're also worried about the uranium part of the total loss.

R. A. Doncals, WANL: Our present estimates of corrosion loss, I believe, are assuming there's very little uranium loss. This is being investigated and I'm not up to date on whether there's any thing that has taken place on it. There are three or four people back in the group who are trying to predict the corrosion loss or the drum run out during the NRX-A4 run.

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PART 4

UTILIZATION OF NDT RESULTS

BY PROCESS ENGINEERING

R. R. Cost

M. D'Amore, WANL: The next presentation is by Ron Cost, who is supervisor of the Process Engineering Group at the Astrofuel Facility. During the last 6 to 8 months, the Quality Control activity at Astrofuel has instituted a number of techniques for rapid feeding of quality data to Ron Cost's group. Now, from Ron's standpoint, anything that doesn't destroy the element is a non-destructive test measurement. We have had a small computer, which was installed this summer, converting our quality information from the shop on a daily basis and have been feeding this information to Ron's people so that immediate corrective actions can be taken on discrepancies. Ron has instituted organizational and operating procedures in his own activity to ensure that very rapid corrective action is taken once a difficulty is determined. We've asked him to give a discussion of the data that he requires and the use of the data for process control. I'm certain that in the next several months the techniques that have been established between Quality Control and Process Engineering will be amplified at the Astrofuel Facility. There are certain ideas in the developmental stage to determine deficiencies in an element at an earlier stage in the processing and Ron will point these out.

Let us assume that one sets a goal which dictates that he will make the best possible fuel element in the shortest possible time for the fewest number of dollars, and further let us assume that he convinces himself and others that this goal is attainable. Having done this, he forever after commits himself to the requirements of a feed-back of performance measurements on a timely basis. In this respect, the process which makes a NERVA fuel element is no different from a process which makes basic steel, light bulbs, or automobile tires. Unlike these other processes however, the fuel element process suffers from a lack

of the experience factors which only come with time. It is these factors which give the process engineer the insight or foresight as to what characteristics should be measured and at what point in the process life of the product to insure maximum yields.

Obviously, the earlier the product can be measured, the more rapidly processing parameters can be adjusted to compensate for that portion of the process which is creating an unacceptable product characteristic and to this end, we are constantly striving to understand process and material variations and their effect on the final product. NDT data is helping in this area.

Perhaps a clarification of what process engineering defines as non-destructive data should be made. We accept any measurement which literally does not destroy the element. These include the run of the mill first piece inspection which qualifies a particular machining set-up to the more sophisticated output from eddy current, beta backscatter, and gamma count.

Non-destructive data feed back falls into two rather definable categories. These are:

- 1) That data which is generated and made available for interpretation within 24 hours of the time when the characteristic being measured was generated.
- 2) That data which is generated sufficiently far down the line that rapid adjustments in the process cannot be made.

Let me give you some examples of the kind of data currently being used.

1) Batch Formulation

As you know, Westinghouse Astrofuel Facility calculates each batch of fuel mix based on the fuel bead chemistry, density, desired loading, coking value of binder, and a carbon density factor based on unfueled material. In the calculation of the batch, these material characteristics are used for calculating the anticipated composite density of the as-graphitized

element. This number appears on the batch formulation run-off and is used as check on the measured as-graphitized composite density. Agreement between calculated and measured densities is a check on the thermal history of the process through graphitizing.

2) Gamma Count (As-Machined)

A ten percent sample of all as-machined elements are gamma counted for uranium loading. These data serve as a check on accuracy of the batching operations which utilized the batch formulation just discussed. In addition, these data serve as a base line of comparison which when compared to as-leached gamma count indicate the performance of the leaching cycle. These data compliment weight change information and furnace run log reviews made by the process engineer.

3) Dimensional Data

Dimensional data feedback is probably the most straight forward form of characteristic measurement and reporting used by the engineer and certainly gives a quick indication of obvious deficiencies in the machining operation. These data are used in a before the fact manner for qualification of a particular machine set up as determined by first piece inspection. In addition, these data provide an after the fact measurement of extrusion tooling by hole location measurement and coating furnace performance as measured by air impedance. Microderm measurements are presently being used to obtain peripheral coating profile information which the engineer uses as a guide in designing furnace parts, coating fixture parts and run parameters.

4) Eddy Current

Eddy current data is fed back to the engineer as it is generated. This data is a prime example of the information which becomes available for interpretation so far down the process line that process modifications cannot be made quickly enough to prevent a large scale rejection rate. It is our belief that structural flaws such as longitudinal and transverse cracks are attributable to the extrusion operation. The nature of the process is such that a three to four week time difference exists from extrusion to the time when the element

is measureable for eddy current quality. At an extrusion rate of 300 elements per week, subtle changes in extrusion tooling, material behavior, or technician performance could generate high reject rates. The obvious answer would be to perform an eddy current inspection on the as-cured element. The solution to this, however, is not as obvious.

The eddy current data feedback is currently used as a diagnostic tool. Eddy current results are reviewed by the engineer and correlated to mixing, extrusion, cure, bake, and graphitizing operation log sheets for indications of causes for eddy current rejections.

Just recently we entered a period where unusually high hash levels were observed in the No. 10 channel. As data was accumulated, it appeared that elements from two consecutive 90-element extrusion days were involved. The data indicated that elements extruded before and after these 180 elements were not affected. A review of all available processing data from dry carbon ingredient preparation through machining failed to identify the cause. In this particular case, although the 180 elements were not rejectable, the fact remained that they were indeed different and this in itself may imply that perhaps we are not measuring and recording the right kind of in-process data.

5) Beta Backscatter

Beta backscatter coating profile measurements on fuel elements and support blocks are fed back to process engineering and used in conjunction with parametric reviews of the furnace run to make corrections or adjustments. Particularly in the two-step element coating process, beta backscatter data on bore coated elements is used along with the parametric review to release the bore coat batch to back coating.

Once again in a recent run, an element was detected by beta backscatter as having an unusual coating profile in one channel. The problem was diagnosed as a channel blockage due to a chip which resulted from coating spalling off the coating fixturing. This pointed to a need for more critical examination of fixture parts prior to assembly and insertion of the loaded fixture into the furnace.

6) Visual Inspection at Fixture Unload

Probably the greatest single cause for rejection in the whole process is the coating chip. Considerable effort is currently aimed at identification and removal of causes of chipping. This is being accomplished by visual examination and recording of the condition of the coated external areas. These data have been recorded and are being used to identify problems in coating fixture design, machine shop fixturing, and material handling problem areas.

In summary, these problem areas in the process can and are being defined as our experience broadens. Non-destructive test data is being fed back to engineering and being used to augment process data which is reviewed and used for process adjustments and corrections. At the outset of the NRX-A5 manufacturing run Process Engineering began plotting daily measurements in an attempt to develop control chart type data which is constantly reviewed to identify the start of unfavorable trends. Not enough information is available at this time to assess the value of these charts. As of now, we recognize that some areas of the process can be controlled by data collection and evaluation, but there still exists those areas where the cause of a defect is too far ahead of the device for measuring its presence. More work is required in developing processing parameters, identifying characteristics which when measured afford process control, and certainly the techniques for measuring, reporting, and interpreting these data.

DISCUSSION

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B. Blanks, Los Alamos: You mentioned the term Microderm measurements on the machined elements. What is this?

R. Cost, WANL: Microderm is an instrument we are using to measure coating thickness.

B. Blanks, Los Alamos: Oh, I misunderstood you. You mean it measures NbC thickness?

R. Cost, WANL: The term Microderm is a commercial tradename.

B. Blanks, Los Alamos: You use the term backcoated for external surface?

R. Cost, WANL: Well, we have the borecoat and the backcoat, and peripheral coating. The peripheral coat is just a longer backcoat. When we talk about the bore coating we talk about 52 inch lengths. We talk about borecoated elements and during the bore coating, we get a certain amount of backcoating. We now have requirements that come back approximately 2 1/2 inches for backcoating.

B. Blanks, Los Alamos: What about the peripheral coating?

R. Cost, WANL: Well, really the peripheral coat is really a misnomer. It's the peripheral element that's coated.

M. D'Amore, WANL: Bruce, we have under construction at the Westinghouse Central Research Laboratories two units of automated beta backscatter equipment for measurement of the external coating. In the interim period, we've adapted a commercial Microderm device to give us measurements on the minimum coating thickness. Actually, it's doing a little better than that. It's reasonably accurate up to about one mil of niobium carbide. Ron is using that information for adjustment of his fixturing in controlling the minimum thickness in the coating distribution along the external surface of our elements.

N. Thielke, SNPO-C: Ron, by extension of your remarks relative to the desirability of eddy current check in the as-cured condition, I wonder whether you're ready to specify the various stages in fabrication at which you'd like some new NDT techniques to be applied.

R. Cost, WANL: We tried awhile back, Norm. We began measurements on as-cured and as-graphitized elements. We had one heck of a time getting anything, meaning fuel, until we got to graphitizing. When we got to graphitizing, we found that there was something a little different about the character of the bore. I think we can now take a look at the process up to graphitizing. It's my opinion that it gets a lot less attention that it deserves.

E. Fatzer, WANL: If it was possible at extrusion you might optimize your extrusion pressures and rates to get this.

R. Cost, WANL: As I said, the earlier we can get the information, the better off we are. For instance, the machinist can generate a dimension and if he has something wrong, say the broach cut is wrong, he can correct it right now before he makes 30 or 40 or 50 of these things. But such is not the case, when we're doing extrusions. We make 90 of these elements at a clip and we could be wrong at all 90.

G. Ross: Are most of your eddy current defects happening after bake?

R. Cost, WANL: It's easier to detect defects as you approach graphitizing. What I'm saying is that eddy current in that condition isn't impossible.

V. C. Jackson, Y-12: What is the element loss prior to graphitizing?

R. Cost, WANL: The loss is really, as we find it today, prior to graphitizing, very small. But if you get beyond that you start talking about 3, 4 or 5 percent eddy current. I guess what we're saying is if we make a mistake on this extruded element it would be nice to know at this point and chop it up and re-extrude it.

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C. C. Wright, Y-12: I'd like to know what features your gamma scanner lacks to keep it from being totally automatic. I didn't quite understand.

E. Fatzer, WANL: We're still using the original equipment that was installed here a couple of of years ago and the equipment has not been modified from the manual operation that we had then so it is a completely manually operated unit.

M. D'Amore, WANL: We've modified the electronic portion of the gamma scanner to give us better precision. As yet we have done very little in the way of design work for modification of the transport system. We do have a contract with our research people to develop as part of their task a vertical transport system. At the present time, our transports, or at least the trays on which the elements are manually pushed past the scintillator, are in a horizontal position. We do want to get our gamma scan unit into a vertical position. We want to put an automated transport on the system. We want automated keypunch from the gamma scanner. It's lacking these characteristics at this time.

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PART 5

INTERCHANGE ELEMENT STATUS AND DESTRUCTIVE TO NON DESTRUCTIVE CORRELATIONS

E. G. Fatzer

M. D'Amore, WANL: About a year ago, one of the major problems at the Astrofuel Facility was the accurate measurement of niobium carbide coating. We had rather antiquated equipment for measuring niobium carbide, at least from the standpoint of comparison with the semi-automatic equipment that Y-12 produced for us. We had a great deal of difficulty in keeping our equipment operational. About that same time, we made a selection of 14 elements. These 14 elements represented seven loading codes from the Westinghouse loading codes 3 through 9. A pair of elements was selected for each loading code. There were two criteria that we used for the selection. One was that the element should normally be a reject, so that we weren't diverting usable elements from the reactor. The second was that each pair of elements had to be processed through the same furnace coating run. These elements were designated as an interchange set of elements and were sent to Los Alamos. Our intent was to get measurements at Los Alamos and use these as a reference to calibrate our own equipment since we were having measurement difficulties. We had also planned on destructively testing one element of each pair as a part of a longer range program. The elements were measured at Los Alamos, at Y-12, and they've been measured by our own activity. The results have been statistically evaluated and will be presented by Gene Fatzer. He'll also be presenting the results of some recent evaluation work which was performed on destructively tested elements. One percent of the elements that are shipped to Astronuclear for use in a core are selected for destructive evaluation. These elements are sectioned, thoroughly examined, 19 hole profiles taken and finally destructively analyzed. Gene has gone through our destructive test results, compared them to non-destructive test results, and will present the results of these comparisons.

	(mg/cc)	(mg/cc)	(mg/cc)	(mg/cc)
	<u>Y-12</u>	<u>LASL</u>	<u>WANL</u>	<u>AVG.</u>
39-17133	137	137	140	138
39-17135	137	137	140	138
Average				
49-17397	183	183	186	184
49-17466	182	183	186	184
Average				
59-17747	220	219	225	221
59-17748	221	221	227	223
Average				
69-15051	248	238	244	243
69-15065	256	249	254	253
Average				
79-15327	317	308	314	313
79-15406	315	306	312	311
Average				
89-15701	373	361	372	369
89-16717	360	349	360	356
Average				
99-17364	416	406	416	413
99-17673	416	406	418	413
Average				

	<u>% Dev. from Average</u>		
	<u>Y-12</u>	<u>LASL</u>	<u>WANL</u>
	-0.7%	-0.7%	+1.4%
	-0.7%	-0.7%	+1.4%
Average	-0.7%	-0.7%	+1.4%
	-0.5%	-0.5%	+1.1%
	-1.1%	-0.5%	+1.1%
Average	-0.8%	-0.5%	+1.1%
	-0.5%	-0.9%	+1.8%
	-0.9%	-0.9%	+1.8%
Average	-0.7%	-0.9%	+1.8%
	+2.1%	-2.1%	+0.4%
	+1.2%	-0.6%	+0.4%
Average	+1.7%	-1.8%	+0.4%
	+1.3%	-1.6%	+0.4%
	+1.3%	-1.6%	+0.3%
Average	+1.3%	-1.6%	+0.4%
	+1.1%	-2.2%	0.8%
	+1.1%	-2.0%	+1.1%
Average	+1.1%	-2.1%	+1.0%
	+0.7%	-1.7%	+0.7%
	+0.7%	-1.7%	+1.2%
Average	+0.7%	-1.7%	+1.0%

Fourteen interchange elements, two from each NRX loading code, were selected by Westinghouse in November, 1964, after the non-destructive test groups at LASL and Y-12 expressed interest in a direct comparison of non-destructive test results. Each loading code pair was coated in the same coating run. The seven pairs of elements were coated in seven different coating runs. All elements were gamma scanned for uranium loading and beta backscatter tested for niobium carbide coating profile by each of the three NDT groups.

The correlation between LASL and Westinghouse niobium carbide thickness was reported in the April meeting at LASL. That is, from 2660 individual locations within the fourteen elements yielding a direct comparison, 97.3 percent were within 0.2 mils NbC thickness. Of the 2660 direct comparisons between Y-12 and Westinghouse, 96.2 percent were within 0.2 mils NbC thickness.

The agreement of beta backscatter NbC thicknesses between Westinghouse and LASL and Westinghouse and Y-12 is within the precision of the Westinghouse equipment at 0.2 mils NbC, which is stated, that at 95 percent of the time, repetitive measurements made at the same location in the same channel will repeat within an indicated thickness of 0.24 mils. Complete details of Westinghouse beta backscatter practice and statistical analysis of equipment performance is given by WANL-TME-1244 by W. H. Horton and WANL-TME-1269 by C. D. Cowfer.

Recent improvements have been introduced by Westinghouse in interpretation of gamma scan results. John Yezerinac will discuss the Westinghouse gamma scan interpretation a little later in this session. Correlation of uranium loadings obtained from the fourteen interchange elements by gamma scanning followed by correction of the raw data for the attenuation of the niobium carbide profile is given in the table of Slide 5-1.

The loading values are in terms of milligrams uranium per cubic centimeter of element volume. Column 5 of the table gives the average value for the three groups. Columns 6, 7, and 8 summate the relative percentage difference of each result from the three group average for each fuel element.

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Slide 5-2

The actual volume base assigned to a fuel element has some degree of uncertainty associated with it. The volume per inch length of Westinghouse elements computed from nominal drawing dimensions differs from that computed from destructive analysis data by approximately one percent. The volume used for the Westinghouse mg/cc comparison of table 1 is that obtained from destructive analysis of Westinghouse fuel elements. Westinghouse calibrates and expresses uranium loadings in terms of grams uranium per inch length of fuel element since its length can be measured with considerably greater certainty than its volume. The grams per inch calibration curve is not sensitive to 1 to 2 mil variations in channel diameter or normal production variations in cross section within the precision of the equipment. Indeed, a 12 channel half element will lie on the same calibration curve as the 19 channel full cross section when the equipment response is properly mathematically formulated and the Los Alamos designed torroidal scintillation crystal is used for scanning the elements.

Slide 5-2 is a plotted summary of Columns 6, 7, and 8 of the table in Slide 5-1. The upper solid curve represents the relative percentage deviation of Westinghouse results from the three group average, the lower solid curve that of LASL, and the dashed curve that of Y-12. The Y-12 data agree with the LASL data between 140 and 225 mg/cc and return a different response between 250 and 420 mg/cc, yielding good agreement with Westinghouse at the highest loading code.

Formula one summarizes the Westinghouse - Los Alamos results and indicates a constant bias with Westinghouse higher by 2.3 ± 0.7 percent of the amount of uranium present. If it were assumed the two groups are repeatable within themselves of the order of 0.5 percent of the amount of uranium present, the range of ± 0.7 percent is certainly acceptable. Much of the constant bias could result from a difference in the volume factors assigned to the fuel elements by the two groups. In any event, a constant bias can be readily resolved in calibration or by computation if it is desirable to obtain directly comparative results.

Formula two indicates that Y-12 averages 0.6 percent less than Westinghouse throughout the NRX uranium loading range with a total spread of ± 2.1 percent of the uranium present. Formula three indicates that Y-12 averages 1.7 percent less than Los Alamos throughout the

NRX uranium loading range with a total spread of ± 2.3 percent of the uranium present.

During the April meeting at Los Alamos, it was established that both LASL and Y-12 were interested in participating in the subsequent destructive to non-destructive correlation of the interchange elements that Westinghouse intended to perform. At a meeting held in Pittsburgh among representatives of the three non-destructive test groups, the assigned objectives of the destructive comparison were confirmed.

Objectives Assigned to 14 Interchange Elements

- 1) Determine precision of chemical analyses within each laboratory performing destructive analysis of segments from one element from each loading code.
- 2) Determine existence and extent of any analytical bias among these chemical laboratories.
- 3) Define what sampling plan of segments along the length of an element constitutes a representative sample to be applied to the destructive verification of non-destructive testing per specification requirements.
- 4) Determine precision of non-destructive beta backscatter and gamma scanning within each location testing the 14 elements.
- 5) Determine existence and extent of any testing bias among the non-destructive test groups.
- 6) Establish an experimental correlation among mercury porosimetry density, x-ray diffraction stoichiometry, beta backscatter response and metallographic thickness of coating throughout the full range of loading codes utilized by Westinghouse.
- 7) Refine the expressions presently utilized in reducing destructive and non-destructive testing to a common frame of reference.
- 8) Provide data to define areas requiring future improvement leading to increased precision and accuracy of both destructive and non-destructive testing of fuel elements.

9) Establish and retain final non-destructive test standards consisting of the remaining element from each loading code whose values have been assigned in terms of destructive analysis collated with non-destructive results for future reference among or within the three non-destructive test groups.

A second meeting was held at Los Alamos in June among representatives of the chemical analytical groups, statisticians, and non-destructive test groups of LASL, Y-12, and Westinghouse to establish the intent and extent of participation of the chemical groups. All three groups have expressed willingness to participate in the program. It was stipulated that a preliminary test of bias among, and precision within, the three groups be made against a sample of known uniformity before beginning destructive sectioning of one half of the interchange elements. Westinghouse has prepared and distributed a homogeneous solution of uranium and niobium among the three groups for determination of the uranium to niobium ratio with their individual analytical techniques. Analytical results are now becoming available and the conclusions of the statistical analysis performed by W. H. Horton will be reviewed by the three chemical groups in the near future.

Comparisons of the non-destructive to destructive uranium loadings for NRX-A3 and NRX-A4 have been performed in terms of the recent improvements in Westinghouse gamma scan interpretation and Westinghouse chemical analyses. Westinghouse destructively analyzes one percent of candidate fuel elements for each NRX core. The results of the comparisons are summarized in Slide 5-3.

Slide 3 indicates the agreement of Code 9 elements for NRX-A3 and NRX-A4 to be -0.6 percent to +0.4 percent on the average for the NDT compared to the chemistry. There is a distinct bias between destructive and non-destructive for the lower loading codes, averaging approximately +1.5 percent for the NDT compared to the chemistry. The bias is separate from reproducibility of the gamma scanning instrumentation. The equipment is

Destructive to Non-Destructive
Comparison from NRX-A3

<u>Serial No.</u>	<u>Total U Chem, g.</u>	<u>Total U NDT, g.</u>	<u>Ratio Chem-NDT</u>
89-19001	125.04	123.83	1.010
99-18830	125.19	123.91	1.010
99-17695	121.13	121.81	0.994
99-16449	119.52	119.19	1.003
99-16352	118.60	118.09	1.004
99-16049	119.20	117.12	1.018
99-15998	119.56	118.75	1.007
99-15805	120.34	118.33	1.017
99-14218	123.19	122.79	1.003
99-13943	120.77	119.42	1.011
99-13542	119.49	120.25	0.994

Average of Code 9 1.006

89-16738	101.51	102.73	0.998
79-15402	89.69	90.97	0.986
69-15140	70.69	73.61	0.960
59-14790	63.96	64.69	0.987
49-14902	52.83	54.11	0.976
39-13440	39.49	39.60	0.997

Average of Codes 3, 4, 5, 6, 7, & 8 0.982

Average of all elements 0.998

Destructive to Non-Destructive
Comparison from NRX-A4

<u>Serial No.</u>	<u>Total U Chem, g.</u>	<u>Total U NDT, g.</u>	<u>Ratio Chem-NDT</u>
99-18535	121.61	122.34	0.994
99-18613	121.61	123.30	0.986
99-19293	120.58	123.08	0.980
99-20003	125.24	124.51	1.006
99-20429	125.81	123.70	1.017
99-20455	126.87	125.62	1.010
99-22044	124.74	123.88	1.007
99-22222	121.64	122.08	0.996
99-22415	118.03	122.36	0.965

Average of Code 9 0.996

89-17335	104.19	105.43	0.998
79-18047	90.56	92.64	0.978
69-17635	72.96	73.23	0.981
69-21111	75.57	75.77	0.997
59-17726	64.69	66.03	0.980
49-20381	54.35	54.71	0.993

Average of Codes 4, 5, 6, 7, & 8 0.988

Average of all elements 0.993

calibrated in terms of uncoated standards analyzed by direct oxidation of the carbon to leave a residue of U_3O_8 . This oxide residue is examined spectrographically for significant contamination. The mixture of U_3O_8 and Nb_2O_5 remaining from oxidization of a coated element segment is analyzed by x-ray fluorescence of a fused borax glass-solid solution of the mixed oxides. There is not sufficient data available to relate the source of the bias between the two destructive techniques, the question of a truly representative destructive sampling plan from the fuel elements, and inter-actions with non-destructive test techniques. Resolution of these questions can be obtained only from a comprehensive program such as the fourteen interchange elements. To obtain performance of NDT equipment within guide lines such as those laid down by Westinghouse Reactor Designers, it is imperative that the fourteen interchange elements and follow-on programs be actively pursued until the techniques for accurate uranium loadings to standards, interpreting non-destructive in terms of destructive analyses and the analytical methods for determining both the uranium and niobium loading of coated fuel elements are unambiguously defined and established in practice.

The possibility has been raised that thermal cycles applied to fuel elements might influence the gamma scanner response due to some redistribution of uranium during a long term operation such as a coating run. Such an influence could bias destructive to non-destructive correlations. Fuel element segments prepared by Process Engineering during qualification of the 2200°C graphitize cycle for NRX-A5 were gamma scanned. Segments from the same element held at various temperatures within the Westinghouse processing range yield gamma scan results within the reproducibility of the equipment.

Westinghouse Reactor Analysis has averaged the beta backscatter profiles and niobium weight increases measured by weighing each element before and after coating for all fuel elements manufactured by the Astrofuel Facility and installed in NRX-A4. These data reduce to a value of 275 mg Nb/mil NbC/cm length of fuel element length. The value computed from the 1 percent destructive analysis of NRX-A4 fuel elements is 272 mg Nb/mil NbC/ per centimeter length of fuel elements. These data indicate a good first order consistency among non-destructive and destructive test data and processing information.

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DISCUSSION

N. Thielke, SNPO-C: Have you ever approached the matter from the standpoint of the number of elements sampled within one code as perhaps biasing the comparison you just referred to?

E. Fatzer, WANL: We have about 1000 to 1100 delivered code 9 elements to a core. We have anywhere from 40 to 200 of each of the other codes. We take a random sampling from the elements delivered such that the destructive to non-destructive comparison is approximately equivalent to the distribution of loading codes in a core.

N. Pollack, WANL: Yes, that's at phase III.

E. Fatzer, WANL: We take one out of 100.

N. Thielke, SNPO-C: I understand you take one out 100. The code 8's are agreeing much better than code 3's.

E. Fatzer, WANL: There's a bias, a distinct bias between the code 3 and 8's. Over the lower loading codes there is greater disagreement between chemistry and non-destructive. Now that bias is not the same extent on the code 9. The code 9 on the average agrees much better between the chemistry and the NDT than does the lower codes.

N. Thielke, SNPO-C: Is this largely the result of the larger population representing the code 9 information?

E. Fatzer, WANL: No.

W. Scheib, SNPO-W: Would the increased concentration characteristic of the higher loaded elements be inherently more accurate?

E. Fatzer, WANL: Not as far as we can establish on any significant basis. We have to assign the same level of significance to the chemistry and NDT for the lower loading codes as for the higher loading codes. We cannot find a bias.

N. Thielke, SNPO-C: Do you find the bias step-by-step as we go down the code?

E. Fatzer, WANL: No. There is some scatter as you proceed from code 3 to code 8, but it doesn't seem to be one of these gradual things.

M. D'Amore, WANL: Are there any other questions for Gene?

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S. Abramson, WANL: Mead, can you compare the percent accuracy with respect to loading? Would you expect a smaller percentage variation for higher loadings?

M. D'Amore, WANL: We would expect on a percentage basis the same degree of accuracy. The result of these destructive and non-destructive test correlations have caused us very recently to introduce changes in our conversion techniques for conversion of uranium loading determinations by gamma scan.

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PART 6

URANIUM LOADING DETERMINATIONS

BY GAMMA SCAN

J. C. Yezerinac

M. D'Amore, WANL:

John Yezerinac of the Quality Engineering Activity, of which Gene Fatzer is Supervisor, is going to present the recent information that has been generated on gamma scan conversions at the Astrofuel Facility. I'd like to point out that we are in the process of modifying our conversions at the Astrofuel Facility. I'd like to point out that we are in the process of modifying our conversion for NRX-A5 elements. We have some elements released for NRX-A5 and since the results to be presented have been generated very recently, we will be re-doing the data packages produced so far for the individual elements. I'm also making the presumption that all of you know what a data package is. I'm sure that you all don't. Jack Richards, in his presentation of Data Systems this afternoon, will review that. For NRX-A5 we will use the new factors of 272 milligrams niobium per mil per centimeter, and we will have the new equations relating to K factor for conversion of our final uranium loading introduced for the entire core. We've coordinated this very closely with our Reactor Analysis people who use this data. As Dick Doncals pointed out this morning, they rely for their shimming on the prior cores worth of experience and loading information. We are in the process also of converting, on an engineering information basis, results generated during NRX-A4 for use by Reactor Analysis. We will not redo any of the A4 data package information but will present that information to Reactor Analysis for their engineering studies. We'll handle that as an independent report to them.

John:

EQ. (2) $K = AU + B$

EQ. (3) $A = -5.68 \times 10^{-6} N$

610792-5B

Slide 6-1

The analytical approach to determine the final fuel element uranium loading from final gamma count data and niobium carbide coating thickness data has recently undergone significant changes at Westinghouse. Changes have been made to the value relating niobium content of niobium carbide, to the K factor expression, and to the calibration curve expression. These changes have resulted in a more accurate definition of gamma scan equipment response than had been obtained previously.

The gamma scan equipment response is defined by a calibration curve which relates average gamma count values to uranium loading values determined by chemistry from a set of standards over the loading range. The equations defining these calibration curves will be discussed later in this presentation. Uranium loading values for as-machined and as-leached fuel elements are obtained directly from this calibration curve. On final coated fuel elements, the final gamma count is attenuated by the niobium carbide coating and must be corrected by a K factor value. K factor is defined as the ratio of gamma counts obtained from a chemically analyzed standard without niobium to the counts from the same standard containing a known amount of niobium in the form of tubing in all channels. It will be shown, as suggested by J. Beene at the last conference at Los Alamos, that the K factor is a function not only of the amount of niobium present, but also of the uranium loading. The final gamma count data is corrected then by the K factor value and the final uranium loading value is obtained from the calibration curve derived from uncoated standards.

The value relating niobium content of niobium carbide thickness has been experimentally determined as 272 mg Nb/mil NbC/cm length for the NRX elements. This value is based on destructive tests of NRX elements and is the average niobium content of niobium carbide coatings computed from NRX-A4 experimental data. This value is included to reflect existing Westinghouse equipment response characteristics more precisely than the previous value of 262 mg Nb/mil NbC/cm length which had been based on nominal drawing geometry and handbook densities.

A very significant change was made to the K factor expression by recognizing the K factor as a function not only of niobium content but also of uranium loading. A relationship

EQ. (1)

K FACTOR VERSUS URANIUM LOADING CURVE AT CONSTANT NIOBIUM

EQ. (2)

Y-INTERCEPT VERSUS NIOBIUM CONTENT CURVE

EQ. (4)

$$B = 6.45 \times 10^{-5} N + 1.000$$

Slide 6-2

of the K factor at various uranium loadings with a fixed niobium level of 575 mg Nb/cm has been reported by WANL-TME-1143. A plot of this data defines a straight line over the specified uranium loading range as shown in Slide 6-1. This straight line can be defined by equation 1 as shown. A family of curves with varying slopes appear to be defined by the limited data at the other niobium levels. If the straight line curve for the 575 mg/cm niobium level is projected to the x-axis or a solution obtained from equation (1), the X-axis intercept is 11.60 g/in. This point is assumed to be the vertex of this family of curves if all would be projected to the x-axis. A general expression can be written for this family of straight lines as equation 2 of Slide 6-1 where A is the slope of the curve and B is the Y-axis intercept. By finding some relationship for parameters A and B, the K factor equation can be defined.

Based on the X-axis vertex assumption and on experimental data relating the K factors at 0.95 g/in. loading, the slope of the straight line curves at the three experimental niobium levels can be computed. Plotting slope A versus niobium level results in a straight line curve as shown at the bottom of Slide 6-1. An equation can be written to define this curve as equation 3 in Slide 6-1.

A similar approach is taken for an expression for the intercept B. With the slope of each curve known and with the experimental data relating the K factors at 0.95 g/in. loading, the Y-intercept values at the three experimental niobium levels can be computed. Plotting intercept B versus niobium level results in a straight line curve as shown at the bottom of Slide 6-2. An equation can be written to define this curve as equation 4 in Slide 6-2.

Expressions have now been derived for parameters A and B of equation 2 (Slide 6-3). They are equations 3 and 4, respectively. Substituting the equations for parameters A and B in the general equation results in equation 5. Equation 5 reduces to the form of equation 6, where the K factor is a function of uranium loading and the niobium content of the fuel element coating. Equation 7 expresses niobium content N in terms of niobium carbide coating thickness from beta profile inspection data. Thus, equation 8 shows the K factor equation in terms of uranium loading and niobium carbide coating thickness. The uranium loading value for U is taken as the average as-leached uranium loading for the fuel element.

EQ.(2) $K = AU + B$

WHERE U = URANIUM LOADING IN GRAMS / INCH

EQ.(3) $A = -5.68 \times 10^{-6} N$

WHERE N = NIOBIUM CONTENT OF NbC COATING IN MG / CM

EQ.(4) $B = 6.45 \times 10^{-5} N + 1.000$

EQ.(5) $K = [-5.68 \times 10^{-6} N] U + [6.45 \times 10^{-5} N + 1.000]$

EQ.(6) $= [6.45 - 0.568 U] \times 10^{-5} N + 1.000$

EQ.(7) LET N = 272 (MILS NbC)

WHERE 272 MG Nb / MIL OF NbC / CM LENGTH IS THE
EXPERIMENTALLY DERIVED AVERAGE NIOBIUM
CONTENT OF NIOBIUM CARBIDE COATINGS
FROM A4 DESTRUCTIVE TESTS.

(MIL NbC) IS MILS OF NIOBIUM CARBIDE
COATING FROM BETA PROFILE INSPECTION
DATA.

EQ.(8) $K = [1.754 - 0.154 U] \times 10^{-2} (\text{MILS NbC}) + 1.000$

690792-16B

Slide 6-3

A program is planned to refine further this K factor expression. Niobium tubing of various thickness will be used with the NRX-A4 standards in this program.

The gamma scan equipment response is of the form shown on Slide 6-4. The uranium loading versus gamma count curve shown is for gamma scanner No. 1. This curve can be precisely described by a hyperbolic function. An inverse plot of the calibration curve experimental data results in the second curve of Slide 6-4 and the resulting straight line experimentally establishes this curve as a hyperbolic function. A general expression for a hyperbolic function is equation 9, slide 6-5, where uranium loading is expressed in grams per inch, A and B are constants, and counts are either as-machined, as-leached or corrected final gamma count data.

The best curve fit to the chemistry values of the NRX-A4 standards is a hyperbolic function resulting in equation 10. All A4 standard chemistry values are within $\pm 1/2$ percent of this hyperbolic expression for gamma scanner No. 1 when using 25 count averages. This $\pm 1/2$ percent disagreement can be due to uncertainties in the chemistry determination and to reproducibility in the gamma scan equipment response.

$$\text{EQ. (9)} \quad G/\text{IN} = \frac{(\text{COUNTS})}{A - B (\text{COUNTS})}$$

WHERE G/IN = URANIUM LOADING IN GRAMS/INCH

COUNTS = AS LEACHED, AS MACHINED, OR
CORRECTED FINAL GAMMA COUNTS.

A = CONSTANT

B = CONSTANT

$$\text{EQ. (10)} \quad G/\text{IN} = \frac{(\text{COUNTS})}{1.0482 \times 10^5 - 0.21604 (\text{COUNTS})}$$

WHERE EQ.(10) IS DEFINED FOR GAMMA SCANNER

NO. 1 RESPONSE AND NRX-A4 STANDARDS

$$\text{EQ. (11)} \quad G/\text{IN} = \frac{(\text{COUNTS})}{-2.7780 \times 10^{-7} (\text{COUNTS})^2 - 0.15128 (\text{COUNTS}) + 1.0128 \times 10^5}$$

WHERE EQ.(11) IS DEFINED BY GAMMA SCANNER NO.1

RESPONSE AND ALL NERVA STANDARDS.

690792-15B

Slide 6-5

The best curve fit to the chemistry values of other standard groups or the best curve fits on gamma scanner number 2 will be the same hyperbolic function with different constants in each case. When older sets of standards are computed by equation 10, disagreement on a particular standard may be as high as approximately 2 percent. This disagreement may be due to uncertainties of the chemistry in the laboratory over the extended period of time involved as well as due to the extreme amount of use of some of these standards resulting in wear and a possible loss of material.

The hyperbolic function can be generalized by a parabolic modification to fit the chemistry values of both old and new sets of standards. This equation for gamma scanner one is shown as equation 11. This expression will yield agreement to the chemistry values on gamma counter number 1 to within ± 1 percent over the entire uranium loading range for all standards whether from older sets or recently fabricated sets obtained throughout the entire manufacturing history of NRX elements.

The long term gamma scan system stability has been improved with an RIDL Scinti-Matic unit installed in gamma scanner No. 1 during this period. The Scinti-Matic unit compensates for system gain changes, due to high voltage drift, power supply drift, component aging, etc., by dynamically controlling the high voltage supplied to the photomultiplier tubes.

A long term stability of gamma scanner No. 1 with the RIDL Scinti-Matic unit was checked by one group of four standards over the last four months and by two other groups of four standards each over the last two months. A total of approximately 862 readings were taken during this period on the twelve different standards spanning the full NRX uranium loading range. The average maximum deviation for all standards from their average is approximately 0.7 percent of the uranium present when only six counts are taken on each standard. System drift that can occur within the limits of the inspection procedure requirements when fuel elements are gamma scanned is a maximum range of approximately 0.3 percent of the uranium present.

DISCUSSION

N. Pollack, WANL: Meade, you might elaborate on that just a little bit by saying any change to NDT standards are all coordinated through the respective organizations here at WANL.

M. D'Amore, WANL: Yes, we could have introduced the curve factors prior to the start of NRX-A5. The difficulty arose in correlating this very closely with Reactor Analysis. Reviewing with them the effect on their activity resulting from any change in the methods for conversion of the uranium loading determinations required several weeks.

W. Scheib, SNPO-W: Were the data on the 14 fuel elements using the old gamma scan formulas, or are they on the new formula? — — —

E. Fatzer, WANL: They were converted to the new formula.

W. Scheib, SNPO-W: Oh, I see, in other words that downward trend is still there.

E. Fatzer, WANL: Yes, those data on that were all presented there. The comparisons among Los Alamos, Y-12 and ourselves on the 14 interchange elements as well as the destructive and non-destructive correlations are all based upon these correlations that John just presented.

W. Scheib, SNPO-W: This fell right around 1 to 2 percent?

E. Fatzer, WANL: Yes.

W. Scheib, SNPO-W: What was it before you applied this formula?

E. Fatzer, WANL: In the case of the NRX-A4 the code 9 average was 0.991. It was improved to 0.996 so it has improved about one-half percent.

W. Scheib, SNPO-W: But you still have this bias?

E. Fatzer, WANL: Yes, it's a constant bias between ourselves and Los Alamos on the 14 interchange elements. — — —

W. Scheib, SNPO-W: Well it's also a little bit of a trend downward?

E. Fatzer, WANL: Well, that's with respect to the three group average, and you see, with the Y-12 response lying on one side of the curve, on the negative side of one region and the positive side on the other, it makes that three group average deviation of the other two assume the form it does.

C. C. Wright, Y-12: This factor, then, is involved in the application of beta back scatter measurement to the gamma count interpretations for lined elements. Is that true?

E. Fatzer, WANL: Yes.

C. C. Wright, Y-12: Does the revision of this factor bring your gamma count analysis into closer agreement with the non-destructive evaluation that you ran through?

M. D'Amore, WANL: Yes, it does. I'd like to point out that we still don't have 100 percent agreement in the lower codes and I think Gene reviewed that we're approaching a 1 to 1 ratio but slowly. We evaluated a great deal of destructive test data to be able to draw these conclusions and make these changes.

PART 7

INTERNAL BETA BACKSCATTER TESTING

C. D. Cowfer

M. D'Amore, WANL: The next two presentations will be given by Dave Cowfer of the Astrofuel Quality Engineering Activity. Dave is going to review the internal beta backscatter testing information that has been generated since the first symposium and will also review the current status of eddy-current testing at Astrofuel. I think, for his presentation, we'll go through the internal beta backscatter and stop if there are any questions. Dave will answer them at that time, then he'll immediately launch into his eddy-current testing presentation which is very short.

Introduction

The application of the beta backscatter system at Westinghouse is three-fold:

- 1) It is a process control system--used to monitor coating furnace performance.
- 2) It is used to determine the NbC coating thickness in an element for that element's acceptability to reactor requirements.
- 3) The NbC profile as reflected by the system is utilized to correct the fuel element as-coated uranium loading for the attenuation of the 185 kev gamma rays by the niobium content.

The use of the system as a process control has been greatly improved with the installation of the PDP-5 computer at Westinghouse. With the two-step coating process of NRX-A5 production elements, it is necessary to check the first or bore coat step for batch acceptability before continuing into the second step--that is the back or peripheral coating step. The NDT operating procedures for the NRX-A5 reactor require that two elements be selected from a bore coat run, profile tested in channel 11; the data is expedited through Data Systems for immediate reduction; and the reduced data is then transmitted to Process Engineering for release of the material from the bore coat run to the second step coating process.

Westinghouse has incorporated a change in the beta backscatter programming and furnace run testing requirements for the NRX-A5 final-coated element. As reported in the April conference, the beta backscatter testing requirements were that 50 percent (or 17) of the elements in a given furnace run would receive a three-channel profile inspection; then three of the 17 elements would be selected for a run or batch profile determination. Finally, 100 percent of the elements in the run would receive a 19-channel spot check measurement at 18 inches from the cold end of the element. Two significant observations here will reflect that this is not the most desirable application of the system. First, this technique involved handling the final as-coated element twice for beta backscatter testing alone. This duplicate handling not only increased the risk of damaging the element, but generated undue accountability problems. Secondly, the three element profiles that were chosen to represent the entire furnace run or 34 elements were also used to correct the fuel element as-coated uranium loading for the entire furnace run. The criterion from which the three elements were chosen was based on their niobium content empirically calculated from the NbC profile displayed by beta backscatter system versus the actual weight gain during the furnace run, as calculated by physically weighing the element. The three elements were chosen because their empirically-calculated weight gain agreed with the actual weight gain better than the remaining elements in the batch. It can be seen here that there were four basic uncertainties involved in this approach: 1) the empirical calculation of the

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weight gain, 2) the gamma scan system, 3) the beta backscatter system, and 4) the assumption that all the element coating profiles are identical in a furnace run. Not any of these uncertainties are great; however, if you consider that a net tenth of a mil difference in coating along the length of an element is a three gram difference in weight, you can contribute significantly to such problems as displaying an unusual uranium bias in the final as-coated element or increasing the uncertainty in the corrected uranium loading of the final as-coated fuel element.

On the premise that the application of the beta backscatter system could be improved from the standpoint of both system application in production and the application of the resultant data, Westinghouse changed the testing requirements reported in April as follows:

The acquisition of a three-channel profile from 50 percent of a furnace run was deleted in favor of obtaining a single-channel profile from each element in a run. Channel 11 was selected as that single channel after a statistical analysis resulted in two significant observations: 1) that the profiles of the channels in a single element do not vary enough to necessitate measuring more than one channel, but 2) that more precise comparisons are obtained from the inner six channels when compared with each other or by metallography. The comparisons on the inner six channels are more precise because, when observing the outer channels, the effects of the loss of beta particles which are not recoverable through the outer wall or the exterior coating induces some error, resulting in a slight distribution of the measurements.

Then, to minimize final element handling, the beta backscatter system logic was modified to intermix the profile and spot check modes of operation to obtain a spot check in each channel and a complete profile from channel 11 in a single cycle of system operation.

Finally, instead of using a batch or furnace run profile calculated from three elements out of the run for correcting the as-coated uranium loading in the final element, Westinghouse started correcting each element's final uranium loading using the profile measured in that

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Fuel Element S/N 99-26294
Bore Coat Run No. F-227
Back Coat Run No. L-156

Spot Check Thickness (10" from S/N)		Profile Measurement		
Channel		Reading Position	Channel 11	Channel 1
1	.4 *	3	1.9	1.1**
2	1.6	6	1.8	.9
3	1.4	9	1.8	.7
4	1.4	12	1.9	.6
5	1.4	15	1.9	.6
6	1.6	18	2.0	.6
7	1.4	21	2.1	.6
8	1.5	24	2.0	.6
9	1.4	27	2.0	.5
10	1.5	30	2.0	.5
11	1.4	33	1.8	.5
12	1.4	36	1.7	.4
13	1.4	39	1.6	.4
14	1.4	42	1.3	.4
15	1.4	45	1.2	.4
16	1.5	48	1.0	.4
17	1.4			
18	1.4			
19	1.4			
*Erratic Reading		**Out-of-spec Reading		

Slide 7-1

Beta Backscatter Output Display

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element. The 16 measurements obtained from the gamma scan system are now correlated directly to the 16 measurements obtained in the profile determination by beta backscatter. This change minimizes the uncertainties in the beta backscatter to gamma scan interface by reducing it to the two systems involved in the measurements. This permits us to establish and control the precision needed to fulfill design requirements.

The interpretation of the spot check measurements has been changed to assure that any single element channel that is not coated properly due to a partial or total blockage in the bore coat process does not go undetected. Experience has shown that even though a spot check reveals an acceptable thickness for that level of the element, it does not mean that the hot end of that channel is acceptable to drawing requirements unless that spot check compares to the other channel spot checks in the element. With this in mind, we initiated an operator training program to give the system operators the capability of detecting an element problem while the piece is in the system so that any additional testing can be performed, if necessary. The training program consisted of establishing a permissible distribution in the raw data counts from channel to channel for spot check measurements in the element and making the operator aware of what each measurement is as he examines the raw data. As a follow-up to this program, Westinghouse has started performing an engineering evaluation of the computed data for each element before the data is released for element acceptability determinations. If a single spot check deviates more than 0.3 mils from the mean thickness in the remaining 18 channels, special testing is performed on that channel to verify that the profile requirements have been met in that channel. This technique has proven very effective for locating discrepant channels, and we feel we can continue to process elements through beta backscatter testing with the present requirements, with the assurance that all the coating requirements are being evaluated.

Slide 7-1 is a typical example of data evaluation where an element exhibited a low spot check reading in channel 1 at 10 inches from the serial numbered end. A follow-up profile measurement in channel 1 reflected an "out-of-spec" profile, indicating that

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Slide 7-2. Fuel Element Coating Profiles

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channel 1 had in fact been partially blocked during the first or bore coating step of the process.

As indicated in WANL-TME-1269*, the response of counts versus thickness has been shown to be expressed as an experimental function. Since this is accepted naturally, any unusual count indicating an unusual thickness would seriously bias the average thickness over an interval if the count data were converted by a linear function and the simple average taken. To prevent such a bias from occurring in the indicated thickness for an interval, all count data are logarithmically related to thickness, and the average log value is finally transformed to a thickness. Utilizing this technique, equal weight is applied to all collected data counts, regardless of the thickness range being measured.

In a recent analytical application of beta backscatter data, Westinghouse defined what happens to an as-bored coated element's profile when that element was processed through a second step back coat process. Another important aspect of the study was to determine if coating fixture-bolt-hole-circle locations had any effect on the NbC profiles in the elements in a furnace run. Nineteen-channel profiles were obtained from each element in bore coat run number C-256. C-256 was then back coated in furnace run L-143 with the elements loaded in the same bolt-hole-circle locations. Nineteen-channel profiles were then obtained from the as-back coated elements. Significant observations in the analysis of the data from these two furnace runs are as follows:

Relative to what happens to an as-bore coated element's profile when that element is processed through a second step or back coat process:

Slide 7-2 indicates that with an average thickness of 0.64 mils at the 6-inch level at bore coat, the coating increased 0.2 mils for an average thickness of 0.84 mils at back coat. The 45-inch level averaged 1.67 mils at bore coat and increased 0.31 mils to 1.98 at back coat. The 48-inch level averaged 1.72 mils at bore coat and increased 0.37 mils to 2.09 mils at back coat. The 51-inch level averaged 1.81 mils at bore coat and increased

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* Report entitled Evaluation of the Fuel Element Beta Backscatter Nondestructive Test System, dated October 16, 1965

One-Inch Thickness

Channel No.	Bore Coat	Back Coat
1	0.55	0.75
2	0.56	0.77
3	0.53	0.77
4	0.57	0.77
5	0.57	0.78
6	0.58	0.80
7	0.58	0.79
8	0.53	0.76
9	0.55	0.78
10	0.58	0.50*
11	0.56	0.86
12	0.54	0.80
13	0.56	0.81
14	0.57	0.79
15	0.55	0.80
16	0.55	0.81
17	0.54	0.76
18	0.57	0.84
19	0.54	0.80
<u>Average (All Channels)</u>		
	0.55	0.77

*Channel 10 less at back coat because of fixturing counterbore.

Slide 7-3

Average One-Inch Spot Check Thickness Per Run Per Channel - Bore Coat Vs. Back Coat

0.5 mils to 2.31 mils at back coat. The one-inch level spot check exhibited a 0.55 mil average thickness at bore coat and increased 0.22 mils to 0.77 mils at back coat.

When the one-inch spot check readings were averaged by channel and evaluated, a rather peculiar thickness was exhibited in channel 10 for the back coat operation (Slide 7-3). Channel 10 had averaged 0.50 mils when all the other channels indicated closer to 0.80 mils. What we were observing was the effects of a machined counterbore and removal of some of the as-bore coated thickness.

Relative to an element's location in the coating fixture during the furnace run:

An average element coating thickness for the first or bore coat step exhibited that over the 6-inch through 45-inch segment of channels a minimum average of 1.23 mils and a maximum average of 1.35 mils of NbC coating was obtained (Slide 7-4). This reflects a 0.12 mil distribution for the entire run over that segment of the channels. The 48-inch and 51-inch segment of the channels exhibited a minimum average thickness of 1.64 mils and a maximum average thickness of 1.85 mils, or a distribution of 0.21 mils in the bore coat run. The analysis of the second step or back coat channels exhibited a minimum average thickness of 1.48 mils and a maximum average thickness of 1.55 mils for a distribution of 0.07 mils over the 6-inch through 45-inch segment of the element. The 48-inch and 51-inch segment exhibited a minimum average thickness of 2.06 mils and a maximum average thickness of 2.27 mils for a distribution of 0.21 mils in the furnace run for that segment. An evaluation of the spot check data exhibits a minimum and maximum of 0.83 mils to 0.93 mils at bore coat and 1.06 mils to 1.13 mils at back coat for a distribution of about 0.1 mil.

Summary

In summarizing, it should be emphasized that, by utilizing the profiles of all the bores in all the elements located throughout the furnace coating fixture, we have defined that the coating uniformity is excellent throughout a bore coat and back coat run. We have defined the effect of the second step-back coating operating from the standpoint of increased

Note: The thicknesses indicated below are averages, therefore, carried out to two decimal places. No implication that an individual measurement by the system is accurate to the nearest 0.01 mil is intended.

Coating Process	Length of Segment Along the Channel	Average Thickness		Thickness Deviation
		Minimum	Maximum	
Bore Coat	6 thru 45 inches	1.23 mils	1.35 mils	0.12 mils
	48 thru 51 inches	1.64 mils	1.85 mils	0.21 mils
Back Coat	6 thru 45 inches	1.48 mils	1.55 mils	0.07 mils
	48 thru 51 inches	2.06 mils	2.27 mils	0.21 mils

NbC Coating Deviation at the Spot Check Locations

(The averages below are the combined averages of all the one-inch and 18-inch spot check measurements in each bore in a furnace run.)

Coating Process	Average Thickness (mils)		Thickness Deviation
	Minimum	Maximum	
Bore Coat	0.83	0.93	0.1 mil
Back Coat	1.06	1.13	0.07 mil

Slide 7-4

NbC Coating Distribution -- All Bores per Furnace Run

thickness and observe that it acts in a controllable manner. And finally, we have shown that the average difference between elements, as determined by a profile in channel 11 across the coating batch, is no greater than the difference found between inner and outer channels in the same elements.

DISCUSSION

E. Price, Y-12: Did you have any elements that lost thickness after backcoating, or did they all gain?

D. Cowfer, WANL: This is a complete comparison of all critical elements that were run. The comparison between two runs individual channel by channel comparison. These results were very uniform throughout the batch. Remarkably so, in fact, they were rather surprising.

E. Price, Y-12: In bore number 10 on one chart, you had a loss of thickness of 0.58 to 0.50. What was this?

E. Fatzer, WANL: The element has a counter bore machined into it, the No. 10 channel.

E. Price, Y-12: How deep?

E. Fatzer, WANL: Approximately 1/2 inch. These measurements are right in that area about 1/2 inch into the element.

E. Price, Y-12: I didn't realize where you make the measurement.

D. Cowfer, WANL: That was the only channel affected by sensitivity of the apparatus itself.

M. D'Amore, WANL: Correct me if I'm wrong, we were not into that but we were reading almost adjacent to this counterbore, weren't we?

D. Cowfer, WANL: We're right at the borderline, within a quarter inch.

E. Fatzer, WANL: We are approximately in that region. The window is 300 mils long and whether a part of that window is actually up into that region or not, you can't tell.

C. C. Wright, Y-12: You said that one of the reasons you chose channel 11 for profile measurement was because of the fact that electrons are escaping through the peripheral bores. Have you evaluated that yet?

D. Cowfer, WANL: We've evaluated this through metallography comparison versus beta backscatter indications. I've performed some experimental testing on comparing non-fueled elements. We start with non-fueled material and progress up through the loading. You can see a definite decrease in the effect. It's tremendous in non-fueled material which does substantiate the fact that you get a lower indicated thickness from a non-fueled element.

C. C. Wright, Y-12: Your gauge calibration is not constant then between channels, is that true?

D. Cowfer, WANL: It's not serious, we said about 1/10 of a mil distribution outer to inner.

W. Horton, WANL: What he's talking about is that if we run these data profiles on the element we find there's about 1/10 difference between the outer channels and the inner channels on the average. We've tried to check this by metallography but sometimes it shows and sometimes it doesn't. We're not sure. The difference of 1/10 between the outer and inner channel happens in the lower readings as well as the higher readings. We suspect as Dave has indicated that it's because we lose beta particles out through the walls but we're not really sure.

N. Pollack, WANL: Bill, you have an interesting phenomena between your corner elements also?

W. Horton, WANL: Yes, really the corner elements are the ones which are 1/10 less.

C. C. Wright, Y-12: Did you observe this for backcoated elements as well?

W. Horton, WANL: It happens in this set of Data that Dave was just talking about. On backcoated elements it happened consistently over all 34 elements where we had the 19 hole profiles. It happened in borecoat, and it happened the same way in backcoat. We found the same differences repeating except at the 51 inch point where we have a buildup of about 1/2 mil on the internal surface and about 1/2 mil on the external surface. We feel that we're probably getting some reflection back now at the 51 inch point.

C. C. Wright, Y-12: Then that lends support to this argument?

W. Horton, WANL: Again we just don't know what the score is. We are doing work in this area.

D. Ritter, AGC: Aren't we sort of kidding ourselves? This is like using a ten place accurate computer and three place data to go into the darn thing. Where we are talking about tenths of a mil, aren't we just making a lot of noise?

W. Horton, WANL: Well again, this repeats itself over and over again. So it's there. You can see in every single channel profile that it happens consistently. I find no cases, and I am sure Dave found no cases where this is different, you can look at one profile, 10 profiles or 1000 profiles and it's there.

W. Scheib, SNPO-W: How many did you look at?

W. Horton, WANL: We looked at 19 times 60 on this borecoat backcoat study.

PART 8

EDDY CURRENT TESTING

C. D. Cowfer

1.1 Introduction

Certainly, the basic principles of the use of the Eddy Current System for evaluating fuel elements were well vindicated at the April conference. The Westinghouse discussion in April included an electrical simulator that we use for Eddy Current System calibrations as reported in WANL-TME-1181*. An observation after some 8 to 9 months of system calibration reflects that the simulator has resulted in exceptional consistency in the system output data.

The three groups discussing the eddy current system at the April meeting all agreed that the system is a good process control tool for determining discontinuities in the graphite matrix. However, another major application of the system, an application not resolved at the April meeting, is that of interpretation of the eddy current data for fuel element acceptability for core use. The Westinghouse application of the eddy current system has continued as reported in April. However, with the completion of the A-3 reactor post mortem evaluations and the results of an eddy current class versus element performance study, we have recently initiated a program to re-evaluate the eddy current criterion we use to reject fuel elements. Our discussion today is based on many eddy current data evaluations including some element destruct sampling.

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* Report entitled Evaluation of Fuel Element Eddy Current Nondestructive Test System, dated August 16, 1965.

2. Discussion

A recent evaluation of 858 ---- A-5 type fuel elements tested on the eddy current system exhibited a 6.8 percent rejection rate on internal to internal correlation of discontinuities.

Slide 8-1 is a bar graph made from the study reflecting the percentage of the total 858 elements that fall into the individual eddy current classes. Classes 11 through 14 are acceptable for core use. Classes 15 and 18 are external visual rejects. Classes 16 and 17 are rejects based on internal to internal correlation. An internal to internal correlation is any two discontinuities or flaws exhibiting a volume equivalent to or greater than an 0.035" hole drilled in an element, or that appear within 0.3 inch of each other in two adjacent channels. The combined Class 16 and 17 rejects is a total of 59 fuel elements out of the 858 evaluated. Certainly, the eddy current system is not meant to build quality into the fuel elements. However, when elements are rejected from core use in these percentages, it is our responsibility to determine if the criterion we use for evaluating the elements is valid. In an effort to make the eddy current evaluation more meaningful, Reactor Mechanical Design has proposed that the eddy current data application be revised to:

Permit no internal transverse cracks.

Permit no cracks through to any surface or on any surface.

Permit no high-conductivity inclusions.

Experience has shown that defining correlation of discontinuities in two adjacent channels does not reflect a transverse crack. Correlation of discontinuities from an outer channel to an external surface can reflect a crack through to that surface.

The effects of the reaming operation on eddy current results is very significant when two channels are used for determining transverse cracks. Westinghouse Process Engineering has been evaluating an extrude to size element in lieu of the existing process of extruding the bores to a smaller diameter and then reaming the bores to final drawing diameters. The

eddy current evaluation exhibits a much lower rate of occurrence in indicated discontinuities for smooth channel surfaces of extrude to size elements. The process of extruding the channels to a smaller diameter exhibits still another characteristic when considering reaming. The center channel--channel 10--is extruded to a yet smaller diameter than the remaining 18 channels. This results in a removal of 6 - 8 mils on a side for channel 10 in the reaming operation, when only 2 - 3 mils must be removed from the remaining channels. Any experience in reaming--no matter what the material--(and considering that the reamer is moving at the same speed)--reflects that the more material removed during that process, the rougher the finish will be on the I.D. Metallography has shown that fuel beads are extracted during reaming leaving voids on the bore surface. Characteristically, channel 10 has more eddy current inducted discontinuities than the other channels and the conclusion is that this increase is due to the reaming operation. Many times the irregularities on the bore surfaces do trigger the AC discriminator, and many times these irregularities do correlate in two adjacent channels. A proposal to be evaluated is to move eddy current testing back one step in the process or before reaming to evaluate internal defects separated from channel surface finish. Another proposal for making discontinuity correlations more meaningful is the possibility of changing our existing computer programming and correlate discontinuities through several channels. This proposal would continue to be conservative as defined by Reactor Mechanical Design in the application of eddy current results for core use.

N. Thielke, SNPO-C: Does the reaming and also the random removal of the beads that are close to the surface, whether they split or are removed entirely, prejudice your gamma scan data, your comparison of loading data, more than it would normally with a normal sized element?

E. Fatzer, WANL: Norm, we might make some kind of guess at this thing by taking a look at some of the data evolved at Y-12. Dr. Metz has specimens from elements with ends polished for bead pullout followed by chemistry to see how bead pullout influences the results. They figure you can get down to a quarter inch length of specimens before it starts getting hairy.

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NUMBER OF FUEL ELEMENTS
Slide 8-2

NIX-A5 Fuel Element Eddy Current Class Distribution (858 Fuel Elements)

PART 9

WESTINGHOUSE NDT EQUIPMENT DESIGN PHILOSOPHY

L. C. Vercellotti

M. D'Amore, WANL: Shortly after the session in April, we placed an order with our Westinghouse Research Group to supply design efforts on machine transports and electronic logic systems. We have about 10 tasks placed with Research at the present time. These tasks include such things as automating our gamma scanner and designing a standard transport system so that as new equipment requirements are generated, a standard design can be incorporated into the new piece of equipment. Our research people have an order from us to produce two external beta backscatter units for measurement of the niobium carbide thickness on the exterior surfaces of fuel elements and one external beta backscatter unit for measurement of external niobium carbide on support blocks. Len Vercellotti, the Manager of the group doing this work for us, will present the basic design philosophies that have been generated during the last several months within Westinghouse on the design and construction of these automated devices.

Westinghouse development of non-destructive test equipment includes the construction of two units of an Automated External Beta Backscatter System for Elements and one unit of an External Beta Backscatter System for Support Blocks. Entry of Westinghouse into this area is based on previous experience in digital data logging and process control systems as well as continued use of beta backscattering techniques for measuring element plating thickness. The integration of skills at WAFF Quality Control Engineering in non-destructive testing with those at the Westinghouse Research Laboratories in data accumulation systems has

Evolution of NDT Equipment

- Verification of measuring technique using manually operated test jig
- Use of semi-automated test equipment having automatic manipulation capability
- Use of fully automated test equipment with automatic manipulation and data accumulation capability

Slide 9-1

led to a new generation of automated NDT equipment. This paper describes the design philosophy of the Westinghouse test equipment and presents a brief description of the equipment being built.

The development of equipment for non-destructive testing has evolved through several stages (Slide 9-1). The first stage concerns itself with the verification of a measuring technique and the study of its applicability to quality control. Techniques thought to be generally useful for NDT are implemented in prototype form, then comparisons of data taken on calibration samples are made to verify precision of the technique. For example, the eddy-current test for defects was known to be a test of some utility. The development of a probe having sufficient resolution to identify defects was the first step to verify the capability of the technique.

Unfortunately some pieces of equipment are developed no further and are immediately pressed into service because of the need to accumulate data on the product. Happily, in the case of the eddy-current tester, a mechanism was built to move the probe past the workpiece after a confidence level was established in the measuring procedure. This tester is indicative of a second stage of equipment evolution which represents the development of semi-automated equipment. In this equipment, data is still dependent on the interpretation or entry capability of an operator. Data may be recorded on strip charts or displayed on indicators. The operator then manually enters data via a keyboard to punched cards.

The third stage of development is the design of fully automated test equipment where the operator is liberated from handling and data entry functions once a START signal is given to the test equipment.

A review of techniques used at the production level for obtaining NDT data shows that by necessity equipment is being used that represents all three stages of evolution. Most of the equipment used is semi-automated. Even programs which have developed high quality test equipment have had to make compromises on a few of the human engineering aspects so

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W NDT Design Philosophy

- To supply data of good quality at a minimum cost of equipment and operating time with due regard for the protection of the material and the safety of the operator

Slide 9-2

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that readings remain operator dependent. It is safe to say that very little equipment exists which is fully automatic. Such equipment would imply that recalibration was automatic, element identification was sensed rather than read by the operator, and equipment setup was foolproof, having a number of sensors to detect malfunction or the exceeding of limits in the equipment itself.

Add to the above review of systems used, the fact that some of the present equipment requires extensive maintenance, and it becomes obvious that a quality control group requires a significant companion development activity. The establishment of a development group in Westinghouse for NDT equipment is, in fact, an extension of the work done on the test floor over the last few years. The goal of this work is described in the next section.

The simple goal of Westinghouse's non-destructive test equipment development is to supply data of good quality at a minimum cost of equipment and operating time with due regard for the protection of the material and the safety of the operator (Slide 9-2). This philosophy reflects the necessities of non-destructive testing and, therefore, should not be unique to Westinghouse.

With regard to the data, measurement techniques of proven utility are used as a basis of this equipment (Slide 9-3). Some refinements in the choice of components have been made, however, based on actual experience on the test floor. Work is being done to reduce human error as it affects recalibration intervals and the actual entry of pertinent format information on punched cards.

With regard to the workpiece, the protection of the material under test is an obvious goal of non-destructive test. Recent work on plating thickness measurement apparatus has included effort to avoid sliding or rolling contact with the material which is a possible cause of surface damage.

Considerations in NDT Equipment Design

- The data
- The material under test
- The operator
- Costs
- Equipment Reliability

Slide 9-3

With regard to the operator, much of the equipment uses probes which contain dangerous isotopes. Of necessity, shielding and interlocks are needed to prevent needless exposure to radiation hazards. Besides protection of the operator in normal use of the equipment, precautions must be taken to prevent probe damage under a number of conditions of equipment failure and operator error. Fracture of an encapsulated source of Strontium 90 is dangerous and costly, as the whole site must be evacuated.

Also pertaining to the operator are the usual concerns of automation: the freedom of the operator from tedious tasks so that he can concentrate on assignments which are proper to him, the elimination of the operator as a needed link in data accumulation, the ease of setup procedures which reflect direct costs in operator time and which usually have major impact on the validity of the data.

With regard to costs, it is, of course, the goal of our development to produce industrial grade hardware at the least possible initial investment consistent with the usage factor involved and the life of the equipment. For example, the Beta Backscatter System for Support Blocks, to be discussed later, does not warrant a fully automated X, Y, Z positioner since the quantity of material to be processed does not represent a usage factor commensurate with the cost of the equipment. The life of the equipment represents another dilemma to the designer as he tries to keep his approach general enough to meet needs of proposed or rumored material changes.

With regard to the reliability of the equipment, it is very conservative to say that improvements have been made in electronic apparatus in recent years. Improvements must be incorporated as they are recognized. Not all improvements can be made because of the possibility that too great a variety of gear will be required in a test area and parts interchangeability is lost. An example of what was done in recently designed equipment to overcome both problems is the redesign of logic cards with silicon semiconductors, while maintaining input and output loadings and pin configurations compatible with the old germanium cards.

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Slide 9-4. External Beta Backscatter Measurement System for Fuel Elements

To show where some of the above thoughts were derived, two examples are given of recently designed NDT systems.

A block diagram of the Automated External Beta Backscatter system is shown in Slide 9-4. The system consists of (1) a transport for moving an element past a beta backscatter probe, (2) electronics for integrating the back scattered radiation level over a period of time and (3) control equipment for advancing and transport, rotating the element, and entering data on punched cards via a card punch. A second fixture provides a means for securing the element so that another probe with a different tip can be brought into proximity to make a measurement on the end of the element.

A vertical transport is used to conserve floor space. It provides means for carrying an element of up to 64 inches in length past the probe. A light pressure contact is made to support the element, but no contact is made between any stationary member and the moving element. The transport drive is of variable speed. A maximum operating speed of one inch per second is required with about a ten to one variable speed range available. The carriage is halted within 0.1 inch after a stop is indicated.

Means for rotating the element in response to a control signal are provided.

Fixtures hold two external beta backscatter probes. The probe must be kept 0.010 to 0.030 inch from the element. This separation is maintained even in the presence of a 0.131 inch element bow. A pneumatic positioning system is used to maintain this spacing for the side measurement. The end measurement spacing is maintained by detents as the end measurement probe is brought into position. A backup sensing means shuts down the system if the minimum tolerable spacing is not met.

The probes containing sealed Strontium 90 sources are adequately shielded to protect the operator. The shield extends two feet above and below the probes. The shielding consists of 1/16 inch steel plate with a one millimeter lead overlay. Windows are made of one inch sheets of Lucite.

Slide 9-5. Test Probe Positioner

Identical equipment as is now used for the internal beta backscattering systems is applied in the analog portion of the measuring system. This confirms compatibility and operating performance consistent with the existing systems.

The precision requires four decimal digits to be recorded on a punched card for each reading.

The control system gives the operator relief from duties of entering the data or advancing the transport. Format information is presettable on thumbwheel switches. The particular increments and faces where measurements are to be taken are also selectable. Readings may be taken by either of two methods:

- 1) STATIC readings, in which the transport is stopped while a four second (typical) integration is done, or
- 2) DYNAMIC readings in which the reading is made as the transport moves the element between two increment contacts.

Other modes which are selectable are the END measurement mode, and the CALIBRATE modes for each of the two probes. During the CALIBRATE modes the high voltage power supplies and the gain of the amplifiers are adjusted while the accumulated count taken from a calibration sample is viewed on the counter decade displays.

Beta Backscatter System for Support Blocks

The other system being built gives an operator means for making a series of plating thickness measurements on support blocks. The system consists of (1) a manipulation means for positioning one of five possible probe types against or within a support block, (2) electronics for integrating backscattered radiation over a time period and (3) control means for entering data on punched cards via a card punch. The five possible probe types represent five different geometric surfaces where readings might be desired: the slide, internal small hole, internal large hole, a collar at end of hole, and a counterbore.

The probes are positioned with respect to the various measuring points on the block under test by a hand operated X, Y, Z pantograph machine (Slide 9-5). The block to be measured is held in a location which is suitably shielded, and a pattern model is mounted on another member of the pantograph where a tracing stylus can be guided to the measuring point desired. One of the probes mounted on a turret is selected without the operator handling the beta source. One fixture holds the blocks so that the ends and internal holes are accessible. A second fixture makes the sides available as it is indexed through 60 degree steps. Identical fixtures are used at the sample and at the blocks under test. The fixtures at the two locations are mechanically coupled by a low temperature coefficient Invar bar so that the two blocks will always be in similar positions. Operator attention, therefore, only requires positioning the stylus on the pattern and keeping track of a reading check list or map in front of him.

Slide 9-5 shows an outline of the manipulation means to help visualize the support block system concept.

The electronics used in this system are almost identical to those required in a Beta Backscatter System for Elements. The only major difference is that the operator must initiate readings, since the readiness of the measuring system depends on his previous manipulation of the probe.

The three dimensional positioner posed some problems to protect the internal probes from damage if, while one was inserted in a hole or below the surface of a block, the manipulator was jarred in a horizontal direction. Although the stylus which leads the probe provides some protection, a fail safe magnetic brake effecting motion of the horizontal slides operates whenever the stylus is within a certain height of the table. Vertical motion of the positioner is the only direction which is then possible for inserting and removing the internal probes.

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Several important factors have been observed to be the basis for NDT equipment design: data of good quality, protection of the material under test, operator safety and independence of the measurement process, costs in terms of equipment and operating time, and reliability as it affects both costs and quality of data. Product assurance demands good data, and continued equipment refinement is a necessary means for reaching that goal.

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DISCUSSION

W. Scheib, SNPO-W: When will these be completed?

L. C. Vercellotti, Westinghouse Research: We are supposed to have them ready the end of January and the transport construction is well underway. The electronics has only evolved in a breadboard form so we have essentially December and January to build the electronics. Of course, we are very hopeful that the analog input system, which is the heart of the Y-12 internal beta backscatter system, will do the same job for us that it does for them. So the end of January is when we should have all three units done. The XYZ positioner is complete and so is the probe fixturing.

D. P. Cowfer, WANL: I think we should mention here that Los Alamos has provided basic design of the probe itself.

M. D'Amore, WANL: Basically what we are doing is taking the design of external beta backscatter head that Bruce Blanks developed and tying it in with the basic Y-12 electronics system. That would constitute our system. Len's group is doing the design work on the transport work as well as following construction at the research labs. We have taken what we like from each of you people and tied them into a system for ourselves.

E. Price, Y-12: Don't you like our solid state detector?

M. D'Amore, WANL: I think we are very interested in the solid state detectors. There are some features in Bruce Blanks type head that we like a great deal more, and one of these features is the fact that you can operate Bruce's device with a clearance of roughly 40 to 50 thousandths inches. We are saying 10 to 30 thousandths inches but you could exceed that and still have an operational piece of equipment whereas the solid state scintillator requires a much closer contact. Now for the type of transport that we are talking about, where we are to scan down the length of an element or move rapidly from spot to spot that clearance becomes exceedingly handy to us. Those are one of the things we like about it. The other thing

that disturbs us about the solid state scintillator is the state of development. We don't feel that it's as well developed as Bruce's design.

N. Thielke, SNPO-C: Where do you stand on the transport system?

L. C. Vercellotti, Westinghouse Research: The design of the transport has been done with a gamma scan application in mind. We are presently writing a proposal for doing a Gamma Scan system but expect to use virtually the same mechanical transport.

W. Scheib, SNPO-W: You enter the elements in one at a time then?

L. C. Vercellotti, Westinghouse Research: Yes.

N. Pollack, WANL: One of the ultimate goals as far as our activity is concerned is to eliminate all operations that come in contact with the coating, if we can. This is extremely difficult when your periphery goes essentially full length. You still have to hold the element. If you take into account a bore coat, back coat operation where you are only back coating several inches, it is relatively easy to perform as compared with peripheral coat. Now, some existing equipment we have will be modified to take this into account like the internal beta back-holding devices and things like that.

M. D'Amore, WANL: Now, one other comment, Earl. The design of this head can easily be adapted to the solid state scintillators in the event that the development warrants a change to that type system.

B. Blanks, Los Alamos: Earl, aren't our counting times a little different, too. What's your counting time?

E. Price, Y-12: External, 5 seconds.

B. Blanks, Los Alamos: Ours is 2.5. I was thinking that you were a little higher than that.

E. Price, Y-12: Yes, you got a pretty high source strength there, so you can count pretty fast.

B. Blanks, Los Alamos: Yes

N. Thielke, SNPO-C: Are these designs currently in fabrication? Can these handle a larger envelope element?

E. G. Fatzer, WANL: Yes, it's merely a matter of changing the mechanical positioning. You have a pneumatic positioner there and you have to relocate these things but there is no major rebuilding of this equipment. There will be some changes, of course.

N. Thielke, SNPO-C: With that fuel, would we have to order new internal beta backscatter equipment or would that be adaptable in a similar manner?

N. Pollack, WANL: Norm, are you driving at the high void fraction fuel?

N. Thielke, SNPO-C: I am, indeed.

N. Pollack, WANL: We had quite a discussion yesterday on quality control relative to high void fraction fuel. This will require considerable tooling. I would guess that the greatest effort relative to doing high void fraction fuel would be on quality control. For all your probes, all your standards, all your calibration curves would have to be changed to comply with the new design elements. I guess we are quite concerned about this. We had a very brief discussion with Jerry last evening and I haven't had a chance to talk to the Y-12 people, yet, but we do plan to do this while they are here.

V. C. Thompson, Y-12: This is in view of a possible transition threshold?

N. Pollack, WANL: That's right, it appears to be the core only for NRX-A6. It will be a different story for NRX-A7. We do have that problem for NRX-A6 and we are concerned.

M. D'Amore, WANL: The problem facing us with high void fraction is the transport systems on automated equipment. The true position of the holes in a fuel element will change, requiring replacement of the transport systems. The other thing, of course, is the larger size. I don't know how this is going to affect the Astrofuel equipment. I talked to Bruce on the telephone last week about his equipment and he can measure up to .110 diameter holes on beta backscatter. We're talking about .115 diameter holes. If our probes are applicable, and I doubt that they are, this would still mean that we would require replacement of the transport guides. Unfortunately, the plans now for NRX-A6 are to include high void volume elements toward the end of the NRX-A6 production sequence and this infers that we'll have a full production load on our equipment right up until the time we begin getting in high void volume elements. It certainly appears as though we will require

additional equipment. We can't move into our equipment and replace the transport readily, that is, pull the transport out and put the new transport in as we go from one type of element to the other.

N. Thielke, SNPO-C: Would they need to rethink this present requirement of sample of elements or requirement for the NRX-A6 core?

N. Pollack, WANL: Yes, we started this last night, Norm. As a matter of fact, Jim Hutchinson should be working on this whole plan relative to the scheduling activities.

M. D'Amore, WANL: I don't want to infer that that's the only problem we have, Norm, because with the high void element we are going to be getting into complete recalibrations of all our equipment so the load on all our engineering people is going to be fairly extensive.

C. C. Wright, Y-12: You mentioned lift-off monitoring here for safety sake on these probes. What type of monitoring do you plan to use?

E. Fatzer, WANL: The same thing that Los Alamos uses. Have you seen the Los Alamos source design? The photo diode that Bruce has there keeps things from getting so close and banging up an element.

C. C. Wright, Y-12: I haven't seen that.

N. Pollack, WANL: You know, Coleman, it might be desirable if arrangements could be made to get together on Thursday to see what's there and what he has and look at some of these drawings. If this would be of any benefit, we could certainly arrange it. If anyone is interested in taking a ride over to Research, it's between here and Cheswick. I am sure we can arrange it.

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PART 10

ASTROFUEL DATA SYSTEMS

J. P. Richards

Mr. D'Amore, WANL: As Bill Horton pointed out this morning, we are generating voluminous amounts of data and have been doing so since December 1963. Certainly, in the processing of data for gamma scan, particularly final gamma scan where one has to manipulate and correlate the calibration curves and introduce K factors and final weights, the computer has been a tremendous asset to us. We are, at the present time, feeding nearly all of the quality data that we're generating for certification of a fuel element into a computer system at the Astronuclear site using an IBM 7094. We transcribe our card information from Cheswick to this site and we maintain our library file for massive amounts of quality control data here in the computer area. In addition, we've installed a small DEC Model PDP-5 computer at the Astrofuel Facility in Cheswick, and it has been operational for about the last 3 months. We have generated a fair amount of software and we have plans for expanding the capability of the computer activity. Jack Richards, Supervisor of our Data Systems Group, will present the data collection and conversion system this afternoon. The PDP-5 computer is generally used for very prompt conversion of engineering information and conversion of data requirements, usually the same day or within a 24-hour period. The system at Astronuclear using the IBM 7094 is designed primarily for checking the conformance of a fuel element to the various specifications or drawing requirements, and for assisting in making the "accept" or "reject" decisions for each of these characteristics.

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Data System Objectives

The Astrofuel data system activity has two basic objectives. They are: (1) to define and effect the design, development, installation and maintenance of scientific and management information systems for the NERVA fuel program and (2) to provide all cognizant activities with all required data analysis and reports which will affect proper development, production, Non-Destructive Testing (NDT), and release of NERVA fuel materials.

Data System History

During the building of the PAX and NRX-A2 reactor cores, the Astrofuel data system consisted of a great many programs and computer output reports. For the most part these were individual reports which had to be associated and matched with other reports before a fuel element could be evaluated. At one time it took 20 separate computer reports, literally a data package, to release one fuel element. Process and Quality Control Engineering feedback reports were either too late to serve a useful purpose or were virtually non-existent. All of the data processing, with the exception of gamma conversions and other minor analytical calculations, was accomplished on an IBM 1401 medium scale computer that was intended originally and primarily to serve as a feeder and receiver of data to and from a large scale digital computer. To make problems even worse, a great deal of the time it could not be determined if all the data was present. Needless to say, in those days we generated a great deal of useless paper. Toward the end of the NRX-A2 reactor build, things began to improve. By that time we had created an audit that was based on the exception principle. This audit would tell us what data was still needed to complete a data package, which, incidentally, by that time had been reduced to three reports. Even with this and other aids, a great deal of manual decision making was required. After the completion of the NRX-A2 core it was jointly decided by the customer and Westinghouse to place more emphasis on the computer for making routine decisions and for processing all data essential for fuel evaluation and engineering feedback. This decision gave rise to the creation of the present data systems planning and data networks.

Data System Ground Rules And Decision Making Routines

Some of the ground rules that were originally established are still in effect today. They are, primarily, that all data fed into the computer is analyzed, as much as possible, for validity. All data is crosschecked for recording and process errors. It should be pointed out that right now, there exist over 6000 input data computer checks which are accomplished during a single updating of our computer library file. The cross-checks and permutations of these checks are infinite. Another ground rule is that the data package, as you will see later, is to consist of a one-page summary based on the acceptance principle. The only data printed is that summarized data which is requested by various activities, such as Reactor Analysis, Quality Engineering and other cognizant activities; also any data found to be in reject condition. In addition, the data package will be generated only when all of the data requirements are present.

Complete decision making routines have been built into this system. These decision making routines will determine if a fuel element meets all specifications and if not, the system will identify those characteristics which are out of tolerance and print them. All of the data fed into the system is edited, aborted or rejected, processed, calculated, and stored on tape during a single manufacturing process event. All information fed into this system during program update is listed. All errors and their causes are listed. Typical errors that are aborted and reported are: the wrong fuel loadings for a specific serial number or the number of channels; incomplete records; rejected conditions without recordings of out-of-tolerance conditions, disagreement between furnace runs, duplicate serial numbers, a fuel element with two process runs on the same date, out of range gamma counts or beta counts and the like, erroneous profiles, and duplicate data for the same element. This gives you some insight into the type of decision making power we have built into the computer.

Computer Equipment And Basic Programming Scheme

At present, the Astrofuel data system network utilizes two computers for fuel evaluation. One, as Meade D'Amore pointed out, is an IBM 7094 Model 2 computer located at the Large site. This is one of the largest commercially available computers. At the Cheswick

- 1) ASTROFUEL MASTER UPDATE SYSTEM
- 2) ASTROFUEL AUDIT REPORT
- 3) BETA BACKSCATTER MASTER UPDATE SYSTEM
- 4) BETA SYSTEM AUDIT REPORT
- 5) COATING FURNACE MASTER FILE
- 6) BETA SPOT CHECK
- 7) AS MACHINED, LEACHED AND COATED U LOADINGS
- 8) URANIUM LOADING REPORT
- 9) HOLE LOCATION SURVEY
- 10) AIR IMPEDANCE SURVEY
- 11) ELEMENT PROCESS CERTIFICATION AND CROSS-INDEX
- 12) NMDR, VR, AND FUEL RELEASE CHECK LIST
- 13) FUEL ELEMENT RELEASE MASTER
- 14) LOADING DISTRIBUTION SUMMARY
- 15) ELEMENT LOADING SUMMARY
- 16) MATERIAL REVIEW TAG MASTER
- 17) SUPPORT BLOCK SYSTEM MASTER
- 18) FUEL ELEMENT ENGINEERING SUMMARY
- 19) BETA BACKSCATTER EXPERIMENTAL ANALYSIS
- 20) EDDY CURRENT MASTER SYSTEM
- 21) BATCH FORMULATION
- 22) FUEL COATING THICKNESS
- 23) RAW MATERIAL BLOCK REPORT
- 24) ASTROFUEL STATUS REPORT
- 25) ANY TAPE SEARCH (ANTS)

Slide 10 -1 WANL 7094 Computer Programs Operational

site we've used a Digital Equipment Corporation computer Model PDP-5. Again, as Meade pointed out, the 7094 computer is used primarily for the large scale systems where vast amounts of data are processed and computed, recorded and filed on tape. At present, we have a number of operational programs on the 7094. The first slide (10-1) lists these 25 operational programs. The last one is called ANTS, Any Tape Search. With the ANTS program, one can retrieve information from any IBM made tape, no matter what the data is as long as it is digital information.

In April of this year (1965), Westinghouse, through the assistance of the Customer, installed a small-scale computer at the Astronuclear Cheswick fuel facility, the PDP-5.

The PDP-5 is shown in Slide 10-2. This computer has made significant contributions to

Slide 10-2 Model PDP-5 Computer

the nondestructive testing (NDT) effort at Westinghouse Astrofuel. At present, the PDP-5 computer is utilized for process point control, to be discussed in more detail later, and for the evaluation of new NDT projects.

Some of the present PDP-5 programs that are operational are given in Slide 10-3. At Cheswick Astrofuel we have the capability of performing on this small computer all the programs shown. This array of programs is very impressive when one considers the fact that only six months has elapsed since the computer was installed. During this period, the systems analysts had to learn a new basic computer language, as well as the most effective operating techniques. Before the installation of this computer it normally took 2 to 3 days to get useful production reports back to engineering personnel. We are presently enjoying a 2-hour turnaround or feedback cycle. In the past, the implementation of the NDT data processing reports on the computer would normally have taken from one to three months. We have found that our implementation time now takes from one to two weeks. This is a great increase in the time in which our data can be working for us. We have also discovered that NDT engineers have gained a knowledge of computers and their applications and, concurrently, our systems analysts have gained a better understanding of NDT. Within Astrofuel, this constitutes a tremendous gain.

Now before we get into the main Astrofuel process flow, to give you a little better understanding, I would like to show you (Slide 10-4) the data flow for the two computer configurations. We have two types of data flow and data acquisition in fuel processing. The first method is the manual input where data is written and recorded on a source document and then the documents are picked up and manually edited. If any glaring errors are found, the material is returned to the originator, together with a data deficiency report. This has improved the accuracy of data at least 200 percent. After the data is manually edited and found to be basically correct, it is keypunched. After it is keypunched, we perform what we call a keypunch verification. This is nothing more than a re-keypunching of

EVALUATIONS AND ANALYSIS - WAFF COMPUTER FACILITY

OPERATIONAL

1. Inspection Form Design Change
2. FCX Data Package
3. Beta Probe Calibration Analysis
4. Beta Probe Calibration Conversion
5. Internal Beta Backscatter on Elements
6. External Beta Backscatter on Elements
7. Support Block Beta Backscatter
8. Gravimetric Density Analysis on Graphite Samples
9. 18" Beta Backscatter Element Spot Check
10. Fuel Coating Thickness
11. Batch Formulation
12. Joint Leak Test Analysis
13. Eddy Current Analysis
14. Gamma Scan Equipment Check Analysis
15. As Leached Gamma Loading Evaluation
16. As Machined Gamma Loading Evaluation
17. Final Gamma Loading Evaluation
18. Automated Length and Perpendicularity
19. Automated Hole Size Analysis
20. Automated Air Impedance Analysis
21. First Machine Inspection Tabulation
22. As Leached Inspection Tabulation

TO BE DEVELOPED

1. External Beta Backscatter of Filler Strips
2. External Beta Backscatter of Cups
3. External Beta Backscatter of Washers
4. Evaluation of Resistivity Measurements of Coated Elements
5. Green Mix Gamma Scan
6. Evaluation of Infra Red Scanning Technique at Extrusion
(to replace Eddy Current)
7. Evaluation of Gas Chromatography Analysis

Slide 10-3 PDP-5 Computer Programs

Slide 10-4.

BETA BACKSCATTER MASTER PROGRAM

the same data without actually making holes in the card. Any time there is an error, the card is nicked at the top and these keypunch errors have to go back to the keypunch operator where they are re-keypunched. So much for the data acquisition and reduction. Over on the automatic input the data is received from the automated non-destructive testing (NDT) equipment. The data is already in the form of keypunched cards. The cards are then picked up and a manual edit performed similar to the manual data; if there are errors, they go back to the originator. The data flows then can go in two directions. It can go on the PDP-5 computer at Cheswick or it can go to the 7094 at Large. The data at Cheswick is read into the computer memory. A check is made for valid data. If it is not valid it goes right back to the originator. If the data is all right, it is processed, converted, and down here at the bottom of the illustration we get a computer report. When data is sent to the site at Large, we use a transceiver. This transceiver looks something like a keypunch machine, but it transmits over a telephone line to another transceiver at another location (here at Large in this instance) where the card is again punched. I might add that this data flow can also go the other way where we read the cards here at Large and punch them at Cheswick. This data then goes to magnetic tape and the data is checked for validity. If the data is not valid, it goes back to Cheswick for correction. The data is then processed, and the reports are printed.

I'd like to define what occurs during a typical update. The Beta System Master will serve to illustrate this point (Slide 10-5). Data, after it is received here at Large, is first put on magnetic tape. Then all the data of all different types is sorted by fuel element serial number and other arrangements. The data is then fed into the 7094 together with the old master which contains the data they had prior to receiving new information. We then start a new master. As serial number comparisons are made and calculations take place, the old data, together with the new data, is placed on a new master. This process is called updating. What we're doing is introducing the latest information to our magnetic tape file. If we elect, we can delete certain records from the old master. We also produce an output, as shown. Now during this update, the following events occurred. Data is entered and

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ASTRO FUEL MASTER UPDATE PROGRAM

06-23-66

19.794

PAGE

30

NO.	DESCRIPTION	S / N	CARD	CARD IMAGE
621	NEW DATA	39-27516	7005	00049M02076BK59156649H
622	NEW DATA	39-27527	5551	0817500283A
623	NEW DATA	39-27527	5552	1102500340A
624	NEW DATA	39-27527	5553	1107500681A
625	NEW DATA	39-27527	6505	1203500375A
626	NEW DATA	39-27527	7004	12225L00175PC
627	NEW DATA ERROR	39-27527 **	7004	12145C00284BC FIRST FURNACE RUN REPORTED AS C 314
628	NEW DATA	39-27527	7005	00175L12165PC64056499A
629	CHANGE DATA ERROR	39127527 **	7005	00284C12115RC59206407A FURNACE RUN CARD 7004 LACKING.
630	NEW DATA	49-27585	5551	0817500283A
631	NEW DATA	49-27585	5552	1104500342A
632	NEW DATA	49-27585	5553	1109500684A
633	NEW DATA	49-27585	6505	1203500375A
634	NEW DATA ERROR	49-27585 **	7004	12145C00284BC FIRST FURNACE RUN REPORTED AS F 279
635	NEW DATA FP4GR DUPLICATE ON TAPE	49-27585 ** **	7004 7004	C4226F00270SS DUPLICATE FURNACE RUN F - 279 F 279
636	NEW DATA	49-27585	7005	C0279F04206SS65056645A
637	CHANGE DATA ERROR	49127585 **	7005	00284C12115BC60386508A FURNACE RUN CARD 7004 LACKING.
638	NEW DATA	49-27586	5551	0817500283A
639	NEW DATA	49-27586	5552	1102500340A
640	NEW DATA	49-27586	5553	1107500682A
641	NEW DATA	49-27586	6505	1203500375A
642	NEW DATA ERROR	49-27586 **	7004	12145C00284BC FIRST FURNACE RUN REPORTED AS F 279

Slide 10-6. Main Data System Update

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accepted or aborted. Inspection characteristics are evaluated. New data for specific fuel elements is added to the file. Machined, loaded or final loading or profile data is calculated. Fuel element status is determined and various fuel element reports are produced.

Slide 10-6 illustrates a typical updating of our main system. This exhibit depicts the type of input, the fuel element serial number (S/N) and the card code process point. During this point of the update, data input errors were detected. In one instance, a re-introduction of duplicate information was attempted, but was aborted as the data had been previously reported. In this same area, we have a similar condition where erroneous information was introduced pertaining to a coating run. In this case, the input states that an element has just received a coating in Furnace Run C-284. However, the system advises us that this is an error because this element was previously processed in F-279, and is contrary to standard processing specifications. This type of message initiated an investigation to determine the facts, as this is a serious mistake. From the looks of this page, it would appear that several source recording errors have occurred.

Slide 10-7 Astrofuel Process Flow

Application of Data System to Fuel Process

I would like now to describe briefly the Astrofuel process flow and how Process Engineering, Quality Engineering, Reactor Analysis and the Astrofuel Data Network all tie together. Slide 10-7 is a Macro flow chart which indicates the fuel element process flow, the process data points, and the closed loop data input and feedback system. This is basically the normal Astrofuel process fuel flow. In the main column are process points which I defined for computer input many years ago, and the flow chart gives us a data loop for fuel processing feedback through all the operations. The first thing we have is the receipt of all the material analyses. The second process point is the determination of batch formulation. The third is weighing and blending through final extrusion. At this point in time, we're not picking up any data from these points, although we do have available, as will be explained, fuel analysis data which was previously recorded. The next process point is fuel element serialization, followed by cure run and evaluation and the other major process points illustrated, terminating in fuel element evaluation and release. The information is then released to Reactor Analysis.

Some of the details of these process points are:

1) Fuel analysis. Upon receipt of the fuel, we take the measurements on the inspected coating of the fuel. This data goes through PDP-5 processing and gives us a PDP-5 fuel coating process report which then goes to engineering evaluation. Slide 10-8 shows the first PDP-5 report, which is the fuel particle analysis report. It gives us the lot number, the number of divisions, the average (the $\bar{X} - 1$).

2) The next thing that takes place is the batch formulation, also shown in slide 10-8. The specified batch formulation (BF) that we get from Process Engineering, Production Engineering, and the aim loading parameters are fed through the PDP-5 computer and give us the batch formulation, which is then used to take us through weighing and from weighing through extrusion.

3) Slide 10-9 is the first Astrofuel Batch Formulation Report. We converted this report to the PDP-5 program and it gives us a great deal of information. It gives the amount of fuel, DCI (Dry Carbon Ingredient), binder that goes into a batch, gives the total batch weight, predicted composite density, predicted uranium as machined, as cured, as baked, as

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Slide 10-8. Fuel Analysis Data System

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ENTER
ALLOW ONLY ONE SPACE BETWEEN FIELDS
03316 12104 02 1420.2 0.6282 0.280 04.44 0.53 0.28 0.127 0.9315

ASTROFUEL BATCH FORMULATION IOP DATE

BATCH NO=+0.331600E+4 FUEL LOT NO=+0.121040E+5 BOT. NO=+2
K = +0.469421E+4 P = +0.136488E+4 F = +0.142020E+4
SUMW = +0.747929E+4 COMPD = +0.214598E+1 **UAM = +0.119285E+2
**UAC = +0.122974E+2 **UAB = +0.130609E+2 **UAG = +0.130476E+2
SSWT = +0.892169E+3 CARDN = +0.186598E+1 **235AM = +0.111114E+2
**235AC = +0.114550E+2 **235AB = +0.121662E+2 **235AG = +0.121538E+2
XWT = +0.831056E+3 XWT(SUBTOTAL) = +0.166456E+4
F(SUBTOTAL) = +0.284460E+4 SSWT(SUBTOTAL) = +0.178697E+4
** = PERCENT

*****DEPRESS CONTINUE

ENTER
ALLOW ONLY ONE SPACE BETWEEN FIELDS
03317 12104 03 1389.9 0.6282 0.280 04.44 0.53 0.28 0.127 0.9315

ASTROFUEL BATCH FORMULATION IOP DATE

BATCH NO=+0.331700E+4 FUEL LOT NO=+0.121040E+5 BOT. NO=+3
K = +0.459405E+4 P = +0.133576E+4 F = +0.138990E+4
SUMW = +0.731971E+4 COMPD = +0.214598E+1 **UAM = +0.119285E+2
**UAC = +0.122974E+2 **UAB = +0.130609E+2 **UAG = +0.130476E+2
SSWT = +0.873134E+3 CARDN = +0.186598E+1 **235AM = +0.111114E+2
**235AC = +0.114550E+2 **235AB = +0.121662E+2 **235AG = +0.121538E+2
XWT = +0.813324E+3 XWT(SUBTOTAL) = +0.247789E+4
F(SUBTOTAL) = +0.423449E+4 SSWT(SUBTOTAL) = +0.266011E+4
** = PERCENT

*****DEPRESS CONTINUE

Slide 10-9. Batch Formulation Data Report

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SERIALIZATION

CURE

BAKE

Figure 10-10. Fuel Serialization, Bake, and Cure Process Data System

graphitized, will give the total uranium as predicted, the carbon density, predictions for U235 as machined, cured, baked and graphitized. It takes roughly 45 minutes to one hour for an engineer to do this, but the computer does it in less than 15 seconds.

4) Going on through the system, and referring to Slide 10-10, after final extrusion the elements are serialized and we get a verification of serial numbers (S/N). This serial number (S/N) fuel lot or block number is introduced in the form of a punch card into the 7094 computer here at Large and it starts a fuel element serial number file for a particular element.

5) From there the fuel element goes into the cure operation (C), but we first have an engineering evaluation by Process Engineering of the actual cure run. This data is then punched onto a card which consists of the element serial number, the cure run number, and the disposition. This information is also then stored in file for each serial number. The same thing occurs in the bake cycle (B), from which the information is also filed on tape.

6) We then get to the graphitizing furnace run (G), (Slide 10-11), and we have some additional pickup where we have a gravimetric analysis of the graphite. This data is introduced into the PDP-5 and produces the Fuel Element Composite Density Report. The engineer evaluates the density and the graphitizing run data and again obtains serialization, run number, and disposition. This data is placed through the computer and onto magnetic tape for further history of this particular fuel element.

7) We go then, after graphitization, (G), to the first machining operation, (FM), (Slide 10-11). After first machining we have as-machined gamma counts which are fed through the PDP-5. There we obtain incremental, average, and total fuel loading. This information is used for an engineering evaluation which may have feedback to the batch formulation, (BF). At the same time we are getting eddy current input data from the automated eddy current devices. These indicate if the as-machined fuel loading varies significantly from the aim loading. This data also is processed by the PDP-5 and produces attribute eddy current results. Concurrently, feeding another flow as shown in the right-hand column of Slide 10-11, we have as-machined gamma counts, eddy current input data, and dimensional inspection data going to the 7094 computer. A different leg of the same data is also fed through the 7094 at Large. This first goes through an eddy current program and prints out a report. The same

Slide 10-11. Fuel Element Graphitizing and First Machining Operations

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data is also introduced into the main system and filed on tape. The eddy current program is a routine which fits a 19 by 520 matrix. It evaluates the data for internal to internal correlations, internal to external correlations, physical and other characteristics, determines the quality classification and prints out the results. In this particular case, as shown in slide 10-12, it shows the serial number, identifies the operator, the date, the class, and a display of the detected internal indications, external indications, internal to internal, internal to external, as well as any engineering review activity, as shown by the heading MRT (Material Review Tag). It also tells us the number of internal defects, the location of the internal defects by segment number, and the total of external defects.

EDDY CURRENT REPORT -- (NRX-A5)									DATE 10-21-65		
SERIAL NO.	OP. DATE	TRAY	CLASS	HASH	INT. IND.	EXT. IND.	VISUAL	INT. INT.	INT. EXT	MRT	DISP.
99-28808	28 10195	0600	15	NO	YES	YES	NO	NO	NO	NO	R.
LOCATION OF INTERNAL DEFECTS BY HOLE AND SEGMENT NO.											
3-494	10-108	17- 82									
TOTAL INTERNAL DEFECTS = 3											
LOCATION OF EXTERNAL DEFECTS BY SEGMENT NO.											
92	TOTAL EXTERNAL DEFECTS = 1										

Slide 10-12. Typical Fuel Element Eddy Current Inspection Report

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LEACH

Slide 10-13. Fuel Element Leach Process Data System

BORE COATING

Slide 10-14. Fuel Element Bore Coating Process Data System

8) Referring to slide 10-13, during the leaching process (L) as-leached gamma counts are also fed to the PDP-5 computer and an engineering evaluation takes place on this as well as on the leach run data. This data may be fed back to improve or change the batch formulation, (BF), the graphitizing (G), or the leach (L) data for the next furnace run. We also have an as-leached inspection, gamma counts, and dimensional and visual inspections which are then fed through the transceiver to Large and processed on the 7094 computer. These calculations and data are entered and placed on tape.

9) In the bore coating (BC) operations, (slide 10-14) we have a split flow between the elements of the 6 through 9 fuel loadings and the elements of the 3 through 5 loadings. Immediately we obtain an automated Beta count, Mode 1, on two elements for Process Engineering evaluation. The count data is fed to the PDP-5 and we produce a Beta Profile Report, and incremental niobium (NbC) thickness. This information assists Process Engineering and Quality Engineering in determining how well the process was controlled and represents, to some extent, the coating for this particular run for two randomly selected fuel elements. In passing, the data run is a beta backscatter equipment check where we're checking against standards of the beta backscatter equipment and then printing their information out on the computer, after calculations to determine if our beta backscatter equipment is in control and is stabilized. Another example of the PDP-5 activity in non-destructive testing is where the counts taken during the calibration of a probe are processed to determine probe acceptability. These counts are made on a daily basis to determine if our equipment is performing within specification. This data is also transceived to Large for generating a Mode 1 Beta Backscatter Report on the 7094. This report gives the relative position and the Channel II coating thickness for a specific fuel element, and indicates the probe used. If an element is to be a peripherally coated fuel element, we release these profiles after Quality Engineering evaluation. Quality Engineering reviews this Beta system report to determine what elements to release and what elements to retest. This data is then released to the main system.

10) In slide 10-15, you will see that after the peripheral and back coating (P/BK), quality control inspections and tests are performed on the fuel elements. The beta count data is again run through the PDP-5 to obtain profiles on two fuel elements. This data, along with the parametric furnace data is evaluated to determine compliance of the furnace run with the specification. After evaluation the serial and run numbers, run data, profiles, coating type, weight changes, and disposition are fed to the 7094 system.

At the same time, through a separate feeder system, we do the Model III beta backscatter on all elements. This data generates a Beta System Profile Report which is used for engineering review and release of peripheral and back coating (P/BK) profiles to the main system. Also, simultaneously, a serial number verification is made of the run number reported by Quality Control against the run number reported by Production to assure that we have valid information. Quality Control also makes gamma counts on the 6 through 9 loadings, along with final dimensionals, air impedance, final weight, leak test, corrosion results, coating thickness (on a Microderm test instrument), and, with a Mode III static and dynamic NbC profile, the data is introduced into the main system.

11) With all of this data we are then in a position to create the data package (DP) shown in slide 10-16 and the data report shown in slide 10-17. As you remember, it originally required 20 separate reports to effect a fuel element evaluation. These 20 reports are now condensed to this one-page report where (slide 10-17) you can see that it gives you the serial number at the top, the batch and block numbers, the date that the package was created, and the run number. Reading down from the top left-hand corner, Paragraph 1 reports the process run summary disposition. If all processes are complete and acceptable with no Variation Requests (VR's), the word NONE is printed. In Paragraph 2, the first machining inspection data is displayed; only when a characteristic is out of specification is any data printed here, but without exception the eddy current class and unfueled tip length are printed at the bottom of this paragraph. Paragraph 3 displays hole data, which takes into account both size and location. In Paragraph 4 the coating deposit data describes the furnace run number and if it was acceptable (AGC), the type of run (bore coat (BC), back coat (BK), or peripheral coat (PC)), the date, the coating weight deposited (DEP), and

PERIPHERAL AND
BACK COATING

Slide 10-15. Fuel Element Peripheral and Back Coating Process Data System

DATA PACKAGE

Slide 10-16. Fuel Element Process Data Package

ELEMENT SERIAL NO. 99-26404

BATCH AND BLOCK NO. 02878 - 14

FUEL ELEMENT DATA REPORT

DISPOSITION - ACCEPTED

99-26404

DATE 10-22-65
RUN - 1

1. PROCESS RUNS

ALL PS 294611 OPERATIONS HAVE BEEN COMPLETED. THE FOLLOWING VRS APPLY.

NONE

2. FIRST INSPECTION DATA

ALL CHARACTERISTICS ACCEPTED PER DRAWING 937J820-- WITH THE FOLLOWING EXCEPTIONS OR QUALIFICATIONS.

NONE

EDDY CURRENT CLASS 12 ACC
TIP LENGTH 0.970 ACC

3. HOLE DATA

HOT ENC - ACC
SELECTED A WAFER DATA

02 .009 190 07 .010 230 11 .010 280

4. COATING DEPOSIT DATA

RUN	TYPE	DATE	DEP	VR
C 251	ACC	BC 08305	50.9	
C 252	ACC	BK 09015	4.1	

5. FUEL LOADING AND COATING PROFILE DATA

BGRE COAT RUN NO. C 252 PDS 3CC21-F-1

RCG PCS	LOADING (GM/IN)	PERCENT DEV	COAT THICK
1			
3	2.44	0.29	1.80
6	2.48	1.99	1.83
9	2.49	2.41	1.83
12	2.48	2.00	1.88
15	2.49	2.31	1.91
18	2.50	2.68	1.89
21	2.49	2.24	1.84
24	2.49	2.23	1.78
27	2.49	2.06	1.73
30	2.48	1.99	1.62
33	2.50	2.01	1.49
36	2.49	2.32	1.38
39	2.49	2.27	1.23
42	2.49	2.31	1.10
45	2.50	2.50	0.99
48	2.50	2.80	0.86
			0.77

BETA SPOT CHECK

ACC

CORRCSION C 252 181010 REJ 20C03 -0 A

6. LOADING AND WEIGHT SUMMARY

AVERAGE LOADING (GM/IN) = 2.49
TOTAL URANIUM WEIGHT = 127.045
TOTAL U WT PERCENT DEV = 2.20

CALCULATED URANIUM LOSS = -1.1
ADJ NON-PERIPH WT GAIN = 53.4
PERIPHERAL WEIGHT GAIN = 0.

TOTAL NB NET WT CHANGE = 55.0
TOTAL CARBON WEIGHT = 524.755
TOTAL ELEMENT WEIGHT = 705.20
FURNACE RUN NO. C 252

7. AIR IMPEDANCE DATA

CHAN	DIA	CHAN	DIA	CHAN	DIA
1	.0953	2	.0956	3	.0953
4	.0956	5	.0955	6	.0955
7	.0956	8	.0953	9	.0956
10	.0955	11	.0954	12	.0953
13	.0953	14	.0952	15	.0952
16	.0953	17	.0952	18	.0953
19	.0951				

FURNACE RUN NO. C 252

8. FINAL INSPECTION DATA

ALL CHARACTERISTICS ACCEPTED PER DRAWING 937J820-- WITH THESE EXCEPTIONS OR QUALIFICATIONS.

NONE

END COAT CL 1 ACC
SIDE COAT CL 1 ACC

9. BLANKET DEVIATIONS

ELEMENT SERIAL NO. 99-26404

* - INDICATES OUT OF TOLERANCE

Slide 10-17. Typical Fuel Element Data Report

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whether or not any variation request (VR) was necessary. In Paragraph 5 fuel loading and coating profile describes the incremental loading in grams per inch, percent deviation from nominal, and the coating thickness. It reports the beta spot check results. It also gives the results of the corrosion test and classification assigned. If the element was rejected you may have a VR, either still rejecting it or showing acceptance. Paragraph 6 displays a loading and weight summary. This section reports the average uranium loading in grams per inch, the total uranium weight, percent deviation from nominal, the calculated uranium loss, whether there's any adjusted non-peripheral weight gain, the total niobium net weight change, the total carbon weight, and the total fuel element weight. We then have a check down at the bottom to make sure we have the last final weight for that particular element. In Paragraphs 7 and 8 the air impedance and final inspection data are reported. At the bottom of Paragraph 8 the end and the side coat classification is displayed. In Paragraph 9 are listed any blanket deviations or waivers that have been approved. As you can see, the data report allows a complete review of the fuel element processing.

Data System Improvements Planned

I'd like to show three more slides. With the limited amount of manpower that we have available, anything that we can do, any type of labor-saving device that we can dream up proves to be to our benefit. Slide 10-18 shows a computer-generated flow chart, generated from its own internal logic. Now I understand that IBM has come out with such a program, but to the best of my knowledge we were about 2 to 3 months ahead of them. This chart will tell you exactly what calculations and checks take place during a gamma calculation. This chart is designed so as to be intelligible to a layman who understands the fuel processes. This system arrangement will probably give us about 20 percent greater output from our programmers and analysts because such a calculation used to be performed by hand; now we have it done by the computer.

As to the future of the Westinghouse Astrofuel digital computer, we're going to expand it, as shown in slide 10-19. We're going to do three things with it. First we're going to

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Slide 10-18. Computer Generated Process Flow Chart

PROPOSED ASTROFUEL DIGITAL COMPUTER FACILITY

Slide 10-19. Astrofuel Proposed Digital Computer Facility

610792-2B

Slide 10-20. Astrofuel Proposed Automated Production and Inventory
Control Data Acquisition System

create a satellite so that we can talk with the 7094 computer at the Large Site. The second thing we're going to introduce is process point control and feedback right out on the inspection floor. Third, we're going to introduce some production and inventory controls. The PDP-5 computer will consist of some magnetic tapes, a larger core, a medium speed line printer, and a random axis drum for storing production and fuel element status information out on the shop floor. Information transfer will occur via a communications buffer and data set. The information will be sent to Large where it will be received through a second data set. This data will be automatically placed on magnetic tape, processed on the 7094, sent back to Cheswick through these data links and printed out on a line printer. Today we're printing data packages down here at Large. I hope that in the near future we'll be printing them at Cheswick automatically. Out on the floor, as seen in slide 10-20, at the other end of this system we will have transactors which will feed information through a controller and coder that sort on the magnetic drum we saw on the previous slide. It will also feed information in from the automated testing devices through the PDP-5 computer and then print the results out again on a teletype printer. This we also hope to have in the near future.

PART 11

EDDY CURRENT AND BETA BACKSCATTER

MEASUREMENTS

E. Price

M. D'Amore, WANL: The first speaker from Y-12 will be Earl Price. He will talk on Beta Backscatter Measurements. He will discuss gage operations, probe design, calibration and loading curves, equations, readout and beta backscatter and metallographic comparisons.

The first slide (11-1) is a view of our internal beta backscatter equipment for 19-hole elements. It utilizes the scintillator-light pipe-photomultiplier detector system. We use a Dymec amplifier and a voltage-to-frequency converter. The photomultiplier tube detects dc level variations that represent variations in bore coating thickness. The voltage-to-frequency converter changes the dc level to pulses, and these pulses are counted by the RIDL counter. Our counting time is five seconds. The readout system scans the counter decades and activates an IBM card punch. We have revised this gage somewhat since our last meeting. A second probe drive motor has been added at the top of the gage. This probe drive motor is used only to pull the probe out of the element. An electric clutch has been added to the original drive motor which is de-energized when the top motor starts pulling the probe out

Slide 11-1. Y-12 Internal Beta Backscatter Equipment

Slide 11-2

BBS-12 BLOCK DIAGRAM
0.086" GAGE ELECTRONIC SYSTEM

Slide 11-3. Beta Backscatter Probe Assembly

Slide 11-4. Source Holder

of the element. The electric clutch on the top drive motor de-energizes when the motor starts driving the probe down into the element. We installed this second drive motor to eliminate light pipe breakage and to reduce the chance of source capsule breakage. The installation of this drive motor at the top was primarily a nuclear safety measure. The 5 inch increment cam, which is bolted to the frame, was relocated to the rear. A limit switch, which resets the counter at each 5 inch increment, keeps a positive pressure on the photomultiplier box and causes less probe vibration. Another change to the gage which was for nuclear safety purposes was the addition of a Plexiglas door to the front of the gage. A split door design was incorporated. The top part of the door is used to shield the operator when source removal is being performed. We used Plexiglas for the doors to permit clear viewing of the element and probe motions. We have also added some rubber padding and felt cloth to all of the areas around the gage where end coat damage might result from bumping the element. The operation of these gages has been quite satisfactory.

A block diagram of our internal beta backscatter gage is shown in slide 11-2. We have added a high voltage power supply to the photomultiplier tube. The light pipe is coupled to the photomultiplier with silicone grease. The output of a dc amplifier is fed to the voltage-to-frequency converter, which changes the dc signal to pulses.

The output of the counter digits are detected by a serial converter with a stepping switch; the digits are then fed to the IBM card punch. We have several requests for making quick measurements on coated elements that are just out of the coating run. These "courtesy check" elements are reported out manually from a calibration curve. To reduce the amount of time and effort required, we have experimented with a direct readout system utilizing a curve follower. A calibration curve is transposed to a metal photoplate and this metal photoplate is attached to an X-Y recorder-digital voltmeter system. In addition, the possibility of attaching a function generator to the dc amplifier has been considered. The design for the function generator is in progress at this time. We feel that this will save a significant amount of time each day.

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THICKNESS CURVE
INTERNAL BETA BACKSCATTER
(LIGHT PIPE NUMBER 21)

Slide 11-5

LOADING CURVE
INTERNAL BETA BACKSCATTER
(LIGHT PIPE NUMBER 21)

Slide 11-6

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Slide 11-3 is a sketch of our present internal beta backscatter probe assembly. This is the same assembly we had last year. The light pipe or quartz rod is 60 inches long. The plastic scintillator is about 1/8 inch long. The shield is about 0.040 inch thick. The source is about 0.030 inch in diameter. A retention plug is used to hold the source stationary. The source holder is about 4 inches long. A silicone grease coupling is also used between the scintillator and light pipe.

Slide 11-4 shows a new source holder design which will permit a 360 degree window. Since we have two gages at Y-12, we must calibrate both of the gages so that they will read the same thickness for a given coating. The three stainless steel ribs have to be aligned in the same position on Gage 1 as on Gage 2 in order to make both of the gages read the same thickness in a given element. The position of the source in these windows is very critical. We sometimes have to adjust the sources a very small amount in order to make both gages agree. We feel that the support ribs on the coupling are detrimental to maintaining equal calibration. Therefore, we searched for a material which we could use as a 360 degree window and one which would be strong enough to withstand the normal stresses applied to the probe. In investigating beryllium we found that this material would indeed be equal in strength, or perhaps a little stronger than, the source holder we now have if the wall thickness was about 0.008 inch. This would be equal to 0.016 inch attenuation since the radiation must emerge through a 0.008 inch wall and the backscattered radiation must return through a 0.008 inch wall. With this beryllium source holder we can achieve an effective 360 degree window. We made the partition 0.015 inch thick, and we plan to insert a piece of gold 0.010 inch thick by 0.045 inch in diameter as a forward radiation attenuator.

Before we selected this material for fabrication, a method was needed for connecting it to the reamer tubing. We discussed this with the Y-12 Development Weld Shop. They had recently developed a method of brazing monel to beryllium. Two of these beryllium pieces were fabricated and the leak check tests were satisfactory. Fabrication of the improved

BPS CALIBRATION EQUATIONS

LIGHT PIPE # 78

COUNTING DATE 100865

STANDARD THICKNESS	AVERAGE COUNTS	FOR LOAD OF	CALC T FOR LOAD OF
	D.	318.	478.
0.	379.	512.	553.
0.65	545.	651.	675.
1.20	638.	719.	745.
1.91	721.	784.	813.
2.86	800.	840.	866.
3.45	839.	879.	891.
4.45	894.	912.	920.
C	964.	960.	955.
V	367.	353.	24.

LOAD	A	B	C	LOAD	A	B	C
133.	13.1264	4.8447	959.7	259.	12.6447	4.7443	959.7
140.	13.1025	4.8405	959.7	273.	12.5852	4.7300	959.7
148.	13.0747	4.8356	959.7	287.	12.5246	4.7151	959.7
155.	13.0500	4.8311	959.7	302.	12.4587	4.6986	959.7
163.	13.0213	4.8257	959.7	318.	12.3872	4.6802	959.7
172.	12.9886	4.8194	959.7	335.	12.3100	4.6600	959.7
181.	12.9552	4.8128	959.7	353.	12.2270	4.6378	959.7
191.	12.9176	4.8051	959.7	371.	12.1427	4.6148	959.7
201.	12.8792	4.7971	959.7	391.	12.0477	4.5884	959.7
211.	12.8402	4.7888	959.7	412.	11.9467	4.5597	959.7
222.	12.7966	4.7793	959.7	422.	11.8981	4.5458	959.7
234.	12.7482	4.7684	959.7	431.	11.8542	4.5331	959.7
246.	12.6990	4.7571	959.7	433.	11.8444	4.5302	959.7

Slide 11-7

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11-8

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design is continuing. When an automatic computer system for converting counts to niobium carbide thickness is used, an equation must be formulated from the calibration curve which one plots. The calibration curves from the gages at Y-12 seem to best fit an exponential equation. Therefore, the logarithmic equation has been selected to obtain the equations to be used in our computer program. In the logarithmic equation a 5 second count value in apparent infinite thickness is arbitrarily selected on a trial and error basis. The counts at each thickness level are subtracted from this infinite thickness count which is referred to as the "C" constant. The "C" minus Counts values are plotted on the logarithmic side of semilogarithmic graph paper. The thickness, in mils, is plotted on the linear side of the graph. When the points fall in a straight line on the semilogarithmic paper, then one knows that the "C" value has been ascertained correctly. If one has arbitrarily selected a "C" value that is too high, the points will cause the curve to bow up. If one selects a "C" value that is too low, the points will cause a downward curve. When the proper "C" value is selected, a straight line will be obtained. These points will vary from the line in the normal manner due to the statistics of counting. We have plotted on the curve, Slide 11-5, our three standards. The standards are for zero load, the 318 mgU/cc load and the 478 mgU/cc load. These standards were prepared at Los Alamos. The same thickness foils were placed in each of the standards.

Slide 11-6 shows a loading curve plotted on semilog paper for these three standards. We experimentally determine the count at an apparent infinite loading (the loading at which the count will not increase when the load is increased). We plotted the zero liner thickness counts for each of the three loadings to make one curve. Then we plotted the counts at 0.001 inch thickness for each of the loadings to make the second curve. Then we plotted the counts for 0.003 inch thickness for each of the loadings to make the third curve. When the proper "C" value for each of the three plots was determined, straight lines resulted. From this graph we interpolate for any loading that is desired, and we compute a liner thickness equation for each desired loading.

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COMPARISON OF CALIBRATION EQUATIONS FOR
BETA BACKSCATTER THICKNESS MEASUREMENTS

LIGHT
PIPE

75

LOAD
MG U/CC

0

ALGEBRAIC
SUM

0.22

318

0.15

478

0.21

24

0

0.20

318

0.22

478

0.21

75

0

0.01

318

0.00

478

0.04

24

0

0.02

318

-0.01

478

-0.01

75

0

-0.02

318

0.03

478

0.03

24

0

-0.02

318

0.02

478

0.02

LE SINGLE
COMPUTED
FROM
RESIDUALS

± 0.35

± 0.24

± 0.16

± 0.20

± 0.22

± 0.23

MEAN LE ± 0.23

± 0.19

± 0.20

± 0.12

± 0.13

± 0.14

± 0.22

MEAN LE ± 0.17

± 0.21

± 0.34

± 0.45

± 0.17

± 0.22

± 0.42

MEAN LE ± 0.30

RESIDUAL = CALCULATED T - STANDARD T

STANDARD T, MILS: 0.00 0.65 1.20 1.91 2.86 3.45 4.45

Slide 11-8

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Slide 11-7 shows a printout of the automatic computer program which is used to determine the equations for any gamma loading. The Phoebus 1B core has 31 different loadings. We have printed here 26 of these loadings. Our computer program also prints out an equation for carbon. Calibration data is taken on the primary standards with each beta backscatter gage and is punched on IBM cards. The thickness of each foil is punched into a card along with 10 counts of 5 seconds each on that thickness. The counts are made with the probe moving very slowly to offset high and low counts due to heavy concentrations of uranium beads in given areas. An IBM card for the zero load is made for each of these thicknesses and a card for the 318 mgU/cc load is made for each of these thicknesses, and the same applies to the 478 mgU/cc load. The standard thicknesses represented are 0, 0.00065, 0.0012, 0.00191, 0.00286, 0.00345, and 0.00445 inch. An average of 10 counts for each of the thicknesses is listed. One IBM card for each of the thicknesses of each loading is included with the calibration data. The computer program will take the data for a given standard, for example the carbon standard, and will compute a trial "C" value of asymptote. The computer program will effectively plot these points on semilog paper and compute the variance of each point from a straight line. When the variance has reached the smallest value, the asymptote at that value is used. The asymptote is 964 in the case shown. The asymptote for the other two loadings is computed in the same manner. Since the infinite thickness should be the same for all loadings, an average of these asymptotes is used in the final equations. The counts used in the calibration are computed using the average asymptote and are printed out. We prepared the table so that we could observe the deviation of the computed thickness from the standard thickness. Calibration equations are accepted or rejected if the sum of the thicknesses are different from the sum of the standard thicknesses by 0.0001 inch. The A, B and C values for each of the loadings are printed out. The cost for the computation of the equations amounts to about 60 cents compared to about three days for a manual determination of the equation.

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11-12

WANL BETA BACKSCATTER--DAILY---CC

3-13-65

ELEMENT	LP	FOLE	1	2	3	4	5	6	7	8	9	10	AVERAGES CT	WT	BC NO GRADE
QC-99937	21	01	.3	.2	.1*	.3	.7	1.0	1.3	1.6	1.9	2.1			
		10	.5	.4	.2	.4	.9	1.2	1.4	1.6	2.0	2.2			
		19	.4	.2	.1*	.3	.7	1.1	1.3	1.5	1.9	2.1			
		AVG	.4	.3	.1	.3	.8	1.1	1.3	1.6	1.9	2.1	1.0	.	3
QC-99942	69	01	.3	.2	.1*	.3	.7	1.0	1.2	1.5	1.8	2.2			
		10	.4	.3	.1*	.4	.8	1.1	1.3	1.6	1.9	2.2			
		19	.4	.2	.0*	.2*	.6	1.0	1.2	1.4	1.8	2.1			
		AVG	.4	.2	.1	.3	.7	1.0	1.2	1.5	1.8	2.2	.9	.	3
QC-99943	21	01	.3	.2	.0*	.3	.7	1.0	1.3	1.6	1.9	2.1			
		10	.4	.3	.1*	.4	.8	1.2	1.4	1.7	2.0	2.2			
		19	.3	.2	.0*	.2*	.7	1.0	1.3	1.5	1.8	2.1			
		AVG	.3	.2	.0	.3	.7	1.1	1.3	1.6	1.9	2.1	1.0	.	3
QC-99946	69	01	.4	.2	.1*	.3	.7	1.0	1.3	1.6	1.8	2.2			
		10	.5	.3	.2	.4	.8	1.1	1.4	1.6	2.0	2.3			
		19	.4	.2	.1*	.2*	.7	1.0	1.2	1.5	1.9	2.2			
		AVG	.4	.2	.1	.3	.7	1.0	1.3	1.6	1.9	2.2	1.0	.	3
QC-99951	69	01	.3	.2	.1*	.3	.7	1.0	1.2	1.6	1.7	2.2			
		10	.5	.3	.2	.4	.8	1.1	1.4	1.6	1.9	2.3			
		19	.4	.2	.1*	.3	.7	1.0	1.2	1.4	1.8	2.1			
		AVG	.4	.2	.1	.3	.7	1.0	1.3	1.5	1.8	2.2	1.0	.	3
QC-99952	21	01	.3	.2	.0*	.3	.7	1.0	1.3	1.6	1.8	2.1			
		10	.4	.3	.1*	.4	.8	1.1	1.4	1.6	2.0	2.2			
		19	.3	.2	.0*	.2*	.7	1.0	1.3	1.5	1.8	2.1			
		AVG	.3	.2	.0	.3	.7	1.0	1.3	1.6	1.9	2.1	.9	.	3
QC-99956	69	01	.4	.2	.1*	.3	.7	1.0	1.3	1.6	1.8	2.2			
		10	.5	.3	.2	.4	.8	1.1	1.4	1.6	2.0	2.3			
		19	.4	.2	.1*	.2*	.7	1.0	1.2	1.5	1.9	2.2			
		AVG	.4	.2	.1	.3	.7	1.0	1.3	1.6	1.9	2.2	1.0	.	3

17*

17**

Slide 11-9

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Slide 11-8 shows the comparison of three calibration equations for the beta backscatter gage. The first group of values was determined by using the semilogarithmic equation; the second group of values was determined by using the reciprocal equation. The third group of values was determined by using the quadratic equation. The algebraic sum was determined from the standard foil thicknesses that were seen on the previous slide. The mean limit of error (95 percent Confidence Level) computed from the residuals for the semilogarithmic equation was ± 0.00023 inch, for the reciprocal equation it was ± 0.00017 inch, and for the quadratic equation it was ± 0.0003 inch. From this study it can be seen that the reciprocal equation fits the points better than either of the other two. However, the semilog equation is not significantly different from the reciprocal equation.

Slide 11-9 is our quality control printout from the 19-hole internal beta backscatter gage. The beta backscatter gage number is referred to as the "light pipe" number and also designates the equation number. Measurements are shown for both gages. The thicknesses vary within a spread of 0.0001 inch from day to day and from gage to gage.

This is a comparison of thicknesses between the external beta backscatter gage and metallographic thicknesses (Slide 11-10.) An attempt was made to calibrate the external beta backscatter gage to metallographic thicknesses. In order to do this several measurements were made by both methods at specific points on the external coating. The metallographic thicknesses were plotted against the beta backscatter counts from those points. From element to element we observed a considerable variation of the curves. The niobium foil curve is represented by the solid line. It is apparent from the plot that the density of the niobium has varied considerably from element to element. However, it is also apparent that a meaningful calibration cannot be made with a metallographical thickness and still retain our measurement tolerance.

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BETA BACKSCATTER COUNTS VS. Nbc THICKNESS

Slide 11-10

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Comparison of Metallographic and Beta Backscatter
Thickness Measurements of NbC

Position I 3/16", II 17/16", III 11/16"   ● Metallographic   ▲ Beta Backscatter
Vertical Connecting Line: Difference between methods

Slide 11-11

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Comparison of Metallographic and Beta Backscatter Thickness Measurements of NbC

Position I 3/16", II 17/16", III 11/16" ● Metallographic ▲ Beta Backscatter
 Vertical Connecting Line: Difference between methods

This is another plot (Slide 11-11) of four elements that were checked and measured metallographically at the same points as had been measured on the beta backscatter gage. You will notice that this plot has been divided into bands around the 0.006 inch thickness and around the 0.0016 inch thickness. A thickness bias of 0.00027 inch was computed for elements in the 0.0016 inch thick range and a 0.0004 inch bias was computed for the 0.0006 inch thick range. This plot also shows that a calibration curve using the metallographic thicknesses is almost impossible to repeat from element to element.

Slide 11-12 shows another thickness range where all of the measurements made on the beta backscatter gage and by the metallographic method agreed much closer. Each one of these plots represents an element, and the constant bias of 0.00021 inch is shown. If all the elements exhibited this much consistency of disagreement, then a calibration to metallographic thicknesses could more reliably be made.

DISCUSSION

Dr. Tenney, LASL: That section element is one element, is it not?

E. Price, Y-12: Yes, it is one element.

Dr. Tenney, LASL: Then how do we have one going in this direction and the other going in this direction?

E. Price, Y-12: Well, of course that is right, maybe the curve went something like that, I don't know, but it looks like there is a discontinuity in either the coating density or else the measurement.

E. Fatzer, WANL: How far up did you go linear? Did you go up to 1.6 there or 1.5?

E. Price, Y-12: Well, yes, 1.7, 1.6. This one says 2.0. Now this is a metallurgical thickness of course.

D. Cowfer, WANL: All in the same probe, is that right?

E. Price, Y-12: Yes, we're correlating to the foil on the element. Well, this is plotted against the counts, actual counts so here we can compare that curve to this foil curve. But if we didn't have this foil curve on here, we had nothing on here but this curve and that one, that would be the calibration curve I would be presenting and it doesn't make sense.

Dr. Tenney, LASL: You cannot compare apples and pears. You cannot compare beta backscatter with metallographic thickness.

E. Price, Y-12: That is my conclusion.

Dr. Tenney, LASL: We knew it all the time.

E. Price, Y-12: Element to element, you will have a considerable amount of variation. If we had chosen only this element and this one we would say yes there is a good comparison. There is not much bias between them. But it so happens that we got that element and this one, and the next two slides will show the same thing. We have three elements here. This is an old evaluation which we made, and I mean these four elements right here, and the thickness in these four elements varies from 0.4 to 2 mils.

Dr. Tenney, LASL: What is the length of your window when you are performing beta backscatter, 30 mils?

E. Price, Y-12: This is external.

Dr. Tenney, LASL: Yes, but what is the length of your window?

E. Price, Y-12: A quarter inch diameter circle.

Dr. Tenney, LASL: Then it is a finite length in the axial direction, in other words, you are integrating, therefore, niobium carbide thickness over a diameter of a quarter of an inch. Then you go and cut them and measure them metallographically in one place.

E. Price, Y-12: No, we are more meticulous than that. We did that in this case, but we considered that something must have been wrong with our experiment, and the case presented in the curves, we measured these. We make measurements every $1/16$ of an inch on this element. We ask the metallographic people to saw the element off at our first $1/16$ of an inch. Another one here, here and here. We just moved that probe $1/16$ of an inch rather than a quarter of an inch, you see. In order to get a good profile of that coat, we first saw the element off here, they took a measurement, then they sawed it off $1/16$ of an inch and took another measurement and did this all the way down. We just used a data, not the data behind this piece of brass but these two $1/16$ of an inch measurements right in here, which we were looking at and which they could look at, metallurgically. Now here we have a range, I want you to notice that this is a $6/10$ th mil range and this band here is a selected average we can observe a correction factor of about $4/10$. But here we have a 0.27 thickness difference between metallurgy and beta backscatter.

E. Fatzer, WANL: Now that is a 6 tenths mil, is that right?

E. Price, Y-12: Yes, that's right. At 6 tenths mil level on the other slide we had a spread of, well we averaged $4/10$ or more.

Dr. Tenney, LASL: What is this 0.21?

E. Price, Y-12: 0.21 is the difference from beta backscatter to metallurgy. That's an average on a mean value.

E. Fatzer, WANL: It looks like it is pretty constant there, is it?

E. Price, Y-12: Yes.

Dr. Tenney, LASL: So it means it's about 33 percent of the range.

E. Price, Y-12: I didn't understand.

Dr. Tenney, LASL: That's about 33 percent of your thickness.

E. Price, Y-12: That's right, that's 33 percent of the thickness. Well, of course, the variation should be considered only from the metallurgical point here, and here, which would be half that, 15 percent. The metallurgical thickness itself varies 15 percent.

W. Scheib, SNPO-W: Do you have the corresponding slides of the 1.6 position?

E. Price, Y-12: There were no thinner positions on that, that was the thinnest. On those elements, in fact, I guess that was the thickest spot on the element.

W. Scheib, SNPO-W: The thickest elements you had though were about 1.6 or 1.7?

E. Price, Y-12: Well, it had a varying range, It went from 4/10, and it had a gradual increase to two mils. These last six had a very flat external coat.

W. Scheib, SNPO-W: But isn't your major problem in the 1.5 to 1.8 mil area, where this major discontinuity occurred?

E. Price, Y-12: I'd say that is an individual element problem. We didn't have the same problem in the other two elements that we had on that curve. I don't know what caused the discontinuity in the dotted line curve.

N. Thielke, SNPO-C: I hear words around the Laboratory here that at about 1.7 mils, there is some change in the slope of the curve, which represents a difference in the probe response.

E. Price, Y-12: Well, you are referring to internal beta backscatter there. I don't know if we would have the same situation on the external beta backscatter.

N. Thielke, SNPO-C: I was going to ask you next, is there a corresponding problem on the internal beta backscatter?

E. Fatzer, WANL: Is all this data taken on unfueled elements?

E. Price, Y-12: Yes, they were.

E. Fatzer, WANL: None of that was from fuel elements.

E. Price, Y-12: No. We, of course, have carbon tips on fuel elements, and we do take measurements on the thin back coat. We consider that the carbon element should be representative. Norm, did I finish answering your question? Do you have another question that I didn't answer?

N. Thielke, SNPO-C: No, I am just getting more and more puzzled.

E. Fatzer, WANL: Do you take your beta backscatter averages when you figure your gamma scan, your loading from the average, right?

E. Price, Y-12: That's right.

E. Fatzer, WANL: Dave said they figure each and every element for their loading. Is that right, Dave?

D. Cowfer, WANL: Yes.

E. Price, Y-12: Of course, we do a beta backscatter on one hole, routinely.

D. Cowfer, WANL: You do a beta backscatter routinely on all elements?

E. Price, Y-12: Yes, and that thickness for each of the increments is used in the correction factor for the gamma counts for the corresponding element. I think that is the same way that Dave does them. Is it?

D. Cowfer, WANL: We do make an individual comparison on the reading at a given increment. We have 16 readings on gamma and 16 readings on beta backscatter and we correlate these.

E. Price, Y-12: Of course, we do the same thing with our niobium thickness.

D. Cowfer, WANL: I am talking about the discrepancy indicated between the two systems on that control element. Is that raw data counts difference or indicated thickness?

E. Price, Y-12: Oh, you mean when I led into the beryllium window. The discrepancy, I think, is caused by the different positions of the window.

D. Cowfer, WANL: You are talking about just counts right now.

E. Price, Y-12: Well, that's beta backscatter, is that what you are referring to?

D. Cowfer, WANL: Yes.

E. Price, Y-12: I will sketch what I meant. I have a photomicrograph there of a coating which had a thick place on it and that's we'll say there's a crack in this element and the coating went down in the crack. Now this is one hole, let's say No. 10 hole, and the crack's right down here. The present probe design for the beta backscatter has three windows. Three single steel windows here that attenuate the betas that come from the source. The betas come out this way, out through these slots. If on one gauge, our slot is oriented here, and here, and here the betas will see this big slot. Maybe it falls at an axial crack. Then we re-calibrated and screwed the source back into the second gauge, and our window ends up right here, and here, and here on the other gauge. Then we do not see that.

D. Cowfer, WANL: We attempt to line up the windows the same relative position within a few degrees.

E. Price, Y-12: That isn't the only thing that will give you trouble. The sources are not loaded symmetrically in the capsule, and turning those infinite amounts, or an unmeasurable amount at least, for as far as we are concerned will cause a change in the slope of the calibration curve--a considerable change. The Strontium 90 is really loaded as one little glob and it can be located over to one side. I mean this rib is in such a position that it would attenuate a large amount of betas, and you would have a change in the slope of your curve.

B. Blanks, LASL: Do you attribute the correlation studies, the correlation studies with metallography to the inconsistencies of the metallography or the beta system, or what?

E. Price, Y-12: No sir, not at all. The metallographic measurements were good to plus or minus a tenth of a mill and some were better than that. The beta backscatter were comparable because all of the measurements on each case, in other words, they evaluated all the

different readings to the same point, to the same location, and they gave an evaluation which we added in the tolerance plus or minus and come up with the answer.

N. Pollack, WANL: You mean you had a void in your source container there, Earl? Can that glob float around in there?

E. Price, Y-12: I don't know if it is a void or not.

C. Wright, Y-12: It's not free to move in there, Earl?

E. Price, Y-12: No, it's not free, but I am talking about when I screw the source in, it's threaded. This will, of course, move it.

N. Thielke, SNPO-C: How often do you do this?

E. Price, Y-12: Well, of course, it depends on light pipe breakage. Usually not more than every month and a half. The source itself sometimes works loose during production.

Dr. Tenney, LASL: What is the ratio between the transparent and the opaque portions of your source container?

E. Price, Y-12: We have computed them, the attenuation of the beta and they're comparable.

Dr. Tenney, LASL: Yes, but how much geometrically?

E. Price, Y-12: Oh, 120 degrees. I think, actually though, it's around 60 degrees. The thickness of the rib.

Dr. Tenney, LASL: It's 50-50 then?

C. Wright, Y-12: Yes.

E. Fatzer, WANL: Earl, getting back to an earlier statement when you said you would like to see the response to both your gauges be the same, or be identical, or however it was you expressed this.

E. Price, Y-12: I meant to say that I don't care if the responses are different, but I want the equations or the calibration curves to give the same thickness.

E. Fatzer, WANL: Oh, I see, you will accept different calibration curves, but you want to reduce the discrepancy between them.

E. Price, Y-12: Yes.

N. Thielke, SNPO-C: Earl, does the loading influence the counts in your beta backscatter?

E. Price, Y-12: Definitely, yes, in fact our calibration is made in the dynamic mode on our 1-inch long foil. We have one inch pieces of foil going down in the center and instead of going in there and taking steady counts we find that the response to beads can occur and influence and in order to average the thing we don't know where to stop. And we go down a little more, a little more and we go back some and we'll get a different count. But we don't know that it's right so we simply take a dynamic count and integrate.

N. Thielke, SNPO-C: I see, it's variable with scatter and variable with the attenuation on the external surface.

E. Price, Y-12: For the elements presented, we didn't have any loading. Well, the only thing to consider then is the difference in density of these coatings, and that is what I feel is the cause of the discrepancy.

N. Thielke, SNPO-C: You mean the difference in density?

E. Price, Y-12: That's what I think. I could be wrong.

W. Schieb, SNPO-W: What's your precision for external beta backscatter?

E. Price, Y-12: Well, $\pm 1/10$ of a mil. One thing about external beta backscatter was that we do get a little extra backscatter from bore coating underneath when the external coating is thin, very thin.

E. Fatzer, WANL: How's your liftoff effect compared to Bruces's?

E. Price, Y-12: I'm guessing, but I'd say it's 6 to 10 mil liftoff.

PART 12

Q. C. PROVISIONS OF THE ROVER NDT EQUIPMENT

GAMMA SCAN

C. Knowles

M. D'Amore, WANL: The second Y-12 presentation this afternoon will be given by Chuck Knolls on Gamma Counting. He is going to describe the equipment operation, talk about migration data, chemical data, slabbing effects, positioning effects, calibration limits and quality control charts at Y-12.

Abstract

This report covers the gamma counting activities through approximately 50 percent of the Phoebus 1B final coated fuel element production and the production startup activities for the NRX-A5 fuel elements. New counting standards are described. Experiments connected with the gamma counting of 16-hole fuel elements were performed. Quality control and calibration procedures are presented.

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Slide 12-1. Y-12 Gamma Counting Equipment

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Introduction

The fact that Y-12 is producing the entire Phoebus 1B core has required the fabrication of standards which cover the complete fuel load range. These standards have been analyzed and have been used to derive equations for determining fuel content in Phoebus 1B fuel elements. Equations derived from these standards will also be used for NRX-A5 fuel elements. The equipment calibration procedure is essentially the same as was discussed at Los Alamos during the Symposium on Nondestructive Testing of NERVA and Rover Fuel Elements held on April 7-9, 1965. Data from a coated quality control element are evaluated for each increment in addition to the evaluation given to the average load.

Summary

Standards for use in determining the fuel content and distribution for both Phoebus 1B and NRX-A5 fuel elements appear to be adequate. Data generated at Y-12 pertaining to these standards have been evaluated and appear to be correct. Experiments show that proper positioning with respect to the sodium iodide crystal window of the 16-hole fuel element is necessary. Another experiment proved that dimensional tolerance affected the mgU/cc value ± 0.25 .

Calibration and quality control data show the equipment to be performing satisfactorily. The calibration information shows that the equipment is counting within acceptable limits and the quality control data is proof that the equipment remains in calibration while counting fuel elements.

Fuel elements produced at Y-12 for both Phoebus 1B and NRX-A5 have their fuel content and fuel distribution measured with the same counting equipment. The gamma counting equipment is shown in slide 12-1. The standards used for determining fuel content and distribution in elements for Phoebus 1B and NRX-A5 are tabulated in slide 12-2. The prefix No. 38 identifies the standards as unlined, while the prefix No. 39 indicates the standard is used with liners

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URANIUM LOAD STANDARDS

19 HOLE STANDARDS 0.100" BORE DIAMETER

38-100-50902	38-368-12185
38-126-50503	39-368-12185
38-151-12326	38-405-12176
38-195-50302	38-428-12175
38-203-12316	38-447-12166
38-250-12306	38-509-12192
38-261-12305	38-533-12335
38-275-50604	38-537-12332
38-297-12196	38-586-12346
38-301-12301	38-590-51004
38-349-50704	38-618-12345
38-350-12186	

16 HOLE STANDARDS 0.100" BORE DIAMETER

38-100-50903
38-162-12325
39-162-12325
38-179-50301

Slide 12-2

TYPICAL BEAD MIGRATION REPORT

PHOEBUS 1B

GAMMA COUNT STANDARDS

SPECIMEN	EVALUATION
100-50902	01-02-2341
125-50503	01-02-2341
179-50302	01-02-2341
275-50604	01-02-2341
349-50704	01-02-2341
590-51004	01-02-2341

MIGRATION OCCURS IN ABOUT 1/10 (01-) OF THE BEADS UP TO A MAXIMUM OF 2/10 (02-) THROUGH THE COATING. GENERAL POROSITY IS FAIR-TO-GOOD (2), BUT LOCAL POROSITY FAIR (3); MICRO-CRACK STRUCTURE IS POOR-TO-FAIR (4), AND MACRO-CRACK STRUCTURE IS GOOD (1).

Slide 12-3

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in each bore. The next three digits of the number indicate the load or uranium content in mgU/cc units. Notice that the load range, in desirable increments, is from 100 mgU/cc to over 600 mgU/cc. The last part of the number is the serial number for each standard. The standards whose serial numbers begin with five were fabricated by Y-12 Development, and those beginning with one were fabricated by the Production Group at Y-12. The 16-hole standards are used only for a few of the Phoebus 1B fuel elements.

Since all the standards are well within acceptable limits of a best fit curve, to be described later, only example data taken pertinent to the standards will be shown in this report. Slide 12-3 shows a migration report of six gamma count standards ranging from about 100 to 600 mgU/cc. The quality of the beads, reported in a coded evaluation, is described below the specimen and evaluation numbers. The tabulation in slide 12-4 shows chemistry, dimensional and count values on the same six standards. The values in the machine load column were arrived at by counting the standards as-machined. These machined counts were incorporated into the equation resulting from the as-leached chemical analysis. The next column shows the values of the leached standards after inserting the count values shown in Column 3 into the equation:

$$\text{Equation } R_1: (YK-853)/(95.45 - 0.001433YK)$$

$$\text{Equation } R_2: (YK-2905)/(82.94 - 0.001134YK)$$

R_1 - covers uranium loads in Phoebus 1B 19 hole elements up to 350 mgU/cc.

R_2 - covers uranium loads in Phoebus 1B 19 hole elements beyond 350 mgU/cc.

Y - count rate.

K - Bore coating thickness factor.

The chemistry values are those values determined from the gram uranium per gram answers reported by the Plant Laboratory. The uranium load values corrected for geometry are

DATA ON STANDARDS												
ELEMENT NUMBER	MACHINE LOAD MG U/CC	LEACHED LOAD MG U/CC	COUNT RATE PER SECOND	CHEMISTRY MG U/CC	DIFFERENCE							
					CORRECTED FOR GEOMETRY MG U/CC	LEACHED LOAD - CHEMISTRY MG U/CC	BORE DIAMETER AIR PROBE	FLATS	ASSAY (%)			
									U-234	U-235	U-236	U-238
100-50902	102.66	97.26	8,897	98.95	98.97	-1.7	100.2	0.7535	1.02	93.06	0.28	5.64
125-50503	133.26	125.99	10,909	127.38	126.67	-0.7	100.2	0.7536	1.03	93.06	0.28	5.63
179-50302	190.01	179.52	14,307	180.95	181.93	-2.4	99.60	0.7535	0.99	93.08	0.27	5.66
275-50604	293.52	275.99	19,489	275.60	277.21	-1.2	99.60	0.7536	1.01	93.09	0.26	5.64
349-50704	373.27	349.70	22,848	350.50	350.75	-1.1	100.1	0.7534	1.01	93.10	0.25	5.64
590-51004	622.68	590.84	31,082	589.60	589.62	+1.2	100.2	0.7534	1.02	93.05	0.29	5.64

those values which are plotted against the count values given in Column 3 to provide the load-count curve which will be described later. The degree to which the chemistry values, corrected for geometry vary from the calculated values is shown in the next column. Since these particular standards were from a different source than the others, and since these residual values are undesirable, the data from these six standards were not used for plotting the load-count curve.

The load-count curve which has plotted the count values against the fuel content values of the standards is shown in slide 12-5. The curve of the standards used in determining fuel content of the 321 Core fuel elements is also shown. The same standards were used for measuring the NRX-A4 fuel element content that were used for the 321 Core. The only difference was the necessary use of a factor to correct for a 0.001 inch hole diameter difference. The significance of this factor is shown in slide 12-5 also. The reason for the difference between the Phoebus 1B and the 321 Core curves is not readily explained by available data.

Two experiments were performed in preparation for measurements of fuel content and distribution in the 16-hole Phoebus 1B elements. One experiment was to determine the effect of dimensional tolerance across the flats. The distance across the flat through the center of the hole No. 10 and perpendicular to a plane through holes 8, 9, 10 and 11 was to be held between 0.601 inch and 0.603 inch. Element No. 179-50304 was used for the experiment and was first counted as a regular 19-hole element. The D flat was machined to within 0.002 inch of the requirement and the element was counted again. Layers were then removed in 0.002 inch increments (see slide 12-6), and were counted after each increment was removed. Results of this experiment are given in slide 12-7. Although it is apparent that the counting equipment is sensitive to a variation of 0.002 inch in the across-the-flats dimension, it can be stated that the effect (± 0.25 mgU/cc) which this variation showed on the change in the

GAMMA COUNT CALIBRATION CURVE

Slide 12-5

Slide 12-6

16-HOLE STANDARD
EFFECT OF SLABBING

ACROSS FLATS MEASUREMENT	ELEMENT NUMBER 179-50304 ACROSS FLATS DIFFERENCE	COUNT RATE PER SECOND	COUNT RATE DIFFERENCE
0.753"	0.000"	14,298	0
0.605"	0.158"	12,484	1814
0.603"	0.002"	12,458	26
0.601"	0.002"	12,427	31
0.599"	0.002"	12,390	37
0.597"	0.002"	12,316	74
0.595"	0.002"	12,262	54

SPECIFICATION FOR PHOEBUS 1B = 0.602"

0.603" TO 0.601" = 31 COUNTS/SECOND

0.001" = 15 COUNTS/SECOND = 0.25 MG U/CC

Slide 12-7

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16 HOLE GAMMA COUNT STANDARD ORIENTATION

FLAT NOTATION:

GROUP	POSITION OF ELEMENT IN ALUMINUM CAN(CIRCLE) RELATIVE TO COUNTER WINDOW (W)	GAMMA COUNTS PER SEC. MEAN OF SEVEN 10 SEC. COUNTS LE OF MEAN = ± 24	MgU/CC COMPUTED BY SUBSTITUTING R1 EQUATION LE OF MEAN = ± 0.4
D NEXT TO CAN RIM	W	12,393	178.8L
	W	12,476	180.3
	W	12,478	180.3
	W	12,458	179.9
A NEXT TO CAN RIM	W	12,426	179.4
	W	12,516	180.9H
	W	12,475	180.2
	W	12,458	179.9

DIFFERENCE BETWEEN HIGH (H) AND LOW (L)
 $\pm$ LE OF MEAN DIFFERENCE

2.1 MgU/CC (1.2 RELATIVE %)
 ± 0.6 MgU/CC (± 0.3 RELATIVE %)

CONCLUSION: THE DIFFERENT POSITIONS OF THE 16 HOLE ELEMENTS IN THE ALUMINUM CAN AFFECTS THE COUNT RATE SIGNIFICANTLY. THE ASTERISK POSITION WAS CHOSEN FOR CALIBRATION AND ROUTINE MEASUREMENT.

Slide 12-8

mgU/cc is not enough to cause concern. The second experiment was performed to determine the effect that positioning of 16-hole elements with respect to the sodium iodide crystal window would have on the gamma count rate. Slide 12-8 illustrates the experiment and gives the results and conclusions. The position indicated by an asterisk was arbitrarily selected for calibration and routine measurement.

The Y-12 Production Group requires that one element from each load be counted in the as-graphitized condition. This is a courtesy check for them and must be handled expeditiously. Slide 12-9 gives the as-graphitized as well as the as-machined fuel content curve. Fuel content values of the as-graphitized elements are taken directly from the curve. This allows faster feed-back information to become available.

Calibration of the equipment is essentially the same as was reported in the Symposium on Nondestructive Testing of NERVA and Rover Fuel Elements held at Los Alamos. New calibration standards covering a wider load range are used. Slide 12-10 shows the acceptable count limit which these standards must fall within before the equipment may be used to count fuel elements. The equipment is checked with these standards periodically within each 8-hour work period. The actual values are recorded along with the acceptable limit values. Slide 12-11 illustrates typical calibration data for gamma counting on coated fuel elements for the Phoebus 1B Core.

A quality control element is counted about four times during each 8-hour work period. This element is counted along with production elements. The equipment is not calibrated for the purpose of counting the quality control element. It is counted, as it should be, just as if it were a production element. Slide 12-12 is a plot of recent data on the quality control element used when counting Phoebus 1B and NRX-A5 fuel elements. The quality control element is a coated element. The average coating for each five inch increment is shown at the top of the loading.

The average total variation in the quality control element data during the period shown was 1.6 mgU/cc while variations for an average five inch increment ranged up to 3.8 mgU/cc, as would be expected.

GRAPHITIZED TO MACHINE LOAD CONVERSION
(COUNTS/SEC. VS. LOAD MgU/CC)

Slide 12-9
CALIBRATION COUNT LIMITS
URANIUM DISTRIBUTION ANALYZER

19 HOLE STANDARD 0.100" BORE DIAMETER

STANDARD NUMBER	ACCEPTED VALUE	LOWER LIMITS	UPPER LIMITS
38-151-12326	1,265,200	1,260,400	1,270,000
38-350-12186	2,281,000	2,273,400	2,288,600
38-368-12185	2,363,800	2,356,000	2,371,600
39-368-12185	2,262,000	2,254,500	2,269,500
38-586-12346	3,080,900	3,071,200	3,090,600

16 HOLE STANDARD 0.100" BORE DIAMETER

38-100-50903	760,600	757,300	763,900
38-162-12325	1,135,800	1,131,400	1,140,200
39-162-12325	1,077,500	1,073,300	1,081,700
38-179-50301	1,238,400	1,233,700	1,243,100

Slide 12-10

GAMMA COUNT STANDARD DAILY CONTROL CHART

Slide 12-11

QUALITY CONTROL ELEMENT

Slide 12-12

DISCUSSION

Dr. Tenney, LASL: Is the element stationary and how is it held in place to protect against chipping?

C. Knolls, Y-12: We're packing this one in such a way that it will be positioned this way in the tube.

E. Price, Y-12: There is a rubber band around it to keep it from chipping.

Dr. Tenney, LASL: Is the rubber band there to keep the fuel element concentric within the tube?

C. Knolls, Y-12: No, not the 16 hole element.

Dr. Tenney, LASL: Oh, I see, not the 16 hole.

C. Knolls, Y-12: You see there is room here. The three holes are looped off here.

W. Scheib, SNPO-W: Does that interfere with the readings?

C. Knolls, Y-12: We haven't noticed any interference with the packing material. It's packed with light material, sponge rubber or something like that. That's a good question, though.

C. Wright, Y-12: Well, it's only packed near the ends of the element anyway, isn't it?

C. Knolls, Y-12: Well, I'm not sure what the packing is, do you know, Earl?

E. Price, Y-12: We planned to just use 3 or 4 sponge rubber discs at each end of the element there to hold it over to one side.

C. Knolls, Y-12: Well, I don't think there will be any problem.

W. Scheib, SNPO-W: Can that go through the other way if you're scalloping off any of the skin effects of material? Would it tend to increase the apparent loading?

C. Knolls, Y-12: Well, let me explain what's happened here. These particular elements that were chosen to make this curve were counted as-graphitized. Then their loading was plotted and then they're machined and then they were counted again as-machined and their loading was plotted. So we just see the comparison there of the counts. For the particular load that counts as-graphitized is quite a bit higher than as-machined. I see what you mean. Now you wouldn't expect an as-machined element to count more than

an as-graphitized element.

W. Scheib, SNPO-W: Well, you didn't correct this to volume?

C. Knolls, Y-12: This is a just counts. Right.

Dr. Tenney, LASL: What is the corrected effect if you're pulling more beads out of the surfact of the greater loading? Because of that the two curves go apart?

C. Knolls, Y-12: There is actually more uranium in here because you do cut off some uranium when you machine it and you do have a little more, perhaps, counts.

C. Wright, Y-12: Truly, it's not a calibration curve for an as-graphitized element but it predicts what the loading will be for an as-machined element. Is that correct?

C. Knolls, Y-12: Yes, that is what the purpose of these two curves are here.

D. Cowfer, WANL: No correction is made for the geometry on the graphitized element, is that correct?

C. Knolls, Y-12: That is correct.

D. Cowfer, WANL: Well after the thing is machined and counted you plot that against the counts?

C. Knolls, Y-12: Yes we do.

N. Thielke, SNPO-C: How much material is actually being taken off just to give us a feel for this?

C. Knolls, Y-12: I really don't know how much or what is the diameter as graphitized.

C. Wright, Y-12: The percentage difference in your curves at the low end of the data that should be a good estimate, the amount that is taken off.

B. Blanks, LASL: All your changes are going to be very close to the ratio of these two curves for a given count rate, at least we've observed this.

W. Schieb, SNPO-W: What is the as-machined diameter?

E. Price, Y-12: The graphitized cross flats is around 0.780, I believe.

W. Schieb, SNPO-W: Is this data plotted manually from the print out?

C. Knolls, Y-12: Yes, this data is plotted manually from the print out. We could expect perhaps a variation of some of these thicknesses to show up. Maybe it wouldn't affect the average.

W. Schieb, SNPO-W: How does your calibration formula compare with the latest one that Westinghouse has set up. Is it the same form with different constants in it?

C. Knolls, Y-12: Our form is very similar to theirs, but it isn't the same. Our statisticians have, of course, taken these points and come up with the best fit empirical equation.

N. Pollack, WANL: Ours are parabolic, I believe, aren't they? And Y-12's is hyperbolic.

E. Fatzer, WANL: Chuck, you have the crystal with a single scintillator on it, is that correct?

C. Knolls, Y-12: Yes, that is correct.

E. Fatzer, WANL: So that we do not exactly expect exactly the same response from your crystal with single scintillator as to what we're doing. We're following right directly in the footsteps of the original design which Los Alamos installed with two windows oppositely opposed to two photo multipliers. If you cut a photo multiplier off, you lose a lot of resolution in the spectrum and I would assume can see some change in the response to the equipment with a single photo multiplier compared to the double multiplier. This could explain why your curve fits that hyperbolic function.

C. Knolls, Y-12: Coleman will probably have some words on that, I think.

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PART 13

GAMMA COUNT INSTRUMENTATION

C. Wright

M. D'Amore, WANL: The next presentation from Y-12 is on the instrumentation of the gamma count. It will be presented by Coleman Wright. Coleman is going to discuss the temperature effects, temperature evaluation, liner experiments, graded shielding, effective response of Torus crystal and analyzer evaluation.

My discussion will involve a study of temperature stability in the Gamma Counter and a series of experiments involving the scintillation detector itself.

The study of temperature effects on the counting system was prompted primarily by the following three reasons:

- 1) Operating experience during the summer months indicated that the procedure for obtaining instrument calibration was more tedious.

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STANDARD COUNT RATE DEVIATIONS
AND ROOM TEMPERATURE VS. TIME

Slide 13-1

PULSE HEIGHT DISTRIBUTION
FOR HIGH AND LOW LOAD
COUNT STANDARDS

Slide 13-2

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2) Control charts showed that frequent adjustments of the calibration controls were necessary.

3) The instability appeared to be more than a simple deviation of the standard count rates from the specified values. Adjustments were necessary to compensate for standard count deviations which reflected a change in the slope of the calibration load curve.

This type of instrument performance was a new experience and was first noted during the summer months when the ambient room temperature generally followed the outside air temperature cycle.

Slide 13-1 shows experimental data recorded during a 42 hour test period. The lower portion of the graph shows room temperature versus time and the upper part shows standard element count deviations from the specified value. The 11 P.M. to 7 A.M. period is an "off" shift and no count data was recorded. The count deviation readings recorded every hour for the high load standard are interconnected by the solid line. Likewise, the response to the low load standard is shown by the dashed line. Note that there is a correlation between the count deviations and room temperature for both standards, but the relationship is direct for the LOW load and inverse for the HIGH load.

In an effort to explain this opposite effect for high load and low load standards, I had supposed that any temperature instability would probably manifest itself by a shift in the system gain. What appeared to be happening was that a temperature change was causing gain shift so that the pulse amplitude distribution for the low load standard was moving into the analyzer window (a plus count deviation), and, on the contrary, the pulse distribution for the high load was moving out of the window and causing a negative count deviation. This response would result directly in a calibration curve slope change.

Slide 13-2 shows how this behavior could be possible. This graph shows the plot of the differential spectrums made with the single channel analyzer for both a high load standard (the upper curve) and a low load standard (the lower curve). The ordinates are arbitrary

SHIELD CONFIGURATION

Slide 13-3

Slide 13-4

count rate units and the abscissas are base line voltage. Now let us assume a typical window setting for the high load standard. Plateau operation requires that the lower discriminator and upper discriminator levels be set so that the pulse distribution is centered between the two levels. Any change in system gain will cause a drop in the standard count rate. Now, note that the system is not in a plateau region for the low load standard and count rate will either increase or decrease depending on the direction of a system gain change.

The following three methods for improving the Gamma Counter temperature stability have been proposed:

- 1) Reduce the ambient temperature fluctuations in the operating area.
- 2) Improve the electronic circuitry so that gain shift due to count rate is minimized.
- 3) Install a RIDL Scintomatic electronic stabilizer. This unit automatically compensates for gain shift.

Progress has been made toward the implementation of each of these proposals.

The next portion of my discussion will involve some critical studies of the scintillation detector system. The single window torus detector used at Y-12 has been described at the previous symposium, and these evaluation studies have been prompted by:

- 1) Problems associated with the lack of gamma energy resolution,
- 2) Inability to obtain agreement on liner absorption factors with similar measurements made with a two window torus detector.

The results of our investigations were startling and indicate areas where the response of the gamma counter has not been well understood.

The first experiment was an effort to improve the shape of the differential spectrum obtained with the torus detector. The contribution of characteristic X-rays to the spectrum had been offered as a partial reason for the poor response.

Slide 13-5. Angle of Incidence Experiment

TORUS DETECTOR WITH COLLIMATED SOURCE;
COUNT ACCUMULATION AT ZERO DEGREES
AND THE ACCUMULATED SUM FOR 15° INTERVALS
(0° - 345°) SCALE: 10k

Slide 13-6

An experiment involving graded shielding, that is one or more layers of metal foil over the exposed lead attenuators, was completed. These materials were chosen with descending order of Z so that subsequent layers have a high cross section for the absorption of fluorescent radiation from the preceding one.

Slide 13-3 shows the results of this experiment. The upper figure shows the lead collimators such as used on the Gamma Counter with the copper and cadmium foil applied to all the surfaces which might irradiate the torus crystal by fluorescence. The lower figures show the comparison obtained by using a multichannel analyzer to determine the differential spectrums both with and without the graded shield. The accumulation times for the two spectrums differ but the count rate associated with the 186 Kev peak was nearly the same for both systems. Note that the 90 Kev peak is lower than the 186 Kev peak when the graded shielding is used. This indicates that there is a considerable contribution to the spectrum by characteristic X-rays from the ungraded lead collimators. The improvement in the differential spectrum by using the graded shielding is comparable to that obtained by wrapping the element with a 0.010 inch lead foil. The lead foil method has the disadvantage of attenuating the 186 Kev photopeak.

Slide 13-4 shows the results with a single channel analyzer. We have concluded that the graded shielding is useful and will be incorporated with the torus detectors used in the production gamma counters.

The peak-to-valley ratio is still only about 1.1:1, and the long tail-off at higher energies makes the calibration procedure tedious.

The next experiment which I will discuss is where the most interesting things were learned about the torus detector. The results will explain the poor energy resolution and the long tail on the pulse height distribution.

PULSE HEIGHT DISTRIBUTION AT VARIOUS ANGLES OF RADIATION INCIDENCE

Slide 13-7
ENERGY DISTRIBUTION VERSUS
ANGLE OF INCIDENCE

Slide 13-8

The study involved the observation of pulse height distributions obtained when the detector was irradiated at various angles with respect to the crystal window.

Slide 13-5 illustrates the apparatus used. The source was a small quantity of UF_4 (uranium tetrafluoride) in the well of the lead collimator. Zero degrees is with the source directed at the window. Readings were made at every 15 degree interval and the distribution was displayed on a 400 channel analyzer CRT.

Slide 13-6 shows the pulse height distribution with a beam incident at 0 degrees and the accumulated sum for every 15 degree position. That is, equal live times were allowed for each position and the stored distributions were accumulated for every 15 degree position. This "accumulated sum" spectrum is then an approximation of the distribution obtained when the torus is uniformly irradiated as in the production application. Note the extreme spread in pulse amplitude distribution. Also note that an analyzer window including the 186 Kev peak of the accumulated sum spectrum also includes pulses resulting from 90 Kev radiation.

The long tail is the result of contributions from the lesser attenuated scintillation photons.

The last thing that I would like you to note is the fact that the accumulated sum spectrum appears to be dominated by the highly attenuated light photons. Slide 13-7 will better demonstrate the point. These spectra were made with a single channel analyzer and show the incremental radiation response at 0 degrees (solid line), 90 degrees (dashed line), and 180 degrees (uniformly dashed line). Note that even at 180 degrees the 186 Kev photo-peak is resolved even though the scintillation light is highly attenuated. Also observe that the relative light attenuation is much more severe in the 0-90 degree interval than in the 90 degree to 180 degree interval. This fact explains why the accumulated sum peak in the previous slide is dominated by the highly attenuated scintillation photons.

Slide 13-8 shows how the scintillation light attenuation varies with the angle of radiation incidence. These data were taken with the 400 channel analyzer and are polar plots showing

Slide 13-9

Slide 13-10

the channel number in which the characteristic peaks appear for various angles of radiation incidence. For example, the radius of curvature for the outer curve represents the channel number or, if you will, the pulse amplitude which corresponds to the 186 Kev photopeak. The fact that this radius becomes smaller as the angle of radiation incidence varies from zero degrees means that the scintillation light is being more attenuated in its journey to the photo cathode.

Finally, the radius of curvature is relatively more uniform in the interval 90 degrees to 270 degrees and, consequently, the radiation incident in this region dominates the shape of the total accumulated sum pulse height distribution. The larger part of response smearing occurs in the intervals 90 degrees clockwise and counterclockwise from the window.

Slide 13-9 shows this clearly. The principle conclusion demonstrated on this slide is that when we choose an analyzer window which appears to include the gamma energy range of 140 to 230 Kev, there are really pulse contributions in the window which derive from radiation with energies in the range of about 70 Kev to 230 Kev.

This means that the X-ray fluorescence radiation from the lead does contribute to the count data and that we still count radiation which is characteristic of the U^{235} daughters. The absorption factor obtained for the liners is dependent upon gamma radiation with energies as low as 70 Kev.

Slide 13-10 shows how the liner absorption varies with energy. The data was taken with a single channel analyzer and the torus detector in the normal operating configuration. The 186 Kev peak appears at a base line setting of about 4.4 volts and the operating window corresponds to a base line range of 3.6 to 5.2 volts.

Slide 13-13 shows the unlined to lined count ratio as a function of base line voltage. For a 209 mg U/cc standard and 2.1 mil liner thickness, the absorption factor is about 1.05 at a baseline setting of 4.4 volts which corresponds to the 186 Kev peak on the previous slide. The ratio varies from about 1.035 to 1.06 in the range of the operating analyzer window.

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Slide 13-11

This concludes the discussion relating to the torus detector. I will now distribute an experimental gamma counting system which does not have the limitations of the single window torus. Slide 13-12 shows the detector configuration. Three right cylindrical detectors (1 1/4 inches x 1 inch) are spaced at 120 degrees about the element as shown in the top view. The element passes through the detector system in a direction normal to this view. The lead collimators and the additional lead rings and the brass guide tubes are the same as for the torus detector.

The signals are summed into a single preamplifier and then fed to the linear pulse amplifier the same as for the torus detector system. Photomultiplier gain balance is achieved by individual voltage control potentiometers from a single high voltage supply.

Slide 13-13 shows the gamma spectrum obtained with a single channel analyzer and a 509 mg U/cc element. The 186 Kev peak is fully resolved and has a peak-to-valley ratio of about 2.1:1. The contributions to this spectrum are equally divided among the 3 individual detectors. The graded shield experiment was repeated for the tri-detector system and the results are shown in slide 13-14.

The 186 Kev peaks are normalized. The peak-to-valley ratio is increased slightly by using the graded shielding.

Slide 13-15 shows the results of placing 2.1 mil liners in the 509 mg U/cc standards. Note the preferential attenuation of the 90 Kev gamma photons.

Slide 13-16 shows the same spectrums overlapped.

Slide 13-17 shows a tabulation of niobium liner absorption data. The purpose is a comparison of liner absorption factors (ratio of unlined to lined counts) for three different detector arrangements. The single window torus gives the highest absorption factors with very little difference between the factors obtained with the tri-detector system and estimated values shown for a two window torus.

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Slide 13-12

Slide 13-13

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Slide 13-14

Slide 13-15

Slide 13-16

NIOBIUM LINER ABSORPTION
DATA¹.

ELEMENT LOADING	ABSORPTION RATIO		
	TORUS DETECTOR		TRI- DETECTOR
	SINGLE WINDOW	DOUBLE WINDOW ² .	
209.4	1.051	1.026	1.0243
333.3	1.045	1.024	1.0246
509.8	1.038	1.021	1.0219

1. NIOBIUM LINER THICKNESS = 2.1 mils

2. VALUES ESTIMATED FROM LASL CURVES

Slide 13-17

DISCUSSION

Dr. Tenney, LASL: Coleman, first I would like to congratulate you on a very excellent experiment. In principle, getting back to the last slide, to what extent are you critical with regard, let us say, to the fourth decimal on the tri-detector system? How good do they look at it? Because you will have, let us say, a divergent tendency between the double windows in the tri-detector system is going from 209 to 333 as far as the fourth decimal is concerned. Just going in the opposite direction.

C. Wright, Y-12: Sir, these items right here were all six taken from curves because I couldn't read the curves better than that. I had to count data. I did evaluate the error associated with these ratios and that number was something like 0.001, but I do not round these numbers off.

Dr. Tenney, LASL: In other words, you were in the experimental error as far as the deviation is concerned. Now what does it prove to you about using the thinner window, you were more sensitive to the lower fuel loadings?

C. Wright, Y-12: It doesn't accomplish for us what we hoped that it did.

Dr. Tenney, LASL: It did just the opposite actually?

C. Wright, Y-12: Well, no, sir. When we had originally begun counting we were using an integral counting system with a discriminator at about 30 to 40 kev and we evaluated the response as the function of angle. The integral count does not deviate if we vary the angle of incidence. We did the same sort of experiment but we didn't extend it to different analysis.

Dr. Tenney, LASL: Wouldn't you, therefore, also say that if you plotted the double window distribution that you would get the egg shape out that you had before, let us say that you would probably have less egg shape than you got or that you would get perhaps a mirror image.

C. Wright, Y-12: I considered the possibility of trying to predict what the two window response would be. I don't believe you can do it from a single window response because of the fact that your reflecting area is affected by two windows. Internal reflection is a large contributor to the attenuation of the scintillation light.

Dr. Tenney, LASL: Light energy is the preferred energy as far as you are concerned?

C. Wright, Y-12: Yes, that is true. Now there is another reason why I say I don't believe it would be possible for you to generate absorption factors this low for the two windows. I would be interested in knowing what that response would be, but I don't believe we can tell from this data.

Dr. Tenney, LASL: Very clever, very clever.

N. Pollack, WANL: Coleman, you show about a 5 degree temperature differential to have a considerable effect on your count rate. You indicated you were doing something to correct this temperature. Are you trying to narrow that band down to about what?

C. Wright, Y-12: We're shooting for less than 1 degree and we're doing that, plus the fact that we plan to use the scinematic stabilizer so that we should eliminate all the effects of temperature variations.

N. Pollack, WANL: You're doing this by isolating the equipment?

C. Wright, Y-12: No, we're doing this by room temperature control. Even localized room temperature control.

N. Pollack, WANL: What about humidity? Isn't there an humidity effect on this?

C. Wright, Y-12: That's just one question I can't answer. I think it might affect the count rate indirectly because it might affect the element more than the detector but I'm not sure.

N. Pollack, WANL: But we're saying that the elements made with the new beads have no hygroscopic effect but there's no relationship apparently, between the instrumentation and the element.

Dr. Tenney, LASL: Nick, that's right. It's true as far as the beads are concerned but has nothing to do with it as far as the graphite is concerned.

C. Wright, Y-12: I feel fairly certain that it is temperature more than humidity, although we haven't checked it by humidity.

PART 14

EDDY CURRENT MEASUREMENTS

E. L. Price

M. D'Amore, WANL: The next Y-12 presentation will be given by Earl Price. He will discuss eddy current measurements, including gauge operations, drive wheel design and directional flaw response.

The internal eddy current system at Y-12 consists of two gages, as shown in slide 14-1. The mechanics of the two gages are mounted on the same framework, but operate independently of each other. There is one probe for each gage. Each probe is programmed into each of the 19 bores by a dual cam mechanism. The element is placed on the gage in this position, as shown on the slide, and clamped tight by a support block at the hot end of the element.

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Slide 14-1

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The instruments are calibrated by first nulling the probe with the amplifier gain at maximum. The amplifier gain is then set such that 15 chart divisions deflection results when the probe passes by a standard sawcut 1/32 inch wide by 0.060 inch deep across the flat of the standard element.

With the amplifier as described, the probe is moved past a 0.035 inch diameter hole and a 0.032 inch diameter hole. The 0.035 inch diameter hole causes 5 chart divisions deflection and the 0.032 inch diameter hole causes 4 chart divisions deflection.

Since the Y-12 eddy current equipment utilizes an automatic readout system, a discrete signal level device such as an ac discriminator must be used. The discriminator triggers at a given frequency or signal rise time. The signal amplitude of a flaw must be high enough to endure the preset rise time. The ac discriminator is set so that it triggers somewhere between the signals given by the 0.032 inch diameter hole and the 0.035 inch diameter hole.

Since the Symposium last year, we have added a new flaw location tachometer drive wheel. The location of the tachometer drive wheel for each of the two probes is shown. It is friction driven by the probe hypodermic tubing. A photocell, which is energized with light shining through slots in a probe driven wheel, triggers a Veeder-Root mechanical counter capable of 1,000 counts per minute.

Slide 14-2 is a sketch of the flaw location tachometer drive wheel which we replaced. The diameter of this wheel is adjustable. This rubber washer, clamped between the two aluminum hubs, can be squeezed to give different diameters within a limited range. We replaced this adjustable wheel when we discovered the rubber appeared to be deteriorating. We chose aluminum because of its high friction properties. The wheel was machined to a diameter of 1 inch $\pm$ 0.001 inch. The slotted wheel mounts on the same shaft as the drive and permits light to pass through at each 1/4-inch increment. The aluminum drive wheels have been in use for about one month in a heavy production period. A shallow groove has

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INTERNAL EDDY CURRENT FLOW LOCATION TACHOMETER WHEEL

Slide 14-2

Slide 14-3

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worn in them, but the wear has not caused any flaw location inaccuracies beyond the tolerance expected. Even though the probe driven wheel has yielded excellent results so far, we plan to consider a more positive flaw locating device on the next generation of eddy current gages.

The mechanical Veeder-Root counter has caused considerable trouble and down time. Work is progressing now to build and install electronic counters to replace the Veeder-Root counters.

Another change that has taken place since the last Symposium is the installation of a chart recorder for each eddy current gage. The chart recorders were primarily installed to record dc level shift, but they are also used as a trouble shooting device. A chart trace is made on each bore of each element. The chart paper is rerolled by hand as it comes out of the recorder. The operator reads each chart recording as it comes out of the recorder and makes sure that all flaw indications are punched into the IBM cards. The addition of the chart recorders has increased the manpower time required for the internal gages. We are replacing the Techni-Rite chart recorders with Sanborn 320 recorders. A take-up reel will be ordered for each Sanborn recorder. The Techni-Rite recorders have caused a considerable amount of down time.

Slide 14-3 is a drawing of a proposed new quality control element for the monitoring of internal and external eddy current testing operations. The element length is a nominal semi-length of 52.290 inches. All flaw locations can be registered by the eddy current gage from the finished location at the cold end. The design incorporates several tests of gage performance. Included is a row of 0.035 inch diameter holes drilled through to the bore. These will test discriminator pickup of minimum flaw indications and their locations. All of the sawcuts are 1/32 inch wide by 0.060 inch deep. The sawcut at the 11 3/4 inch position was added in order to create a minimum hash condition. Another sawcut is located at the halfway point in the element and will be used as a location test. The alternating

BASE LINE SHIFT

SLOW PROBE SPEED

NORMAL PROBE SPEED

QUALITY CONTROL ELEMENT NO. 2, 480-12266
GAGE NO. 2, BASE NO. 2, 3-11 SHIFT, 10-29-65.B.B.

PROBE SPEED	FLAW NUMBER										
	1	2	3	4	5	6	7	8	9	10	11
NORMAL	2	2	2	2	1.5	1.5	1.5	3	1	2	1.5
SLOW	1	0.5	2	0.5	0.5	0.5	2	3	2	2	1.5
△ (SHIFT)	1.0	1.5	0	1.5	1.0	1.0	-0.5	0	-1.0	0	0

Slide 14-4

INTERNAL EDDY CURRENT

FLAW NUMBER	ELEMENT POSITION							
	NORMAL				REVERSE			
	DISCRIM	AMPLITUDE ⁽¹⁾			DISCRIM	AMPLITUDE ⁽¹⁾		
1	X	7			X	6		
2	X	6.5			X	7		
3	X	7			X	6		
4	X	6			X	5.5		
5		4				4		
6		4				4		
7		4.5			X	6.5		
8		5			X	4.5		
9		4				5		
10	X	6			X	6.5		
11	X	6			X	4.5		
12		3.5			X	4.5		
13		4				4		
14		3.5			X	4.5		

(1) AMPLITUDE AT LEADING EDGE.

Slide 14-5

slot-hole condition will test the gage's ability to detect a small flaw immediately following a large flaw. The sawcut located at the 50 inch position will again test the ability of the gage to locate the flaw accurately. The adjacent sawcuts, spaced at 1/4 inch intervals, will test the gage's ability to pick up large flaws followed by large flaws. Two flaws are included which are 1/32 inch diameter holes drilled through to the bore. Flaws which are just below the minimum condition required will be used to set the ac discriminator along with the 0.035 inch diameter flaw. The sawcuts are the same size as those in our primary standard which are used to set the gain of the amplifier. This element will be used to check both calibration and quality control.

The three corner cuts which are 0.010 inch wide by 0.033 inch deep will be used to check the calibration of the external eddy current gage. The three flaws were placed in the same plane as the 0.035 inch diameter holes in order to have an alternating large flaw-small flaw condition. The flaws are spaced 1/4 inch apart, beginning at the trailing edge of one flaw to the leading edge of the next flaw.

Slide 14-4 shows the results of a proposed speed experiment. The chart recording shows a group of flaws in our quality control element made at normal probe travel. The anomaly in this trace is the apparent baseline shift in the area of the flaws. This condition occurred in our No. 2 gage, but did not occur in the No. 1 gage. Also shown is a trace of the same flaws, except that the probe was moved very slowly by hand. A straight line was drawn as a reference base line from the extremities of the group of flaws. The valley to base line distance, expressed in chart divisions, is tabulated for both the normal probe speed and the slow probe speed for each of the 11 flaws. The shift difference is also tabulated. This experiment indicates an average shift of 0.4 chart divisions. The conclusion is that a slower probe speed does not significantly improve the base line anomaly.

During an investigation of eddy current performance, the question was raised as to whether the chart trace was a representative picture of what the ac discriminator saw. With

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Slide 14-6

the gage in proper calibration, the flaws shown (slide 14-5) in the quality control element were scanned in the normal direction. The element was reversed end for end on the fixture and scanned again. The "X" above the chart trace of the flaws indicates that the ac discriminator triggered the IBM card punch. The amplitude of each flaw was measured at the leading edge for both normal direction and for reverse direction. Flaw No. 7, with 4.5 chart divisions amplitude, did not punch out in the normal direction. The amplitude of 4.5 chart divisions is below the ac discriminator setting of 5 divisions. The same flaw showed 6.5 chart divisions in the reverse direction and was punched out. Flaw No. 8 shows 5 divisions in the normal direction without punching out, while 4.5 divisions were registered in the reverse direction and did punch out. Flaws 11, 12, and 14 showed 4.5 chart divisions in the reverse direction and did punch out.

The conclusion indicated is that the ac discriminator is triggered by the leading edge to the center of the flaw, and the rise time of the indication determines whether or not the discriminator will trigger. A minimum flaw condition, such as a 0.035 inch diameter hole, does not necessarily react the same when probed from opposite directions. All of the flaws in this slide from No. 3 through No. 14 were made with a 0.035 inch drill.

Slide 14-6 is a view of our external eddy current gage. The only change that has been made to this gage since our last meeting is the addition of a chart recorder.

DISCUSSION

Dr. Tenney, LASL: Earl, do you mean one probe per channel or one probe per element?

E. Price, Y-12: Well, we have one probe per channel. I am equating that with gauge. I didn't mean the channel of the element, I'm sorry.

Dr. Tenney: Yes, but you have the reaction time to consider. In other words, you are traveling too fast. For instance, if you are traveling, let us say, in reverse and you pick up 7, skip 6, 5 and pick up 4 again, the reason you did not pick up 6 and 5 was because of the speed.

Earl Price: I assume from the previous slide that this speed had very little effect on the flaws.

Dave Cowfer: You made quite a difference in the speed on the previous slide, didn't you Earl, you had quite a difference in that, whereas in this case you are traveling in opposite directions at the same speed.

Earl Price: At the same speed, that's right.

Dr. Tenney: Well, haven't you run the same experiment at the same speed both ways but at different speeds?

Earl Price: No, I haven't.

Coleman Wright: You can't evaluate the discriminator if you vary the speed widely, because we know it's right sensitive.

Earl Price: Right. In this experiment we wanted one thing which I will point out, and I think it's very important, is this: All of these flaws were made with a 35 mil diameter drill. Now I'm not saying all of them were drilled with the same precision, but they all were made with a 35 mil diameter drill except these two. So you probably get a variation.

Dave Cowfer: I see. Well, with a 35 mil flaw you're getting down to a borderline situation with the discriminator set too.

Earl Price: Oh, yes. I have tabulated here the actual amplitude of the leading edge. This will be the leading edge for the reverse direction of that flaw, and this would be the leading edge for the normal direction, this way. I have these tabulations here. In the normal direction, the discriminator figured the amplitude of the flaw, and the flaws which do not trigger are 1 chart divisions or 4.5; we're set at 5, you know, on the AC discriminator so

that it will trigger at 5. Here is one 5 that did not trigger; 4 and 6 triggered, and over here for the ones which triggered over here and not over here, the first one is 4.5 which is a normal direction and with 6.5 in the reverse direction so that it is apparent that the amplitude of the leading edge is the factor which causes the discriminator to trigger. We have one case of a 4.5 here that triggered, but that's borderline conditions, of course.

Norm Thielke: You're getting down to where a very small change in value can affect the discriminator, shouldn't you have done an evaluation with a little larger flaw?

Earl Price: Well, then you'd have 100% in both directions.

Dr. Tenney: We're working in a grey area. I don't think we can really draw a conclusion, because you see, for instance, Point 7 and Point 14. Why did you pick up these two points in the reverse direction that did not pick up in the forward direction? For instance, you had enough time between Point 4 and Point 7 in order to pick up 7, in other words, the baseline would be smaller than an increment between 4 and 7, when going from 7 to 4, but in going from 4 to 7 we don't pick up 7 so you are in a grey area.

Dave Cowfer: There is a difference in slope between one direction and in going the other.

Earl Price: Well first, the sharpness of the peak has to be considered because the discriminator is rate sensitive and the height of the peak has to be considered in order to integrate.

Dave Cowfer: Well, the right side of the peak is longer.

Earl Price: Yes, this side is longer, that's right.

Norm Thielke: Were the curves the same shape in going both directions?

Earl Price: Yes, well let's say, the reverse. Yes, they were the same shape.

Coleman Wright: Not precisely, Earl.

Earl Price: Well, there was a little difference, but they had approximately the same shape.

Bruce Banks: Are you sure the difference in amplitude is not just due to overshoot as you come down and then back up?

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Coleman Wright: No, I agree with Dr. Tenney. I don't believe you can decide anything unless the defects were chosen so that they would be detected if they were still alone; that you could be sure that they would be detected if they were alone, but it does demonstrate the fact that, I believe, that the discriminator is sensitive to the initial transient. I say that's the only conclusion we can draw.

Earl Price: The next slide (14-6) is a picture of our external gauging. I'd like to point out that fact that we have added a chart recorder to this gauge. I have no performance data on it.

R. M. Ford: Earl, we've got some light going through the slat triggering the Veeder Root counter. What do we do with it then?

Earl Price: Well, the digits in the Veeder Root counter are wired to the card punch; these digits are quarter inch increments and they punch out. That's part of the data collection system. I have a slide here (not available) of several traces of some unusual flaws which I can't explain. These are just for information. This particular trace on this bore, Bore No. 12, is unusual in that all the other bores were normal. In this case, in Bore No. 14, we have a high conductivity flaw right near the cold end, about an inch or so from the cold end.

Dr. Tenney: What is the scale as far as length is concerned?

Earl Price: 52 inches. This is a complete trace of the bore.

Nick Pollack: Is that on a production element, Earl?

Earl Price: Yes, it is.

Nick Pollack: Was it accepted?

Earl Price: It's laying over in the rack from the run. I haven't pulled it out. It's got to be reviewed. It would be accepted, yes, normally. Now here's an example of our high conductivity flaw, of which we've seen a few lately, like 10% on the NRX-A5 elements.

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Gene Fatzer: What percentage, Earl?

Earl Price: About 10.

Gene Fatzer: You say 10% of the elements show a high conductivity excursion.

Earl Price: This is an operator's estimate, by the way. I didn't have time to count them up myself.

Dr. Tenney: You see the elements you get. You should see the elements we get. You can see the elements which you get on the right and look at the elements we get on the left.

Earl Price: That's going to be a two inch tip on that one. Now here's another example. I thought you might get some fun out of this. Here's another example of an unusual trace. Of course, all of these were rerun and we know that something didn't happen to the gauge. This bore had suddenly shifted like so and then like that. Here's another run with the thing really torn up and a month later we ran the same bore and got the same trace. It started out here, jumped up to here and along a way. I don't know what caused that, we haven't cut it up. Maybe somebody else knows.

Norm Thielke: Is that when they had that underground blast up in Alaska?

Earl Price: Did they have two of them a month apart? Well, here's another trace where we had to shift downward and it goes along like so. Oh, wait a minute. This is two elements. It was right at the hot end. The operator said it was not the carbon tip. This happened in all the nineteen bores for this particular occasion, we found a very large metallic inclusion and immediately we went off on a very large metallic inclusion definition and wherein we had a negative blip. Just last week in the process of evaluating a new lot of varcum, which we do to establish the coat value on unfueled material, we found an element that low and behold after machining that has a substantial negative blip in it. We radiographed the thing and if it's a high density inclusion, it's so darn small, we can't even see it with radiography. We needed to radiograph the thing normal to the axis of extrusion and parallel to the axis of extrusion and it showed nothing. The sample is down in Materials Department right now being evaluated and I just thought I'd throw that in to show that a negative blip doesn't necessarily have to be metallic inclusioned.

Dr. Tenney: What energy did you use?

Ron Cost: I can't answer that, Jerry. The radiography was done by another department.

Earl Price: That was an unloaded element?

Ron Cost: Yes, that was an unloaded element.

Earl Price: Well, then the radiography on it should be good. If something was in there, it should show up. Of course, it depends on the energy.

Gene Fatzer: One thing we ought to be careful when we talk about eddy current testing on unloaded elements. Exactly how is this bridge phased? In our operation at Cheswick, we do not attempt to phase this bridge so that we get linearly many on the unloaded stock at all times. Now if someone submits an element and it is tested without our knowledge it is possible for that bridge to be misphased. To have the true type of flaw, it should be a positive indication, but since the bridge is misphased, it will actually come out to be a negative indication. Now if these data were run without us being able to go back and evaluate the bridge phasing so that there is some uncertainty here as to whether it's actually high conductivity or bridge phasing.

Chuck Knowles: Well, you should see that when you radiograph if it were a high density inclusion, shouldn't you?

Gene Fatzer: Well, not necessarily. If it were a high density inclusion you could see it, but if it were a crack you wouldn't necessarily see the crack.

Earl Price: Well, that might be a better answer than any of the rest of them.

Coleman Wright: Is that in graphite, there?

Earl Price: No, this is in a 430 load element.

Dave Cowfer: Earl, we also evaluate some effects again on peripheral channels. When we get into an element that has, say, significant bulge 6 inches from a given end and during the broaching operation the wall thickness has been decreased. Then we always had a base line shift over that breach back to the end of the element.

Walt Scheib: Would it be this sharp?

Dave Cowfer: No, I have none similar to that.

Gene Fatzer: Of course, this is a corner bore.

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PART 15

EDDY CURRENT INSTRUMENTATION

C. Wright

M. D'Amore, WANL: The last presentation of the afternoon will be given by Coleman Wright. Coleman is going to discuss the Y-12 instrumentation on their eddy current system.

This presentation will include discussions related to system improvements, anticipated improvements and gage comparisons.

Slide 15-1 shows the internal eddy current gage in block diagram form and will serve as a reference to indicate the areas of design modification.

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BLOCK DIAGRAM
EDDY CURRENT ELECTRONICS

Slide 15-1

EXTERNAL EDDY CURRENT COIL ARRANGEMENT

Slide 15-2

The hash detector, as shown, is not included in the gaging system any longer. Rather, the hash condition is ascertained by use of additional program features in the automatic reduction of the incremental flaw data. The hash detector worked satisfactorily, but added to the gage complexity and compounded the calibration and quality control procedures.

Strip chart recorders have been added to the external gage and both internal gages. These will provide verification of the automatic readout data and the traces will be interpreted for determining long term shifts in the eddy current signal which would not be detected by the ac discriminator.

Design improvements in the ac discriminator have been made. The flaw signal amplifier section has been replaced with a fixed gain stable amplifier. The discriminator trigger circuit has been redesigned to eliminate an ambiguity concerning the point at which trigger action occurred.

The one-megacycle bridge excitation power source design has been improved. The output voltage has been increased from about 5 volts peak-to-peak to about 15 volts (p-p). This improvement has reduced the gain required for the tuned amplifier.

Operating experience has indicated other areas where system improvements could be made. Maintenance of the tuned amplifiers has been difficult due to a tendency for self-oscillation. Laboratory experiments have shown that an improved circuit board layout will eliminate many of these problems.

With the two internal gages operating simultaneously and in the same fixture, a cross talk interference at the eddy current signal output has been observed. The interference consists of a beat signal superimposed on the eddy current signal which is fed to the recorder and discriminator. The frequency is the difference frequency (0-30 cps) between the two one-megacycle power sources, and the amplitude is sometimes as great as 30 percent of the discriminator threshold level. The crosstalk has been reduced by relocating the probe coaxial

TYPICAL PROBE TRACE COMPARISON

Slide 15-3

INTERNAL EDDY CURRENT PROBE

Slide 15-4

cables. It has been proposed that the frequency of one of the power sources be shifted by some 2 or 3 percent and thus causing the interference beat signal frequency to be 20 to 30 kilocycles. This frequency is well beyond the band-pass capability of the one megacycle demodulator and the interference would not appear at the gage output.

Considerable investigation of eddy current probe designs has been made. Slide 15-2 shows the external probe design. This is the same configuration as presented at the April session, but we have learned more about the construction techniques and response of the probes. In order for the sensitivity to be good, care should be taken to insure that the individual coil windings are very closely coupled to the element. We have learned that the web thickness on the phenolic form can be reduced by hand finishing to about 20 to 30 mils and thereby increase the sensitivity. Also the 18 coils must be wound uniformly to provide equal sensitivity on each of the six faces.

Slide 15-3 shows the comparison of eddy current traces made with both internal gages on the same group of flaws. Note that on the record made with the Number 2 gage the trace appears not to return to the normal baseline as well as the trace for the Number 1 gage. We have not been able to fully explain this difference, but it appears to be associated with the probe rather than the R.F. electronics. The probe design has not been changed and is shown on Slide 15-4. Slide 15-5 shows a tabulation of design parameters for eight internal probes. The list of parameters includes dimensional and electrical measurements. It is hoped that our experience with these probes and subsequent ones will allow us to develop acceptance criteria and more meaningful design specifications. Much of the data shown here was obtained from measurements made with an optical comparator on radiographs of the probes. This allows us to make an evaluation of the coil turns and winding uniformity. Slide 15-6 shows the radiograph of probe 1. This is considered to be a good probe from the standpoint of a long tube slot and a uniform and closely spaced winding. Slide 15-7 shows an example of a poor probe. The tube slot is short and not properly de-burred. Also, one of the outer windings is distorted.

INTERNAL EDDY CURRENT PROBE CHARACTERISTICS

PROBE IDENT.	PROPERTIES						
	DIMENSIONAL				ELECTRICAL*		
	A (INCH)	B (INCH)	C (INCH)	D (INCH)	INDUCTANCE (MICRO HENRY)	RESISTANCE (OHMS)	Q
10145-1	.075	.132	.182	.0875	205	10.26	.13
10145-2	.073	.140	.160	.088	200	10.34	.12
10145-3	.155	.135	.152	.0895	210	10.45	.12
10145-4	.170	.133	.135		183	10.44	.118
10145-5	.145	.135	.142	.088	185	10.45	.115
10145-6	.150	.130	.155	.089	180	10.43	.115
#1	.220	.130	.155				
#3	.085	.138	.170				

* MEASUREMENTS MADE AT 1 KC AND WITH THE COAX CABLE ARE INCLUDED.

Slide 15-6

Slide 15-7

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Slide 15-8

Slide 15-9

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15-8

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Slide 15-8 shows a view of the complete tip of probe No. 1. The brass tip is silver soldered onto the steel tube, and the solder has not flowed into the tube slot. Slide 15-9 is yet another view of probe No. 1 and the radiograph has been masked so that the protective epoxy coating can be viewed. Any exposed windings will be extremely noisy and not usable.

Slide 15-10 describes a probe resolution experiment. The artificial defect in groups of three are spaced more closely together in steps of 0.025 inch. The probe under investigation completely resolved (the trace returned to the base line) the defects when the flaws were no closer together than 0.200 inch.

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PROBE RESOLUTION EXPERIMENT

INTERNAL EDDY CURRENT TRACE (BORE NO. 2)
(PROBE NO. 10145-6)

PROBE RESOLUTION TEST ELEMENT
ALL SLOTS ARE 0.010" WIDE X 0.035" DEEP

Slide 15-10

DISCUSSION

M. D'Amore, WANL: If there are no questions, that concludes our presentation for today.

N. Pollack, WANL: I guess Norm Thielke brought up a good point a little earlier about this high void fraction fuel. I don't know how involved we should get into the discussions of this but it should be some food for thought for this evening and we might generate some discussions on this thing. Bill, I hope you don't mind my pre-empting but would you stay a minute or so and tell the group what they might expect in the way of high void fraction fuel from the standpoint of what your anticipated schedule for A6 is?

W. Ellis, WANL: Yes, we discussed this at our meeting this morning, Nick, and I put some of your boys on notice that we will have some high void fraction elements to check. We'd like to get eddy current, beta backscatter and gamma counts. We will be extruding these probably within the next two or three weeks and about two weeks after that you will have some for eddy current testing; but we expect to put about somewhere between 100 and 200 high void fraction elements in NRX-A6, and we will go into production on these about the first of April. What we need is indication as to whether or not we have problems with our dies and our coating process long before that.

N. Pollack, WANL: Is Y-12 working on eddy current probes?

E. Price, Y-12: What's the diameter of the hole?

W. Ellis, WANL: It's a 110 mil hole. There's a 10 mil difference and the hole location is a little different.

N. Pollack, WANL: Do you know what the hole location is, Bill?

W. Ellis, WANL: I don't know it off-hand.

R. Cost, WANL: The outer holes are moved in 8 or 9 mils.

N. Pollack, WANL: Yes, there's the same number of holes. The geometry of them is basically the same, but they are just distorted from true location.

N. Thielke, SNPO-C: Isn't Los Alamos making some 110 mil hole elements?

D. Cowfer, WANL: Yes, we got a drawing from them about a month and a half ago.

B. Banks, LASL: Yes, we've done some experimentation on them.

W. Scheib, SNPO-W: I think your philosophy would be then, Nick, to adapt equipment, forget the automated equipment and go back to your manually operated equipment to get the data on these 200 or so odd elements.

N. Pollack, WANL: On a developmental basis, we are fortunately in a position where we might be able to take one of our pieces of equipment and convert it from a transport standpoint but not necessarily from a computerized output standpoint. But that is not the significant problem. The biggest problem that confronts us, and we've already discussed this with our people and requested the necessary funding, is to convert the equipment that we have plus generating standards and calibrations.

W. Scheib, SNPO-W: Will you evaluate these standards against the probes that are the appropriate diameter? Do you have probes of that diameter?

N. Pollack, WANL: You don't have to change the probe diameter. If high void fraction fuel materializes, as a result of the developmental effort that's being incorporated in NRX-A6, I would presume that certainly we will also have to convert to all new standards and calibration curves, and so forth.

W. Ellis, WANL: The entire NRX-A6 will be high void fraction fuel and we are planning to start the extrusion of NRX-A6 within a couple of months. We will probably hold off on extruding the NRX-A6 high void fraction elements until the end of the NRX-A6 extrusion which will probably be about the first of April.

N. Pollack, WANL: Yes, and the NRX-A7 extrusions will start this summer. We've only got about 5 months to be in a position with essentially new facilities, new standards, and new calibration curves for the high void fraction fuel. I don't know what you people are doing relative to this, Jerry, as far as whether it's a significant effort on your part.

N. Thielke, SNPO-C: Well, maybe then on an interim basis we should consider the use of Y-12 facilities and contract this work out.

E. Fatzer, WANL: Are you set up to do it?

E. Price, Y-12: No, we're not.

N. Pollack, WANL: We are considering right now, Norm, unless I've been shot down, to subcontract every bit of this to Research for both the equipment and engineering.

N. Thielke, SNPO-C: I meant the actual QA work. Other people will be in this game a little sooner than you will.

N. Pollack, WANL: I think not, that's the problem. We'll probably be in it sooner than the others, because of the development effort we'll have to spend to qualify the elements for NRX-A6. We're talking like three months for us. Probably from the standpoint of Y-12 on the production basis it won't mean a significant effort until NRX-A7. We don't know what's going on at Los Alamos.

R. Cost, WANL: Actually, Chuck Vogel extruded some 110 mil elements last week and he has them already in the system, but he's not going to be doing as much QA work on them as you. I think he's going to be doing mostly destructive testing.

N. Pollack, WANL: Well, we were just officially asked yesterday for the cost relative to doing this work and we turned it in today, right, Jim?

J. Hutchinson, WANL: Right.

W. Scheib, SNPO-W: It sounds expensive. It doesn't necessarily have to be lengthy. Actually the transport system itself is a machinist type job; if you forget the electronics, you just take manual readings.

N. Pollack, WANL: That's right, Walt, but it's the standards and calibrations. That's the big work there. I think the least common denominator is, as Jerry has mentioned back in April this year is very well being standardized relative to the three activities. Certainly there is some amount of effort, and there always will be, toward getting a more refined common denomination. This high void fraction fuel could upset that whole applecart and we'll have to start all over again.

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PART 16

**PROGRESS REPORT ON BETA AND GAMMA
SCANNING TECHNIQUES**

B. L. Blanks

The beta-backscatter scanners previously described during the April 1965 NDT meeting have been operated continuously with no significant changes in either the mechanisms or the operation procedures. These units consist of (a) the two vertical, semi-automatic bore probes, (b) the external, flat-surface scanner, (c) the large diameter, internal bore scanner for center-support elements, (d) the 5 inch bore probe for support block bores, and (e) the 50 mil diameter flat-surface probe for miscellaneous small parts. The LGP-21 computer is still being used for coat-thickness read-out to a certain extent.

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Coat Thickness Comparison
Sample No. 191-13820

- Beta Backscatter
- o Metallography

Slide 16-1
Coat Thickness Comparison
Sample No. 480-14586

- Beta Backscatter
- o Metallography

Slide 16-2

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Coat Thickness Comparison
Sample No. 371-14343

- Beta Backscatter
- o Metallography

Slide 16-3

Coat Thickness Comparison
Sample No. 480-14608

- Beta Backscatter
- o Metallography

Slide 16-4

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Internal Beta Backscatter
Calibration

9 November 1965

o Molybdenum
• Niobium

Slide 16-5

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The Phoebus-1A fuel element inspection consisted, among other things, of a program of stationary readings taken at a point 11 inches from the G-end of the element in each of the 19 bores plus a 5 inch long segment scan taken along the entire length of bore number 9. Metallographic samples were taken for coat-thickness comparison from four Phoebus-1A production elements. The metallographic thicknesses are compared to the beta-backscatter thicknesses in slides 16-1 through 16-4. Note that two elements have perfect agreement but the other two have significant differences. These data are somewhat similar to those shown earlier by E. L. Price of Oak Ridge which indicate excellent agreement on one element and a definite disagreement on another. These observations would possibly suggest that a difference of NbC density from one coating batch to the next was being experienced.

In the interest of measuring molybdenum coat thickness on current experimental elements, a Mo calibration of the bore-probe has been performed. The results are shown in slide 16-5. Note the greater response of the probe to a given thickness of Mo compared to Nb. The signal current ratio of Mo to Nb at two mils is about 1.18. This compares favorably to the ratio of the two densities which is calculated to be 1.20 from handbook density values.

The gamma counting equipment described in the previous meeting has also continued to perform satisfactorily. The only significant changes have been a relocation of the discriminator settings on the single-channel analyzer to slightly higher energy values. This was done to aid in rejection of the lower energy peak. A count-rate loss of about 15 to 20 percent was observed. The gain-curve plateau was found to be still in existence at the new settings.

A gamma counter for measurement of total uranium in a full-length fuel element has been developed by Group CMB-1, LASL. This is described in report number LA-3196-MS. Subsequent calibration data for this counter indicate a very good calibration response and good agreement with both the GMX-1 gamma counter and analytical chemistry. It has been calibrated for both coated and non-coated elements of standard cross section and length.

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16-6

Slide 16-6

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No immediate plans exist for designing it as a production-type system, though this would be possible should the need arise.

Four Phoebus-1A fuel elements (coated) were obtained for sectioning and chemical analysis. Comparison between loads obtained by chemistry and by gamma counting showed the gamma count value to be about 1.5 percent greater than the chemistry value. A typical comparison is shown in slide 16-6. More recent data indicate a closer agreement although these points have not been plotted at this time.

The problem of an increase of observed gamma count rate associated with high-temperature fabrication processes remains unsolved. Additional evidence of this effect was seen in a group of elements which received abnormally high temperatures during a "runaway" graphitizing run. Elements from the "runaway" batch exhibited higher gamma counts than sister elements graphitized normally. After leaching, however, the "runaway" elements showed a much lower gamma count, with an inverse profile as shown in slide 16-7. This fits the theory that high temperatures can cause a break-up of the beaded fuel, distributing it throughout the matrix, therefore causing a reduction of the gamma self absorption. The threshold for this effect is unknown, but it is believed to lie in the vicinity of 2350°C.

The chemistry exchange elements, discussed during the 30 June 1965 meeting at Los Alamos, have been gamma counted by each of the three laboratories. Gamma scan data are shown in slide 16-8. The average loads (per nominal cross section) for the elements as reported by the three labs are as follows:

	<u>No. 433-16563</u>	<u>No. 353-16715</u>
Los Alamos	444.2 mg U/cc	364.6 mg U/cc
Oak Ridge	445.2	365.1
Westinghouse	441.2	364.1

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Slide 16-7

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This is an amazingly good agreement, considering that no common calibration standard had been exchanged prior to this exchange. These elements will now be sectioned for exchange of samples between the analytical chemistry groups of the three laboratories.

Slide 16-8

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PART 17

PROGRESS REPORT ON THE THREE PHASE

EDDY CURRENT SYSTEM

R. M. Ford

The three phase system does not orient the cracks. All it does is shift the primary sensitivity to defects from the longitudinal axis to the transverse axis. That was our major reason for looking at the three phase system. Transverse defects are generally thought to be more detrimental than longitudinal defects and it was thought that such a system with its primary sensitivity and a transverse plane would be a more desirable inspection tool. If you want to know exact locations then you would probably have to make two eddy current inspections. One as it is used now to determine if it is primarily longitudinal, and the three phase inspection to determine if it is transverse. The background

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3 Ø EDDY CURRENT SYSTEM
BLOCK DIAGRAM

Slide 17-1

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EDDY CURRENT SYSTEM TEST STANDARD

Slide 17-2

EDDY CURRENT SYSTEMS 3 ϕ VS. CONVENTIONAL

Slide 17-3

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on the coil configuration that we used originally was one we knew was not particularly sensitive to the transverse defect, but we couldn't figure out a way to get a coil into a hundred mil hole. So that when the possibility of using three phase came along we just stuck with eddy current system as it was. Slide 17-1 shows the basic features of the system. We have a conventional one-megacycle oscillator and amplifier which feeds a phase splitter. This is basically an RC and LC circuit giving one signal which leads a reference by 120 degrees and another which lags by 120 degrees. In return these are fed into power amplifiers which drive the exciting coils. The major difference is that for the external configuration on which we have worked, the driving coils are sheets of copper approximately three inches long and the width of the fuel element flat. We connect two of these coils in series and on opposite sides of the fuel element. When all three sets are hooked up you set up a rotating one-megacycle field in the center of this coil configuration. The principle is the same as the windings of a three phase motor. Our sensing coils are the conventional 90 turn four mil wire hypodermic tubing type coils that are used on the conventional eddy current system. The pick-up is fed with a balance and null network in which we block out the round signal we get in good graphite so that any output from the balance and null network is indicative of something which has changed the eddy current distribution in the graphite matrix. This is fed to a one-megacycle amplifier and put on an oscilloscope, or rectified, filtered and fed to a recorder. Slide 17-2 shows a defect sample which the graphite shop made for us. It was made by taking a piece of fuel element, and breaking it. I do not know how they broke it but I have a feeling they just cracked it over the edge of a table. Then we asked for a real sharp transverse defect which they made by cutting off the end of the element. The longitudinal defect is made by taking two sections and cutting on either side of the centerline and then re-gluing the whole thing back together. We specify a non-conducting glue for this operation and we have had success using either Eastman 910 or the conventional radio

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servicing cement. For comparison of the conventional versus the three phase system, we picked a point in bore 17. We made a longitudinal cut (slide 17-2) through bores 8, 9, 10, 11, and 12 right across the center of the element. For comparison of the two systems we went into the break area and tried to find a place where this break was at roughly 45 degrees. We set the gain of the two systems to give equal indication to that area of the break which turned out to be in bore 17. These two traces on slide 17-3 show the calibration on this 45 degree section break. Now as you see, with the three phase system through the 45 degree break, the 90 degree saw cut and the two longitudinal (or the ends of the longitudinal) cuts we have, in effect, the transverse defects followed by a longitudinal and then another transverse defect at the end of the element. On our conventional eddy current system we see the 45 degree break and then just some small indications of the transverse cut. The longitudinal cut wasn't too good at bore 17. The only way we can explain the difference in amplitude between the 45 degree break and the 90 degree cut is that there must have been some material broken away, giving us a void in this area where we had a saw cut and where it was glued back together. In the area where we are going through bore 12, we should have the longitudinal cut. This point of the break is roughly 90 degrees which shows where the transverse cut comes in and where we first see one end of the longitudinal cut and then the second end of the longitudinal cut at the end of the element. Our conventional system comes along until you see a small indication at the 90 degree break and an even smaller indication at the real smooth saw cut. We see the real large indication in the longitudinal defect area in the end of the element. This signal here is roughly the same magnitude as the error signal of our system. I think on the basis of this you can see that the three phase system is indeed primarily sensitive to the transverse type defects. It has minimum sensitivity to real long longitudinal type defects. There are many areas of work required to make this a usable production and inspection system. One, the phase generating amplifying system we have at the present is not optimum by any means. It has proved the feasibility of this type of inspection and it's good enough for lab work, but it would never do for a production tool. What we have is not as smooth and doesn't put out as much power as we would desire for an inspection system. We must also

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investigate design of the driving coil configuration such that the interior bores of the element could be inspected. This is a design problem, a mechanical design problem of a pretty large order in my opinion. The work we have done has been strictly on inspection of the external surfaces which proves the feasibility and desirability of this type of inspection. Our work has been primarily in the laboratory and much remains to be done to make this a good inspection tool. Are there any questions?

DISCUSSION

N. Thielke, SNPO-C: In this system, does the field go essentially to zero in the mid-line bore?

R. Ford, LASL: Right now, with one megacycle, we're penetrating roughly 30 to 40 mils in graphite; that is about the upper limit of a one-megacycle signal.

N. Thielke, SNPO-C: Really you couldn't use this on the counter bore yet.

R. Ford, LASL: No. To get down into the center bore you have to get in to these bores with a drive coil configuration of some kind.

E. Price, Y-12: Can you give us a sketch of the coil?

R. Ford, LASL: We have one coil connected to a second coil on the opposite side of the fuel element. Then two points are taken off and phase B is connected to one and phase C is connected to the other. They're connected up to opposite sides and the coil is along the longitudinal axis.

C. C. Wright, Y-12: What is this coil? Is it mounted on a form then with the axis longitudinal?

R. Ford, LASL: This is just a sheet of copper. A thin sheet of copper. It shows up the eddy current along the longitudinal axis of the element.

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M. D'Amore, WANL: Do you have any plans for doing anything with the three phase inside the bore?

R. Ford, LASL: Yes, when we get time to do it. We have made some studies that show it can be done. All we have done so far is just to take pieces of bus wire and slip them down the bore, then connect the opposite ends with an alligator clip, and we can pick up defects in the interior bores that way. The mechanical part of the problem is really the big thing right now.

M. D'Amore, WANL: Well, would it be possible to build a system where you had a three phase probe, and a single phase probe in series, so that when you were scanning the element you would be picking up both the longitudinal defects and the transverse defects at the same time?

R. Ford, LASL: I can see no reason why it couldn't be done. Basically you would have two systems mounted into a single probe.

M. D'Amore, WANL: This is something along the lines of what we have had in mind, if we were actively pursuing it, which we aren't.

W. Scheib, SNPO-W: Do you get any better resolutions of hash problems with this? Does this have the same old hash problem the one phase system has?

R. Ford, LASL: Hash is not a problem of the eddy current system, it is a problem of the fuel element, but no, I don't know whether this system would give you any more hash or not.

M. D'Amore, WANL: Thank you for helping us solve what hash really is.

R. Ford, LASL: Well, for the one hash element that we have seen in the last few months, I have asked to have that bore replicated. I don't know whether it's been done or not, but that was with our conventional system. We haven't tried it with the three phase system. If I remember right, it was in one of the interior bores, and right now, all we can inspect with the three phase system is the outer surface.

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C. C. Wright, Y-12: Dick, does the high void fraction fuel give you enough room with the bigger bore to go to a coil design for the transverse?

R. Ford, LASL: No, because we can never really figure out a way.

C. C. Wright, Y-12: Well, you could stagger coils at different angles, but then you make your length resolutions poor.

R. Ford, LASL: Well, you really haven't increased the bore diameter enough to really do yourself much good. Back in the old days, when we had nice half inch diameter bores, and things like that, they did have eddy current coils sensitive to things in the transverse direction.

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PART 18

REPLICATION

N. B. Edenborough

M. D'Amore, WANL: The next presentation by Los Alamos will be a progress report on replication techniques and will be given by Ewell Edenborough.

At the last conference, D. A. Garrett presented our replication techniques as developed, and now used by the Los Alamos Scientific Laboratory. For those of you who are not familiar with this technique, I will review it briefly. Replication is performed using polyvinyl chloride tubing which is commercially available, and is bought in sizes which are just slightly smaller than the inside diameter of the bores of fuel elements (slide 18-1. The tubing is inserted in the element as shown here, with a teflon reinforcing sleeve at the end. Internal pressure is applied to these polyvinyl chloride tubes, at about 40 psi through this manifold. The element, after it's loaded, is then placed in the furnace and brought up to forming temperature. At forming temperature the sides of the polyvinyl chloride tubing soften and the internal pressure forces the tubing into the bore surfaces. Slide 18-2 is a block diagram of the furnace we are using. As you can see it is simply a wire wound resistance type furnace, with the element

Slide 18-1

PRODUCTION REPLICA FURNACE
PRESSURE FORMING TECHNIQUE

Slide 18-2

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Slide 18-3
Modified Microcard Mark IV Micronegative Viewer

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18-4

Slide 18-4
Mark IV Micronegative Viewer Showing Replica Image

Slide 18-5
Micronegative Viewer -
Method of Making Contact Prints of Replicas

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placed as shown. After it has been forming temperature for about twenty minutes, the heat is turned off and cool air is passed around the element to cool it. After the element is cooled, the replicas may be stretched to break them away from the bore surfaces, and pulled out of the element, they then retain the configuration of the bore upon cooling. Our group has been involved in an R&D program to improve the coating of fuel elements. This program made available large numbers of elements in both the pre- and post-hot-gas test state. There was also a considerable amount of nondestructive test data available on these elements. So, as a parallel effort, we used this to evaluate the replication technique, and as such, we replicated some of these elements in both the pre- and post-gas test state. What I'm giving now will be a progress report of this evaluation. The first problem that was facing our group, and a problem we have reported on previously was, "How do you view a replica?" How do you interpret it? You end up with a 52 inch long piece of what we call spaghetti. It's only 100 mils in diameter. You must realize that this is very difficult to interpret. You have to magnify it, obviously. Yet, the length and the quantity of them make this very difficult. One of the methods that we proposed at the last conference was the photographic method in which we were going to cut replicas into smaller segments, suspend them from a bar, take pictures of them, and magnify them in this way, so that the interpreter could look at the magnified pictures. Another method which we didn't propose at the conference but we proposed among ourselves was to use a camera which would take a full length picture of a full length element at once, and magnify it from the negative. However, both of these methods were discarded when it was discovered that a commercially available micro-card reader could be used to view replicas and do an extremely satisfactory job. This unit (slide 18-3), is what you would get if you purchased this unit commercially. This is a micro-card Mark VI. Micronegative viewer. The transmitted light image is cast upon this frosted plate at about 18X. We added a glass table and the transporting mechanism, for ease in handling replicas. Slide 18-4 is a view of the reader in operation. You can see, here's our light source. The

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Slide 18-6
Typical Replicas Showing Bore Surfaces Without Cracks

Slide 18-7
Typical Replicas Showing
Bore Surfaces With Circumferential Cracks

replica is right above the light source. We are projecting the image on the glass. Of course you can notice that we have a place for up to about 4 replicas which you can view at once. Actually, in practice, we found that 2 is the best number and this is what we generally interpret: the pre- and post-test replicas of one bore. We have just built a scale on the table such that it is not projected with the replica at this time, but it can be projected so that the interpreter can tell where he is along the bore at any given time. We have also made another scale so that the interpreter can measure size of defects that he saw directly on the frosted glass. Notice the detail available using this technique. You can see circumferential cracks and you can also see bore surface roughness. We find that by taking the two replicas and laying them on the table and stretching them just a little bit but forcing their ends to line up that they correlated very well. Photographs may be also made with this unit, as shown in slide 18-5.

He is about to take a picture using this viewer. This is simply a cutdown radiographic flexible film holder. Inside this we place a normal piece of photographic enlarging paper. This enlarging paper is placed directly against the frosted plate and we make, in effect, a contact print. It is then exposed and developed in a normal manner. Of course, you get a reverse image; however, we have found these to be extremely satisfactory. This whole process is done in the dark. Slide 18-6 shows two pictures of replicas we got using this photographic method, if you recall what we saw using the viewer in operation you'll see that this is in reverse. After some preliminary investigation it became apparent that we had to evolve a standardized method of interpreting these bores. We found that this was a different problem than most facets of non-destructive testing. I'm thinking particularly of radiography, because in radiography you have most generally a surface that is uncracked and you are looking for a crack that you hope isn't there. In the case of bore surfaces we

Slide 18-8
Typical Replica Bore Surfaces
Having Circumferential-Longitudinal Cracks

Slide 18-9
Typical of Replica Bore Surfaces
Which Show Crazing

found that they are almost always cracked so the problem became one of differentiating between crack patterns or between conditions that we saw. We divided the kinds of crack patterns into kinds of conditions we saw or categories. The first category I've put up here, slide 18-6, is for bore surfaces without cracks. Each of these categories we've divided into sub-types and here we call these two sub-types: -frosty and grainy, for want of better words. The frosty surface looks like what you would see if maybe you were viewing a sandy beach from maybe 50 feet up. You are aware that it's rough but you cannot make out the individual pieces that make up this roughness. Grainy, on the other hand, was just an extension of the frosty, except that now we can actually see the grain patterns in the niobium carbide. The second category is where we find different crack patterns. Slide 18-7 shows what we call circumferential cracks and we've divided this into sub-type of faint, moderate, and heavy. Now these refer to the width of the cracks and not necessarily to the number of the cracks within any one segment. The next category (slide 18-8) we called circumferential longitudinal cracks. These, as you can see, are extensions of the circumferential cracks. You can see what's happened here is that we have circumferential cracks in this bore, but there's one or two little cracks connecting these. Slide 18-9 shows the last category, the typical example of crazing. As you can see this is a random orientation of crack patterns and again we have faint, moderate and heavy. The faints get pretty faint here. As with any classification system there are often crack patterns which fall within sub-types or many categories, but with a good interpreter using sound judgment this system seems to work quite well. For correlation we wanted to reduce the crack patterns to numbers and since we were planning to correlate with other non-destructive testing data and also from replica to replica, it's much easier if you try to do it with some sort of number. We put the crack patterns in the order that we thought might be greater bore damage. Then we assigned an arbitrary number to them denoting this rank. I'd like to call your attention here to the abbreviations on slide 18-10. We will see them later on a graph. Remember, we had three types of crack patterns.

PATTERN

FROSTY
GRAINY
FAINT CIRCUMFERENTIAL CRACKS
FAINT CIRCUMFERENTIAL-LONGITUDINAL CRACKS
FAINT CRAZING
MODERATE CIRCUMFERENTIAL CRACKS
MODERATE CIRCUMFERENTIAL-LONGITUDINAL CRACKS
MODERATE CRAZING
HEAVY CIRCUMFERENTIAL CRACKS
HEAVY CIRCUMFERENTIAL-LONGITUDINAL CRACKS
HEAVY CRAZING
COAT MISSING

ABBREVIATION

FROSTY
GRAINY
FCC
FCL
FCRZ
MCC
MCL
MCRZ
HCC
HCL
HCRZ
MISS

VALUE

1
2
3
4
5
6
7
8
9
10
11
12

Circumferential cracks are abbreviated CC, circumferential longitudinal cracks, are CL, and crazing is CRZ. In each of these crack patterns we have faint, moderate and heavy, which are F, M, and H. Therefore, H CRZ stands for Heavy Crazing. At first we scanned every inch as we were reading the replica. This was an extremely long and tedious process. After we had read several elements we noticed that if a significant crack pattern developed it extended at least two inches along the length of the bore, therefore, we reduced our inspection to once every two inches. That is the inspection that we are doing now. However, even at two inches, the inspection time is extremely lengthy. It takes approximately 20 minutes to read one set of replicas. That is, pre- and post-test for one bore using two people. Therefore, if you took the 18 bores, and I say 18 because bore 19 is used for a replication process control thermocouple. If you read all 18 bores, you are talking about 6 hours or 1 and 1/2 man days. In the production involved, this of course, is too long. So one of the goals of our evaluation was to find out how bad the interpretation would be if we only used sample bores. We wanted the sample bores to meet the following criteria for this evaluation. That is, the number had to be small enough so that the inspection time was reasonable and should contain all possibilities of bore locations. Now this is particularly important for the hot gas test. You realize that you have internal bores and you have external bores on the corners and you have external bores which are near the flats. All these bores will see a different temperature, during the hot gas test particularly. We wanted to have at least one sample bore from each of these groups and also, as much as possible, we wanted to pick the same bore that had been inspected by a visual examination by one of our groups. They sliced the element through the BCEF corners, and therefore, looked at bores 8, 9, 10, 11 and 12. We selected bores 2, 8, 9, 10 and 12 as our sample bores. To try to get some sort of a handle on how bad our error was, we read all of the bores of one element. We picked this element especially because from the other non-destructive testing data, it appeared that this element should correlate. The element was

CALCULATED STANDARD ERROR OF ESTIMATES
FROM AN EIGHTEEN BORE REPLICA INTERPRETATION
OF ELEMENT O-480-11584

SAMPLE BORE	BORES PREDICTED	STANDARD ERROR OF ESTIMATE	
		BEFORE TEST	AFTER TEST
2	EXTERIOR, FLATS (4,7,13,16,18)	1.55	1.50
8	EXTERIOR, CORNERS (1,3,12,17)	1.39	1.41
9	INTERIOR (5,6,11,14,15)	1.19	1.35
12	EXTERIOR, CORNERS (1,3,8,17)	1.28	1.30

Slide 18-11

COMPARISON OF BEFORE HOT-GAS-TEST
CRACK PATTERNS TO AFTER HOT-GAS-TEST
CRACK PATTERNS ON SIX UNLOAD-
ED ELEMENTS GIVEN A HOT-GAS-TEST
AT 2250°C

24 SEPT. 1965

SEGMENTS OF FUEL ELEMENTS
Slide 18-12

torn up about as bad as it could be so we assumed that it would probably correlate worse than any other element. We wanted to see all of our points on a 45 degree line. If they were not lying on a straight line, then one may find two error limits which would be called S_y or the standard error estimate. These two lines would then contain about 2/3 of the points. It is very similar to a sigma in normal calculations on this, but here it's called standard error of estimate. We didn't do real well, I'm afraid. You can see in slide 18-11, that we have thoroughly high centered error of estimate. However, the only thing that we can say is that 50 percent of the points would be predicted by sample bores within plus or minus one. We also wanted to evaluate how long and how hot a hot gas test should be before we could see significant changes in the bore surfaces. To evaluate this, we generated a figure called average change. This figure is proportional to the average change over the whole element caused by a hot gas test. We correlated this figure with the length of the hot gas test and its temperature and made the following conclusions. A hot gas test of 2250°C should last at least 20 minutes, or a test of 2400°C should last at least 10 minutes before replication is really justified, before you see any real significant changes in an element. We also tried to see how a hot gas test affects the crack patterns of these elements. Slide 18-12 is a bar graph showing the different crack patterns for a particular unloaded element at 2250°. These are cracked pattern pairs. That is, it was frosty before test and it was frosty after the test. Now here's another one. It had faint crazing before test and moderate crazing after the test. Now we have this quantity that we found in these elements. You can see the preponderance of crack pattern curves that we see in the first 13 inches show little change. For instance, it was frosty before test and it's frosty after test. From 13 to 26 inches, again the majority shows little change. However, you can see that we're now starting to get some change. The real change starts from 26 to 52 inches. Here you see the majority of the instances where we have faint crazing before test changed to moderate crazing or widening of the cracks. From 39 to 52 inches is frosty before the test with faint crazing after the test.

COMPARISON OF BEFORE HOT-GAS-TEST
 CRACK PATTERNS TO AFTER HOT-GAS-
 TEST CRACK PATTERNS ON FOUR UN-
 LOADED ELEMENTS GIVEN A HOT-GAS-
 TEST AT 2400°C

Slide 18-13

COMPARISON OF BEFORE HOT-GAS-TEST
 CRACK PATTERNS TO AFTER HOT-GAS-
 TEST CRACK PATTERNS ON FIVE LOADED
 ELEMENTS GIVEN A HOT-GAS-TEST AT
 2250°C

Slide 18-14

Here we have some fairly heavy crazing. I'd like you to notice another fact here too, that these are unloaded elements and in these we see almost all crazing. Slide 18-13 is the same thing, except it is for an unloaded element that was given a 2400° hot gas test. Again we have this same condition from 0 to 13 inches, but from 13 to 26 we're starting to see a little bit of change, still not much; but from 26 to 52 is where we start seeing the change again. If we were to compare these we would see that the significant difference which you see between the two hot gas tests occurs in the last segment from 39 to 52 inches. Here the cracking is more severe, on the whole, than it was at 2250°. Otherwise the elements look about the same. Slide 18-14 shows loaded elements. Now you can see the difference. In fact, remember in the unloaded elements we saw almost all crazing and here we're seeing almost all circumferential cracks or circumferential longitudinal cracks. The interesting thing to note here is the fact that the hot gas test seems to primarily or preferentially leave an element with longitudinal cracks or cracks with longitudinal components. Here is an example. Here are circumferential cracks which became circumferential longitudinal cracks in the after-test state. You can recall that the difference is that there's just a longitudinal crack connecting the circumferential cracks. At the same time, faint crazing is in the same region, also moderate circumferential longitudinal cracks, steady longitudinal circumferential moderate cracks and we see the same thing in the next segment. Here we have circumferential cracks, they became crazing. This is primarily an addition of cracks with longitudinal components. If you had cracks with longitudinal components you didn't propagate any apparently and if you didn't have any you propagated some during the hot gas test. As shown in the next slide (18-15) we tried to get a typical profile of before-test crack patterns. That is what they would look like for loaded elements and for unloaded elements. The way we did this was just simply by taking the mode of all the bores of 5 loaded and 8 unloaded elements and we came up with this sort of a profile. You notice that what we saw before in the hot gas test result is what we see here, the loaded elements have circumferential and circumferential longitudinal cracks and the unloaded elements have strictly crazing. I'd like to review the conclusions that we have presented.

We found that significant crack patterns will extend at least two inches so that you can interpret a replica if you want to every two inches, and we also found that you can use sample bores 2, 8, 9, 10, and 12 but you have to live within an error of ± 1 value. Hot gas tests at 2250° should last 20 minutes and at 2400° they should last 10 minutes before you see any significant changes on the bores. Hot gas tests of 2250° and 2400° on unloaded elements affect these elements approximately the same except from 39 to 52 inches, and in this region the 2400° test causes more severe cracking. The hot gas tests of loaded elements tend to propagate longitudinal cracks if they were not present. We also determined the typical crack pattern profiles of loaded and unloaded elements.

TYPICAL BORE SURFACE CRACK PATTERN PROFILES BEFORE HOT-GAS TEST

LOADED ELEMENTS

UNLOADED ELEMENTS

6 OCTOBER 1965

Slide 18-15

PART 19

POST MORTEM EVALUATION

D. E. Grimm

M. D'Amore, WANL: The last speaker will be Mr. D. E. Grimm from the Los Alamos Scientific Laboratory, He will discuss the Post-Mortem Evaluations.

D. E. Grimm: When I stepped up here I told Bruce that my talk could either be five minutes or a half hour or so since we're running late, let's get right on and we'll make it five minutes. Look at slide 19-1, please. You see here the center element in the jig. Slide 19-2 shows all the attachments in the hot cell for the radiography, and slide 19-3 shows how the film holder is inserted into the hot cell. In slide 19-4 we have a sample radiograph where you can see the thermal capsule - whether they've melted or whether they've not melted, if they are intact or if they have changed. We're showing indications of melting. It turned out in the NRX-A2. We ran across what we called the third case where we saw some slight changes in some of the capsules; we compared them with the original radiograph to see if it was indeed a change or not and it turned out the original radiographs were positive. These changes we were looking at were so insidious that we could not compare them with a positive, and the original negatives were not available. In the next slide (19-5) we tried to pick three definite cases. This is a capsule and there's definite melting. This one is intact. This one is intact and this one would be one of the ones in the

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case of the NRX-A2 where we said we didn't know. It had sort of a hairy effect on both ends of the thing. Well, as it turned out in the case of the A3, we did have enough of the original pre-test radiographs as negatives to compare and see that this particular capsule, while it had not melted, had definitely changed. The little hairy things on each end were not present in the original pre-test radiographs. We then went ahead and read all these capsules, indicating what we saw, whether they were fused or unfused or whether we had seen any indication of change as you see on the capsule on the left. We tabulated all this data as you can see on the next slide (19-6). At the left are the element numbers and this is the alignment of the capsule. Fifty-one of these capsules were supposed to have been present in these various elements, and some 53 of the capsules in the various elements makes somewhere in the order of 2700 separate entries. I've indicated the condition of the capsule as "F" meaning fused condition, "I" is for intact condition, and "C" is for the change condition. In other words, those are the capsules on which we saw this little hairiness. After I had sent out this report I saw a definite pattern, particularly on the "C" condition, as you see here; with this I was able to check against the actual thermal capsule materials and I was able to see that all the ones with this "C" which had this whiskering evidence were tantalum containing thermocapsules. Whatever this means, I don't know, but I did want to dramatize it and that is the reason I ultimately ended up doing this chart so it would be more graphically illustrated. There are certain capsules, which are hard to see radiographically, which do not melt but do change somehow or other. One thing we do need right along, and it would be appreciated, is if we can have the original pre-test radiographs as negatives and not positives; it is absolutely essential in many cases because we have to be able to compare pre-test and post-test pieces capsule for capsule. I think that just about does it.

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Slide 19-1. Fuel Element in Hot Cell Positioned For Radiography

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Slide 19-2. Hot Cell Observation Window Showing 275 KV X-Ray
Unit Tubehead and Appurtenances

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Slide 19-3. Loading X-Ray Film Holder Into Hot Cell

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Slide 19-4. Sample Radiograph of Thermal Capsules

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Slide 19-5. Enlarged Radiograph Showing Various Conditions of Thermal Capsules

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LOS ALAMOS SCIENTIFIC LABORATORY

NDT Report No. 291

July 6, 1965

J-9 NRDS RADIOGRAPHIC EVALUATION OF NRX-A3 THERMAL CAPSULES

LEGEND:

	FUSED, MELTED
	INTACT, NO CHANGE
	CHANGE, BUT NOT FUSED
	LOST, MISSING

Slide 19-6. Radiographic Evaluation of NRX-A3 Thermal Capsules

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Ron Cost: They had a problem in calibrating the niobium tantalum thermocouples on the melting temperature determination carbiding problem.

Grimm: You say you had a problem in calibrating?

Ron Cost: Well, they had originally in A2, when they calibrated the niobium tantalum capsules. They couldn't get a picture of melting.

Norm Thielke: With respect to that last slide, is the abscissa the axial position?

Grimm: Yes, the axial position from left to right is hot to cold.

Norm Thielke: So these capsules that we see are actually positioned in their axial stations?

Grimm: Yes, there are several. I have the list of the capsules here and there are maybe 4 or 5 tantalum containing capsules of this series.

Norm Thielke: Therefore, these failures occurred at a variety of temperatures.

Grimm: That's right.

Unknown questioner: I didn't hear your first remarks as to the location of these thermocapsules.

Grimm: Where are they located, you said?

Answer: Yes

Grimm: Usually there is a slot milled into the side of the element indicating where they're located.

Ritter: Were there any capsules of this type which didn't show up as having changed? Were there any significant number of these? I mean was it significant that these changes occurred on that axial position or was it just significant with that type?

Grimm: No, it was strictly with that type capsule.

Ritter: Then you're answering my question that all of those capsules had that condition without regard to axial position.

Grimm: In general, all of them as far as we can see. Ironically enough, before I knew these were tantalum containing I had gotten one bum steer as to the material of the capsules and they were iridium to begin with and iridium 192 and something has happened. Then they gave me another plot of the capsules and these turned out to be all tantalum instead.

Meade D'Amore: Are there any more questions? That concludes the Los Alamos presentation.

Thank you Don. Now Mr. Pollack will present a summary which will conclude the formal portion of this symposium.

PART | 20

GENERAL DISCUSSION

Nick Pollack: Gentlemen, I'd certainly like to thank everyone for taking time from valuable schedules and attending this symposium, and especially those individuals who have presented papers. I certainly feel it has been worthwhile. We had a meeting last evening and have decided several things. One of these was that this symposium possible came too soon after the April meeting. Mr. Jackson from Y-12 has indicated that he would host the next meeting and Dr. Tenney, Mr. Jackson and I will meet to determine when the next meeting should be held. It appears that an annual get together might be a little more desirable. This meeting has certainly indicated several things. One is that we definitely need the cooperation and the coordination between the three groups. The common denominator that Jerry was hoping to obtain during these sessions has been fairly well established, but we still have some work to do relative to standards and coordination of data. And again, we are taking a considerable amount of data. How meaningful is this data? Is it really being used? To give you a brief idea of what we at Westinghouse feel, relative to NDT effort on elements, we have taken several approaches. One is rapid data retrieval. In this way, we get the information to the process people, the materials people, the design people and the reactor analysis groups as rapidly as possible so they can evaluate the process during the manufacturing of an element to get a better idea of the yields and also what the final product might be. We've also taken another approach whereby we would like to reduce the amount of handling of a coated element. As you know, our friend, the chip, is there. We don't want that friend. One of the best techniques to eliminate chipping is to reduce handling of

the coated element. If at all possible, without degrading the known quality of the element, move the inspection efforts back into the stream ahead of the final coating operation. One of the things that we are considering moving is gamma count, for instance, moving it to the as-leached position and hopefully not doing any more gamma counting in the as-coated state than we absolutely have to. We are looking at twist, bow, and perpendicularity, to move those back into the stream. Now there are some things like envelope and final dimension which we'll more than likely still have to handle after our final coat. One other big factor, and I guess it's true in all of the quality control and inspection efforts, is the human error. If we could eliminate the human error, we'd probably be considerably better off than we are right now. The technique that we have taken, and I'm sure that all of you have taken, is to automate as much as we possibly can. The one thing that we have foremost in our minds, and I'm sure that everyone does, is that we must know the quality of the element. We must know the quality of the final product and we can't do anything to change or jeopardize this. Does anyone wish to make any comments?

D. Ritter, AGC: I'd like to say just one thing, Nick. You have a very good technical approach in your coordination and correlation efforts and it appears that you're working quite well. I'd like to ask who is on your public relations committee to sell some of these things to the balance of the activity that are associated with this kind of a program?

N. A. Pollack: You mean within Westinghouse?

D. Ritter, AGC: No, this is a joint effort.

N. A. Pollack: I guess every man in this room!

D. Ritter: Well, one of the biggest problems that you have is that you have a lot of very capable quality control people but you don't have very many PR men.

N. A. Pollack: Any other comments? Would you like to make a presentation, Jerry?

Dr. Tenney, LASL: I believe it is always in order to look at such gatherings, and I myself have been doing it over the years continuously, even if I take a trip by myself somewhere, to find out, did the taxpayers really get their money's worth for paying for such meetings? In principle, I would say, based on the various discussions we had privately and so on, that indeed this meeting did contribute greatly to the overall problems of non-destructive testing,

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as far as the ROVER and the NERVA elements are concerned. We have learned quite a few things during the last two days; we have reached certain agreements and certain conclusions and I would like somehow to emphasize a little bit the highlights from the technical point of view. First of all, I want to say that this meeting, more than any other meeting, has indeed clearly crystalized and shown what the strong and what the weak sides of the three agencies are in the field of non-destructive testing. Now, suppose I just mention the strong sides and I would like to say that as far as the host agency is concerned, as far as Westinghouse is concerned, indeed their great strength is in statistical approaches, as well as where data evaluation and retrieval activities were concerned. I can see that in no time you will have everything automated if we go in this direction but the question is where do we draw the line. I do feel that such meetings as this one somehow, I hope, balance the thinking and apply brakes where brakes are in order so that we should not bypass the permissible RPM, if I may say so. For this reason I would like to say that we, Los Alamos, and I'm convinced Oak Ridge, for this reason, are looking at these automation approaches, that Westinghouse is really emphasizing, with great anticipation to know how far one can go. I would like to say that automation does not eliminate the human error, inasmuch as automation works only as well as do the human beings who feed the information into the automated system. I would like to say out of experience, as far as automation is concerned, that indeed we have found out that mistakes have been made, as far as non-destructive testing of elements is concerned, by innocently putting the wrong program into the entire automated system. It took us quite some time to find out where the mistake was made, after some thousand or so elements had been inspected according to the established program which turned out to be wrong. Now, why? This is something we all have to keep in mind. There are definitely those people who have their specialties. And I would say that we live in an age of specialization to an extent that people go ahead and come up with ideas the way they see fit without, let us say, being fully aware of the technical background of those data that they are trying to automate. And this is something we all have to be watching for. I have, as far as the data evaluation and statistics is concerned at Westinghouse and, as I say,

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statisticians and system engineers really have been at work here at Large and Cheswick, and we are looking forward to see how they are going to work out. It is very very difficult in my opinion, based on past experience, to stop if certain activities have reached such a point that if you stop the activity, disregarding if it is worth it or not, that so many people might lose their jobs. In this respect we have to be quite critical, especially as it costs quite a bit of money. Now Oak Ridge has done excellent applied R&D work through the last six months on problems we have brought to the surface. I would like to say that it just happened. There is no specific reason why it happened, but between April and now, Los Alamos had more personal contacts with Oak Ridge than they had with Westinghouse, and vice versa. I always consider these two-way streets. So, therefore, this, over a shorter period of time can help and in stretching out the time period from one meeting to another, I believe we can balance it a little bit better by getting some fires, brush fires, that occur between, let us say Westinghouse and Los Alamos. And right now we have to take care of a few brush fires between Los Alamos and Oak Ridge and that was the reason that we had the better communication with Oak Ridge. One thing I would really like to bring up, and to me it was quite apparent, that somehow a certain, let us say, jargon, had entered the various activities at Westinghouse and expressions have been introduced which are practically not known, let us say, to Los Alamos and so on. I mean a uniform nomenclature understandable to everybody should, by all means, be maintained. There are quite a few expressions that were new to me and I among others want those introduced to our congressional delegation who have been asked, "Do you believe in a centimeter-gram-second system and move away from inches, and so on", that I believe and am in favor of it, especially when you see that you have not only a loading in grams per inch but, also in milligrams per centimeter in the same organization, that's going a little bit far. I have taken many notes, but I would say the most important thing for non-destructive testing is, indeed, what does it do and what is its validity? Now, non-destructive testing as far as fuel elements are concerned performs three functions. First of all, it guarantees the user that the elements they put into the reactor have certain criteria. The second phase of non-destructive testing by fast feedback can improve the

production procedures; that's the second important point. But a third important phase, and indeed the acid test, is to do the post-mortem work on the elements in order to determine to what extent specifications, and I'm just talking about non-destructive testing for the moment, to what extent are these specifications, are these tests, are these data, indeed making sense? I appreciated very much when yesterday morning the reactor analysis people told us that we need to depend on non-destructive testing. Maybe the next time we will hear from these people more in absolute fashion as to what accuracy do they really need as far as the loading is concerned, what is the spike of the temperature near the periphery, how accurate is this, and to what extent do they need to know the uranium loading. Maybe down to 1/2 percent or maybe they can live with five percent. In other words, the less accurate the data should be, the cheaper and faster the actual feedback, and I do hope that data will be yielded here at Westinghouse where some feedback and certain evaluation has taken place on the NRX-A3. We really would be interested in knowing, are we of service doing non-destructive testing? We are putting an awful lot of NDT data into the Phoebus IB for, hopefully, we will have a good test in Nevada where we are going to evaluate them. And I'd like to quote Rod Spence, the N-Division leader of Los Alamos. I had quite a chat with him on the post-mortem work regarding non-destructive testing. Indeed we have to keep in mind that roughly a post mortem NDT test, and that goes for all other post mortem evaluations, is about ten times as expensive for each information bit you get as compared to the pre-mortem test because you have to audit under post mortem conditions. This means hot cells and so on and actually you would not want to occupy the MAD building for too long so that the next test can be performed. So I do absolutely feel, and I want to emphasize it again as I did in the closing remarks in April, that we are furnishing an awful lot of data; how many are necessary? And for this reason it is very easy, as I say, to build empires and let the Parkinson's Law be very active in this respect. But let's be sensible and let's not build a fantastic information center with data we don't need. I believe we have reached such a point that we know non-destructive testing will be here so we don't have to fight for our existence in this respect. On the other hand, there are many phases in the entire nuclear rocket program where non-destructive testing hasn't even appeared on

the surface as yet. I refer, let us say, to the entire glued tip problem. We have not developed, and Rod Spence again and again said, "Jerry, we're looking to you people so that you should come up with a decent non-destructive test to determine how sound is a glued tip." We haven't been able to do it yet. I know that nobody else is doing it, in this respect. So therefore, we still have to do pioneer work in many phases as far as the fuel element program is concerned. Now, something else I also would like to focus your attention to as I've mentioned it privately, that we at Los Alamos have been doing, I believe, very good work utilizing the electron microscope to study the interface of niobium carbide on the matrix between the loaded and unloaded, and what have you. And the data we are feeding back to our coating people, to Mel Bowman and his group, is quite illuminating. Let us say the various phases of niobium carbide, as a function of temperature, would tend to layer itself where the electron microscopy indeed determines, for instance, three layers of types of niobium carbide, and so on. Purenium. We have been able to find out the uranium migration from the matrix into the niobium carbide. We have found out that the area in the matrix adjacent to the niobium carbide is quite spongy and is a function of the amount of the niobium carbide being deposited. So all these data make sense when trying to evaluate the beta backscatter problem. And I do feel that these various things, such as softness of the matrix underneath the niobium carbide, will indeed explain many things; why we have slight discrepancies between the metallographic data and the beta backscatter data. In other words the beta backscatter data are being influenced by many factors, many of which we don't even know as yet. Now, in addition to that I would like to say that we in the non-destructive testing field; we at Los Alamos are very deeply engaged in it and I mentioned it to Nick yesterday, that we should probably start comparing notes in all the components that go into a reactor that are not fuel elements. We have a fantastic problem on our hands as you see on the PHOEBUS II on the tie tube design, where brazed joints have to be inspected, and we are spending an awful lot of time to evaluate and come up with good non-destructive test methods to guarantee the soundness of the tie tubes. In non-destructive tests, for instance, yesterday when Walt Scheib asked Westinghouse, "What guarantee do you have as far as the boron 10 content in the boron plate is concerned?" the answer was, "we take the certified

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statement from the manufacturer". Fine. Good. But I am quite skeptical, to be very frank, about such things. We at Los Alamos have just developed, for instance, a neutron DXT gauge using one of our reactors as a neutron beam to study the Boron 10 content; starting at the beginning of January we will go into full production by scanning all the boron plates for the Boron 10 content and this on the principle of N-gamma reactions. Therefore, we have to be active in all the other phases because we know very well that many things can contribute to a failure out in Nevada. Might it be a pump or might it be the braze joint in the nozzle or what have you. Therefore, we should put all the efforts into the quality of the fuel elements, but there is a big chain that makes up such a reactor and this big chain is as strong as the weakest link. For this reason I do feel that non-destructive testing has to play by ear, has to be neat and as far as the PR is concerned, public relations, the question has been asked just before. My fundamental philosophy is very simple. Those who have known me know that I have been preaching it all the time. We cannot sit at the desk and wait till the jobs come to us. We have to go after them, and we have to be original, and we have to be pioneers. That is the only way we can justify our existence and our hope to be able to contribute. In general terms, I would like to say that I personally am extremely pleased with the information exchanged and what has taken place in the last 1 - 1/2 days. And from the constructive criticism point of view, I would say that we all have learned and therefore, have enough foundation to come up with an even better meeting than we had this time, and there as Nick said, Nick, Jackson from Oak Ridge and I should get together at some intervals and evaluate the entire plateau of activity in order to plan such a symposium again. I would like to close my remarks by stating above all, it is the atmosphere that really contributes to such a success and many thanks once more in the names of all the out-of-town visitors here, to Westinghouse for hosting this meeting.

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