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TRIP REPORT

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ASTRONUCLEAR LABORATORY

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PURPOSE OF TRIP:

Review the ORNL graphite fracture program and discuss the problem of NERVA fuel structural design.

ATTENDEES:

<u>ORNL</u>	<u>SNSO-C</u>	<u>WANL</u>
B. L. Greenstreet	H. L. Brammer	P. A. Stancampiano
J. M. Corum	J. J. Lombardo	P. P. Zemanick
S. E. Moore	J. R. Richardson	
C. E. Pugh		
R. S. Valachovic		
G. T. Yahr		

(Dr. Rowley of LASL was scheduled to attend the meeting but was forced by competing commitments to cancel out at the last minute.)

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SUMMARY:

1. The ORNL Applied Mechanics Section reviewed their most recent work (as yet unpublished) on graphite failure criteria. Much of the work is reaching completion and in general is resulting in consistent packages of information on graphite behavior.
2. Salient items from previously reported ORNL work with graphite were reviewed in summary form.
3. The final topic was a discussion of how to proceed with the NERVA fuel analysis with immediately available properties and analytic tools. No real criticisms of the current WANL approaches were made. Some codes available now or in a short time were suggested for our consideration by Dr. Greenstreet. ORNL agreed to give some attention to the coating-matrix interaction stress analytic representation.

DISCUSSION:

A program for investigating fracture of graphite is being conducted at Oak Ridge National Laboratory (ORNL) by the Applied Mechanics Section of the ORNL Reactor Division. This program is aimed at furnishing basic information on the fracture behavior of graphite for application in NERVA.

Work began early in 1969 and is continuing. The graphites under investigation are commercially produced ATJ, isotropic POCO AXM and reconstituted AXM or RAXM. RAXM is extruded using ground AXM graphite, carbon black, and furfural alcohol and is similar to the PW-2 high expansion graphites. The entire program at ORNL is under the direction of Dr. B. L. Greenstreet, Manager of the Applied Mechanics Section. The SNSO-C coordinator is J. J. Lombardo. In addition to the graphite fracture program, the ORNL people discussed the results of some earlier research with RVD and AGOT graphites, and the status of their finite-element stress analysis computer code development.

1. Fracture Studies - G.T. Yahr

Mr. Yahr discussed the results of room temperature fracture toughness measurements with different specimen designs. Tests were run using notched tensile specimens, small notched beams (flexure), double cantilever beams (which are essentially long WOL specimens), and compact tension (WOL) specimens. Most of the fracture mechanics testing has been completed. Preliminary indications are that the small notched beams and compact tension specimens are yielding the best results. The notched beams specimens were taken directly from support element extrusions and indicated that the fracture toughness varies within the cross section of the element. Fracture tests were conducted on unnotched beams which were used to estimate the inherent flaw size. ATJ was found to have about an 8 mil inherent flaw, AXM about 3 mils and RAXM about 8 mils. ORNL presented metallography of these materials that seemed to support these preliminary back calculations of inherent flaw size.

Investigations with Weibull Theory continue. The data collected to date apparently do fit the Weibull statistical distribution, however, the volume effect is not the same as that predicted by Weibull. This was essentially the conclusion reached earlier in 1965 by S. E. Moore at ORNL on AGOT graphites. In other words, the Weibull statistical form fits the data but the Weibull solid mechanics statistical theory of failure with its essential idea of a volume effect does not apply.

Testing will continue with the following schedules:

<u>PROJECT</u>	<u>ESTIMATED COMPLETION DATE</u>
Complete Weibull (RAXM)	4-1-71
Bi-Axial Stress Studies	
Disc Crush Tests (ATJ, AXM)	3-1-71
Element Crush Specimens (RAXM)	
Support Elements	2-1-71
19 Hole Elements	
Thick Wall Pressure Vessel (ATJ, AXM, RAXM)	4-1-71
Thin Wall Tubes (RAXM)	5-1-71
High Temperature Fracture (AXM)	8-1-71
Tension	
Compression	
Fracture Toughness	
Specimens from Elements	
High Temperature Tests of NERVA Graphite from the Support Element	8-1-71
Tension	
Dynamic Modulus	
Creep	
Relaxation	
Comparison of Ambient Temperature Bi-Axial Test Data and the Various Fracture Criteria	7-1-71
Reports on Previous Work at ORNL	7-1-71
Weibull	
Fuel Element Room Temp. Mechanical Properties	
RVD Graphite	
Thermal Shock	

ORNL has asked WANL to perform finite element stress analysis in support of their element across flats crush tests which are planned to be tested by February 1, 1971. J. Swanson had originally agreed to perform these supporting calculations.

2. Non-Linear Stress-Strain Behavior

S. E. Moore presented the results of his Masters Thesis research on an anisotropic elastic-plastic stress analysis of a thick-walled AGOT graphite cylinder subjected to internal pressure. Tests were conducted on 30 thick-walled AGOT cylinders subjected to internal pressure. Neither the elastic solution nor plastic solution really seemed to correlate well with the experimental strain gauge results. Moore solved the orthotropic differential equations by numerical integration. It would be interesting to compare this work with a finite element ORTHOFEATS elastic-plastic solution. Moore tested the 30 cylinders to fracture and it seems that much statistical information relating to bi-axial stress failure criteria can be obtained from these tests. ORNL has characterized AGOT graphite statistically.

C. E. Pugh presented the results of his studies of RVD graphite at elevated temperatures. He developed a set of anisotropic visco-elastic constitutive equations to describe the time dependent stress-strain behavior at temperatures ranging from 3500 to 5000°F. The equations appear to be valid up to stress levels of one-half the ultimate tensile strength. The data are based on tensile tests. It was pointed out that some of NERVA's creep and relaxation problems deal with compressive stresses and load cycles that may result in strain ratcheting. Dr. Greenstreet pointed out that strain ratcheting depends on how the material yield surface develops with loading and that ORNL is planning to do more work on this extremely complicated question in the near future.

3. Finite Element Codes

J. M. Corum discussed the finite element codes that ORNL and Gulf General Atomics are developing. Some of these GGA "SAFE" series are in use at ORNL. These codes were developed to analyze prestressed-concrete pressure vessels. These codes consider creep, relaxation, and crack formation. It may be possible to extend these codes to graphite and composites. However, such an undertaking would probably require considerable analytical and programming efforts. It may be more appropriate to modify WANL's FEATS and ORTHOFEATS codes to include plasticity, creep and eventually multi-axial fracture criteria. Dr. Greenstreet indicated that ORNL was developing a modular finite element code which would permit the module containing the constitutive equations to be removed and replaced with any set of constitutive equations which describe the material elastic-plastic-creep behavior. The first version of this code would be available in June 1971. This first version will be limited to equations of state creep and will not be able to do cyclic problems.

4. NERVA Fuel Structural Problems

Dr. Zemanick presented the problems associated with the structural analysis of NERVA fuel. These were the complex coating-matrix interaction, definition of a valid design fracture criteria applicable for the 19 hole geometry, definition of a meaningful thermal stress test, and implementation of probabilistic structural design.

4. NERVA Fuel Structural Problems (continued)

J. J. Lombardo asked Dr. Greenstreet to consider the possibility of including composite fuel in the fracture program. He stressed the point that the ORNL applied mechanics section was in a better position (than WANL) to perform these basic investigations due to their experimental stress analysis lab which also reports directly to Dr. Greenstreet and their lack of distraction with day-to-day NERVA calculational demands.

Signed P. A. Stancampiano

Approved John P. Genovese