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AECU-3566

General Electric Company
KNOLLS ATOMIC POWER LABORATORY
Schenectady, New York

Extension of Operating Life of
KAPL-30 Thimbles

by

D.M. Lewis

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REFERENCES

- (1) The Materials Testing Reactor, Chapter 3, Light Water Moderated Reactor
- (2) MTR Hazard Evaluation, ANL-SM-236, by Stuart Molain and R.E. Winkleblase
- (3) Letter to T.R. Neville from D.M. Lewis, Subject - Hydrostatic Testing of KAPL-30 Loop, 4/17/57

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Abstract

On June 24, 1957 the KAPL Pressure Systems and Pressure Vessels Review Board completed their evaluation of the radiation damage to the KAPL-30-4 carbon steel thimble.

The Board decided that it was safe to extend the operating life of the thimble from 9 to 16 MTR cycles, subject to review if further extended low temperature operation occurs.

This memorandum summarizes the data and evaluation which were the basis for the decisions and recommendations of the KAPL Pressure Systems and Pressure Vessels Review Board.

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AECU-3566

EXTENSION OF OPERATING LIFE OF KAPL-30 THIMBLE

A. DECISIONS AND RECOMMENDATIONS OF THE KAPL PRESSURE SYSTEMS AND PRESSURE VESSELS REVIEW BOARD

The KAPL Pressure Systems and Pressure Vessels Review Board met on June 24, 1957 to review the KAPL-30 thimble data presented at previous meetings, to decide on the course of action to be taken following the extended operation at low temperature, and to evaluate the feasibility of extending the operating life of the thimble from 9 to 16 MTR cycles.

The decision and recommendations of the Board were as follows:

1. On the basis of presently available information, the present KAPL-30 thimble may be used for a total of 16 MTR cycles. If at any time during the 16 cycles there is an extended period of low temperature operation below 500 F totaling 5 days or more while the reactor is at power, the Board recommends that it be informed so that it can review the existing situation and make additional recommendations.
2. Following the extended period of low temperature operation at the end of Cycle 88 the recommended course of action was:
 - (a) Conduct the leak test at the maximum pressure of 1800 psi and a temperature of 200 F.
 - (b) Anneal the thimble at 600 F or higher for a minimum of two hours. The maximum pressure during this procedure should be 1800 psi.
 - (c) Conduct the hydrostatic test at 110% of the maximum operating pressure and at 200 F.
3. Annealing procedures need not be conducted during or following reactor operation as long as operating temperatures exceed 500 F while the reactor is at power. Should low temperature operation occur for 24 hours or more while the reactor is at power, not followed by at least two hours operation above 500 F, annealing is recommended prior to hydrostatic testing or operation. Hydrostatic testing may then be performed at a minimum test temperature of 70 F. Hydrostatic testing following periods of normal operation at 500 F to 600 F may also be conducted at 70 F minimum temperature.
4. The ability of the existing angle iron restraining members to prevent ejection of the thimble from the HB-1 hole during a cold water accident should be checked and provisions made to increase the restraint if necessary. (It is estimated that a force of 3000 lbs. will exist to displace the thimble outward. It is not considered possible to stop ejection if a hot water accident occurs.)
5. The hydrostatic test procedure in which two rupture discs are used should be modified to require the use of a specially marked blind flange.

*The KAPL Pressure Systems and Pressure Vessels Review Board provides special pressure systems codes in cases where industrial codes or government specifications are not applicable in their entirety. Review Board decisions require a five out of six majority. The voting members of the Group are: W.E. Cooper, Consulting Engineer, SAR Structural Evaluation; W.L. Fleischman, Consulting Engineer, DLG Reactor Materials; D.R. Miller, Consulting Engineer, SAR Power Plant Systems; L.H.B. Peck, KAPL Safety Specialist, R.H. Simon, Manager, In-Pile Loop Design and Operation; and H.E. Stone, Manager, SAR Arrangement, Shielding and Safeguards.

B. DISCUSSION

The operating life of the KAPL-30 carbon steel thimble was originally approved by MTR at 4 MTR cycles in March, 1956. KAPL data on carbon steel specimens irradiated to the equivalent of nine MTR cycles on the thimble indicated that some annealing was taking place at the loop operating temperature (500 F to 600 F). A request was made to MTR for an extension of the operating life to 9 MTR cycles. This extension was approved.

The Mechanical Metallurgy and Metallography Group at KAPL have now completed a series of tests on ASTM-A-201 tensile and notched bend specimens which were irradiated to an nvt equivalent to 16 MTR cycles of the KAPL-30 thimble tip. These tests were performed to obtain the necessary data to demonstrate that the thimble life could be extended to a total of 16 MTR cycles. The results of these tests are contained in Section D of this memorandum.

The operating history of the 30-4 thimble is different from the history of previous thimbles because the thimble had been operated for an extended period at temperatures below 400 F, where annealing of irradiation damage does not occur to any significant degree. (The normal temperature range of the water in the thimble is 530 F to 560 F) Consequently, the 30-4 carbon steel thimble was more embrittled than previous thimbles after 6 MTR cycles of operation, and there was some concern about the safety of hydrostatic testing. During hydrostatic testing the stresses are high and the temperatures are low, with the possibility existing that the test temperature is below the nil ductility temperature which has been elevated because of irradiation. The thimble was operated with lower temperatures for approximately 3 MTR cycles because

1. A defective pressure tap connection necessitated operating at approximately 400 F until the extent of the resultant bypass leakage was known.
2. A pump failure and subsequently a leak in the loop necessitated operating with 120 F process water.

A meeting was held on 4/19/57 to discuss the progress of the KAPL program to extend the thimble operating life. At this meeting there was some concern about the consequences of brittle fracture of the thimble tip during hydrostatic testing. The concern was that, because of the amount of stored energy present in the entire loop, high velocity fragments might cause damage to the reactor. As a result of this meeting the problem was discussed with MTR, and precautionary measures during hydrostatic testing were recommended (Reference 3). These measures included isolating the thimble from the loop (the compressed volume is reduced from approximately 80 gallons to 13 gallons), and testing at 200 F instead of room temperature (the temperature is more likely to be above the brittle-ductile transition temperature). This meeting also emphasized the importance of obtaining a stainless steel replacement thimble which would not be subject to appreciable radiation damage.

On May 29, 1957 the Pressure Systems and Pressure Vessel Review Board reviewed the KAPL-30 thimble situation and the annealing data presented by R.L. Meahan. Recommendations were made concerning the method of hydrostatic testing to be used following the period of low temperature operation.

On June 10, 1957 the detailed operating history of the KAPL-30-4 thimble was presented to the Board. The conclusion of the Board was that further information was needed to make a decision. It was apparent that the areas of most uncertainty were:

1. Consequences of a brittle fracture of the thimble.
2. The probability of the presence of stress raisers in the thimble from any mechanism such as corrosion, hydrogen occlusion, or a mechanical defect.

On June 25, 1957 an evaluation primarily concerned with Items 1 and 2 was presented to the Board. The material presented is summarized in Section E and F of this memorandum. Upon completion of the presentation, the executive members of the Board met again and arrived at the decisions and recommendations outlined in Section A.

C. ACTION TAKEN ON KAPL PRESSURE SYSTEMS AND PRESSURE VESSELS REVIEW BOARD RECOMMENDATIONS:

Following the extended period of low temperature operation (April 30 to June 24), the recommendations of the Board (Section A - Paragraph 2) were generally followed. The leak was repaired, the two hour 600 F annealing was completed, and the loop is now operating at a thimble inlet water temperature of 560 F.

Analysis of the angle iron restraining members for the KAPL-30 thimble indicates that the thimble will withstand a force of 3,000 lbs and will not be ejected from the HB-1 hole. See Appendix Page 32.

The recommendation concerning use of a specially marked blind flange during hydrostatic testing is being investigated by the KAPL representative at MTR.

This memorandum has been sent to MTR as an attachment to KAPL's request to extend the operating life of the KAPL-30 thimble to 16 MTR cycles.

D. ANALYSIS OF KAPL-30 IRRADIATION DAMAGE EXPERIMENT

The preliminary analysis of the data from this report is contained in the letter which follows. The data show that the A 201 carbon steel specimens regain considerable ductility after annealing treatments between 525 F and 600 F. It is, therefore, evident that the thimble is subjected to a significant amount of annealing during normal operation at thimble inlet water temperatures between 530 F and 560 F.

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General Electric Company
KNOLLS ATOMIC POWER LABORATORY
Schenectady, New York

June 6, 1957

Dr. C. E. Lacy
Room 106, Bldg. D-1
K A P L

Subject: Preliminary Analysis of KAPL-30 Irradiation Damage Experiment

Abstract

A preliminary analysis is presented of a series of irradiations of A-201 carbon steel, conducted to help determine the safe operating life of the KAPL-30 in-pile carbon steel loop at MTR. It is shown that this material loses ductility and is quite notch sensitive after irradiation at 190C and testing at room temperature, but considerable ductility is regained after annealing treatments between 525F and 600F.

Introduction

The KAPL-30 loop is a high temperature high pressure water loop located in the MTR and used as an irradiation facility for SAR fuel elements and other materials. The loop is constructed of A-201 carbon steel. During operation the loop tip receives an estimated fast flux of 2.6×10^{19} nvt per operating cycle (15 days) and the loop tip temperature may vary from 530F to 600F. The present allowable operating life of the loop is 9 MTR cycles.

It is known from past work that carbon steel exposed to fluxes of the above magnitude suffer irradiation damage which results primarily in a loss of ductility, increase in strength, and rise in the transition temperature. This damage, if severe enough, could result in unsafe operating conditions in the loop. Consequently, a series of irradiations have been conducted on notched bend and un-notched sheet tensile specimens to determine the degree of damage sustained by this material after neutron exposures of 2.3×10^{20} nvt fast and greater and to determine the degree of recovery with annealing temperatures which roughly correspond to the recovery resulting from operating the loop at 530F to 600F.

This letter report is intended to be only a preliminary presentation of the data. All experimental results have not yet been obtained, literature work has not been performed, and the data have not been thoroughly analysed. A final report will be issued on this investigation in the next several months.

Experimental Procedure

The material used in this investigation was cold rolled and annealed ASTM-A-201 carbon steel 1/16" thick. There were two specimen types machined from this starting stock. One was a notched bend specimen 2" long, 3/8" wide, and 1/16" thick with a .012" deep notch machined normal to the surface of the specimen. The notch had a 45° included angle and a notch radius of .010". The second

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type was an un-notched sheet tensile specimen 1/16" thick with an overall length of 3". The specimen had a gage length of 1/2" and was 0.75" wide.

Both types of specimens were irradiated in helium filled aluminum capsules in a high flux "L" position at MTR. The calculated irradiation temperature was approximately 1500°. A total of five capsules were irradiated and the exposure conditions are summarized in Table I.

Post-irradiation testing was performed in the RMI in cooperation with RML personnel. Bend testing was performed at room and elevated temperatures and after annealing treatments. The specimen was loaded as a simple three-point loaded beam with the notch on the tension side. Tensile tests were performed in the RMI Instron machine.

Test Results and Discussion

The results of the bend tests are shown in Figures 1 through 3. The reported curves are averages of three individual specimens. It will be noted that no plastic flow occurs in specimens tested at room temperature and the general effect of increasing temperature of test is to increase ductility and lower strength. The effect of increasing irradiation is to suppress this recovery mechanism. In all cases annealing for one hour at 600F restored an appreciable amount of the pre-irradiation ductility.

Tensile data are shown in tabular form in Table II. Figure 4 shows schematically the effect of annealing five hours at 525F as compared to unannealed tests on the nominal stress-strain curve. Figures 5 and 6 show graphically the effect of annealing temperature and exposure flux on the yield point and uniform plastic elongation. Uniform plastic elongation is defined as the plastic elongation to the point of maximum load on the load-elongation curve. The effect of annealing in general is to increase ductility and reduce strength levels.

The data in Figures 5 and 6, as well as the other tensile properties in Table II, show a curious effect in that the higher exposure (3.6×10^{20} nvt) result in lower strength properties and, in some cases, greater ductility than the lower exposure (1.4×10^{20} nvt). No ready explanation is available, although perhaps the phenomenon is due to irradiation annealing. This will be investigated further.

Comparison of the notched bend data and the tensile data demonstrate quite well that irradiated A-201 in the unannealed condition is notch sensitive. At 9.9×10^{19} nvt (fast) notched bend specimens tested at room temperature without annealing show no plastic deformation, while tensile specimens at 1.4×10^{20} nvt (fast) tested in an equivalent condition give a total plastic elongation of 11.5%.

It must be emphasized that the unannealed room temperature data are in no way indicative of the condition of the loop tip material after irradiation. The test specimens were irradiated at about 300F and the loop tip runs at 530 to 600F. Although annealing at 550F, for example, is not necessarily equivalent to running the loop at 550F, it is a much better approximation than the unannealed data. As the schematic stress-strain curves in Figure 4 show, even an anneal at 525F for 5 hours is sufficient for a fair amount of recovery, particularly at the higher flux levels.

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The highest flux investigated for the tensile specimens (3.6×10^{20} nvt fast) is equivalent to at least 14 MTR cycles of the in-pile loop tip and the bend data equivalent to 16 MTR cycles. The data presented in this report show that if the loop is annealed for at least one hour at 600F (which is the current practice) the material has a uniform plastic elongation in excess of 10% and is ductile even in the presence of a notch.

Conclusions

ASTM-A-201 carbon steel irradiated at 1500 to fluxes in excess of 1×10^{20} nvt fast and tested in the un-annealed condition loses considerable ductility. The yield point can increase to three times the pre-irradiation value. Annealing between 500 and 600F restores ductility and decreases the yield point to only twice the pre-irradiation value.

R. L. Mehan

RLM:g

Attachment

cc: RE Armstrong
EE Baldwin
HE Barrie
S Bigelow
CA Bruch
LJ Cherubin
HE Stone
T Dreier
JD Dunbar
WL Fleischmann
TJE Glasson
RS Kukfa
DD LaRocque
DM Lewis
RM Mains
DR Miller
IH Peer
DJ Ruggiero
RH Simon
HE Stone
H Suss
JL VanAllen
TS Weissmann
FW Wiesinger

R. L. Mehan

MECHANICAL METALLURGY & METALLOGRAPHY

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Table I

Exposure Conditions for KAPL-30 Carbon Steel Irradiation

Capsule	Specimen Type	Irradiation Conditions			
		Atmosphere	Temperature	MTR Cycles	Integrated Fast Flux
7-11-1	Notched Bend	Helium	Approx. 150C	3	9.9×10^{19}
7-11-2	Notched Bend	↓	↓	5	2.5×10^{20}
7-11-3	Notched Bend			10	4.3×10^{20}
7-11-4	Sheet Tensile			5	1.4×10^{20}
7-11-5	Sheet Tensile			10	3.6×10^{20}

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Table II

Summary of Tensile Properties of IrradiatedUnirradiated A-201 Carbon Steel

Exposure, Nvt fast	Test Temp, °F	Annealing Treatment	No. of Spec Tested	Tensile Str, psi	0.2 Yield Str, psi	Plastic Uniform Elong, % (1/2" gage)	Plastic Tot. Elong, % (1/2" gage)
None	RT	None	3	66,500	40,400	30.7	49.7
None	300	None	2	67,300	38,400		37.2
None	600	None	1	77,100	33,200	31.0	48.0
None	RT	5 hrs @ 525F	1	70,400	44,700	36.0	49.6
None	RT	5 hrs @ 550F	1	67,200	41,600	30.1	52.1
None	RT	5 hrs @ 600F	1	68,400	43,600	37.8	52.0
1.4 x 10 ²⁰	RT	None	1	121,000	119,000	6.0	11.5
1.4 x 10 ²⁰	525	None	1	95,300	78,900	11.9	17.7
1.4 x 10 ²⁰	550	None	1	89,700		15.0	17.8
1.4 x 10 ²⁰	600	None	1	86,300	72,900	13.0	14.9
1.4 x 10 ²⁰	RT	5 hrs @ 525F	2	116,000	109,000	7.3	13.1
1.4 x 10 ²⁰	RT	5 hrs @ 550F	1	107,000	93,500	11.4	19.0
1.4 x 10 ²⁰	RT	23.5 hrs @ 550F	1	101,000	88,300	16.3	25.9
1.4 x 10 ²⁰	RT	5 hrs @ 600F	2	101,000	85,600	15.7	24.4
3.6 x 10 ²⁰	RT	None	2	105,000	105,000	0	3.5
3.6 x 10 ²⁰	RT	5 hrs @ 525F	2	88,900	81,800	9.5	18.4
3.6 x 10 ²⁰	RT	82 hrs @ 530F	1	80,800	72,600	13.8	22.8
3.6 x 10 ²⁰	RT	5 hrs @ 550F	2	78,800	69,300	12.8	23.4
3.6 x 10 ²⁰	RT	5 hrs @ 600F	2	85,400	74,700	11.3	21.2

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012

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UNCLASSIFIED

RdM
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UNCLASSIFIED

— = IRRADIATED SPECIMENS
--- = UNIRRADIATED SPECIMENS

RJH
4/16/56

460-014

11

UNCLASSIFIED

R2M
10/26/56

510 097
460 015

FIG. 4
SCHEMATIC STRESS-STRAIN
CURVES AS A FUNCTION
OF EXPOSURE AND
ANNEALING.
ALL TESTS AT R.T.

460-016

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FIG. 5. YIELD STRENGTH AS A FUNCTION OF EXPOSURE AND ANNEALING. ALL TESTS AT RT.

R. J. M.
6/5/57

450
017

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FIG. 6. PLASTIC UNIFORM ELONGATION AS A FUNCTION OF EXPOSURE AND ANNEALING. ALL TESTS AT RT.

RZm
6/5/57

460-018

2. PROBABILITY OF THE PRESENCE OF STRESS RAISERS IN THE KAPL-30 THIMBLE

The evaluation of this phase of the problem was conducted by Mr. J.D. Dunbar, Manager of SAR Materials Application. This information is included in the two letters which follow. The evaluation indicates that there are no significant stress raisers present, and that the KAPL-30 thimble is satisfactory for 16 MFR cycles of operation. The significance of the possible pitting corrosion mentioned in these letters is further evaluated by Dr. W. Cooper, Consulting Engineer, SAR Structural Evaluation, page 20 of this memorandum.

General Electric Company
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Schenectady, New York

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C O P Y

June 21, 1957

MEMORANDUM

Subject: KAPL-30 Thimble

As requested in D.M. Lewis' letter to J.D. Dunbar, 6/18/57, the following data and opinions are submitted as contribution to the solution of the subject problem:

1. Metallurgical history of thimble forming operation - Subject thimble was one of a group produced by the Christy Park Works, National Tube Division, U.S. Steel Corporation. Data on this production work were acquired from the National Tube Division "Report of Physical Tests" and, informally, from Mr. G.R. Lyall, Assistant Plant Metallurgist, Christy Park. (Should formal acquisition of this data be required, they should be requested of Mr. D. Fletcher, Manager of Sales, National Tube Division, Pittsburgh office.

Material: ASTM-A-201, Grade B "Fire box quality"; carbon .19 manganese .65, silicon .20, sulfur .034, phosphorus .026.

Process:

- a. Slab was cross-rolled to 7/8" thickness.
- b. 16 1/2" diameter blanks were torch cut from the 7/8" plate.
- c. Blanks were cupped in two operations, each at 2100-2200°F first over a 6" diameter punch, second over a 5" diameter punch through open dies.
- d. Thimbles were drawn in three passes, each at 2150-2250°F (slow cooled after each pass) down to finished size.
- e. Thimbles were normalized from 1750°F.
- f. Thimbles were machined to 3.312 plus .000 minus .062 I.D. and 4.000 plus .062 minus .000 O.D.
- g. Finished thimbles were hydrostatically tested at 3,000 psi.

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C O P Y

MEMORANDUM

June 21, 1957

The above processing is considered to constitute, in itself, a very severe quality test as to the soundness, cleanliness, and homogeneity of the material. As such, it is considered to obviate the possibility of any significant metallurgical stress raisers.

2. Stress Raisers - An appraisal of the possibility of inherent metallurgical stress raisers is believed adequately covered above. Specific question has been raised as to the probability of existence of other types of stress raisers, particularly those due to pitting corrosion, hydrogen embrittlement and mechanical defects. These are specifically discussed as follows:

- a. Pitting Corrosion - Attached is a special memorandum on this subject, prepared by Mr. G.E. Galonian 6/20/57. In essence, the memorandum states that pitting corrosion can be anticipated in the specific thimble under consideration, as a worst condition, to .010" depth, with the likelihood that the diameter of such pits would be several times their depth, (a diameter depth ratio of 1.0 as an extremely lower limit) and with rounded rather than sharp lips and bases. Mr. Galonian and I concur that stress analysis should be made for defects of this type. It is my opinion that such pits do not represent a significant stress intensification factor.
- b. Hydrogen-embrittlement - A cursory review of readily available literature and an informal conference with authorities in this field reveals no record of ruptures due to hydrogen embrittlement occurring in low-carbon, plain-carbon steels of the type under consideration in this case. In view of these facts and in future view of the metallurgical processing history of the above, it is my considered opinion that hydrogen-embrittlement is not a factor of consideration as a stress raiser. Such embrittlement may probably have taken place in this thimble but since no impact loading is anticipated, this element is not considered significant.
- c. Mechanical Defects - No direct data as to the present condition of the subject thimble as regard mechanical defects is available to this unit. Inspection reports record it to have been machined to a very fine finish and inspected twice to insure the absence of any such mechanical defects. Careful handling has been the rule in continuing operations on the thimble. Mechanical defects do not, therefore, appear to be a factor as stress raiser.

June 21, 1957

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3. As a general conclusion, it is my belief that the KAPL-30 thimble under consideration is, in its present condition, a mechanically more effective load bearing device for its service conditions than at the time of its first installation. I believe it entirely adequate for such service and that its operation may be safely extended to 16 irradiation cycles.

J.D. Imbar, Manager
SAR Materials Application

JDD:dcg

General Electric Company
KNOLLS ATOMIC POWER LABORATORY
Schenectady, New York

cc: RE Barrie
WL Fleischmann
TJE Glasson
CG Lindquist
DM Lewis
RH Simon
CE Weber

C O P Y

June 21, 1957

Mr. J.D. Dunbar
Room 110
Bldg. D-2

Subject: Corrosion Pitting in the KAPL-30 Carbon Steel Thimble

Concern over continuing operation of the present KAPL-30 thimble in the MTR has raised the question of stress intensification due to corrosion pits in the carbon steel thimble. As an aid in the evaluation of this problem my opinion of the condition of the thimble with respect to corrosion pitting is as follows.

It appears safe to assume that pits do exist in the thimble. From tests of carbon steel in the TF-20 loop we found that pitting does occur in high temperature, high purity water under conditions similar to those in the KAPL-30 loop. The extent of pitting is small; about 2 mils in 1000 hours. Also we have observed pitting in carbon steel specimens tested in the KAPL-30 loop and in the KAPL-120 loop.

Since a varied water chemistry has existed in KAPL-30 and especially since it has been subjected to process water, it is reasonable to expect that pits do exist. It cannot be said with certainty just how deep the pits might be, but the depth could be 10 mils. In general, pitting corrosion results in cup shaped depressions with a diameter several times larger than the depth since corrosion propagates radially. However, pitting is very unpredictable and a pit with equal depth and diameter could possibly exist.

To evaluate the effects of such pitting corrosion on the thimble, it is suggested that the stress intensification due to the two types of pits be considered to obtain a quantitative estimate of the stress levels expected. If this investigation shows that stresses are not significantly increased, no difficulties should result from pitting corrosion.

G.E. Galonian
Coolant Chemistry

GES:dag

C O P Y

**E. PROBABILITY OF THE PRESENCE OF STRESS RAISERS IN THE KAPL-30 THIMBLE
(Continued)**

The significance of pitting corrosion was evaluated by Dr. Cooper as follows:

Should such pitting occur, the theoretical stress concentration would be less than four in the worst case (pits 0.010" deep with a diameter - depth ratio of 1.0), and less than three in the more probable case (pits 0.010" deep with a diameter - depth ratio of 2.0 or greater). The effective stress concentration will be less than these values as long as the A-201 carbon steel retains ductility. The stress resulting from these stress concentration factors is not considered to be significant as long as there are less than 1,000 pressure cycles of operation.

F. CONSEQUENCES OF A BRITTLE FRACTURE OF THE THIMBLE DURING HYDROSTATIC TESTING

The following evaluation is based on the premise that fracture, if it should occur, is most likely to take place during hydrostatic testing of the thimble. This assumption is made because the pressure is approximately 10% higher and the temperature is at or less than 200 F at the time of hydrostatic testing as compared to normal operation at 2200 psi pressure and 560 F. It is assumed that the reactor would be shutdown and the valves which isolate the in-pile thimble from the remainder of the loop would be closed. The approximate volume of water which is compressed is the 13 gallons in the thimble and not the 80 gallons in the entire loop.

The calculations indicate that there is practically no possibility of rupturing the aluminum housing surrounding the thimble tip (see Sketch #1 in the Appendix) by a missile from the KAPL-30 thimble during cold (up to 200 F) hydrostatic testing.

Assuming that it were possible to puncture a 1" diameter hole in the aluminum liner, the cooling water leak to atmosphere would be approximately 100 gpm (at a pressure of 70 psig).

The cooling requirements of the MTR reactor at shutdown are very low in comparison with the supply of cooling water available. The MTR hazard evaluation (reference 2) indicates that one minute after reactor shutdown only 51 gpm of cooling water are required (100 F ΔT between reactor inlet and reactor outlet), and that one hour after shutdown only 20 gpm are required.

MTR cooling water is supplied by gravity system with a working head of 170 feet as shown on sketch No. 2. Total working capacity of the cooling water reservoir and sump is 210,000 gallons. Considering this total capacity and a loss rate of 100 gpm, it is apparent that 33 hours are available to take measures to reduce the leakage and provide additional cooling water capacity. The normal cooling water flow during reactor operation is approximately 20,000 gpm. From this data it is evident that the potential supply of reactor cooling water is adequate to compensate for considerable leakage.

Considering the personnel hazards associated with a brittle fracture of the thimble, the following possibilities were examined.

- (1) Spillage of large amounts of contaminated water onto the main floor of the reactor building.
- (2) Release of gaseous fission products
- (3) Loss of shielding resulting in high intensity shine or localized beams of gamma and neutron radiation.

Item one represents the most probable hazard associated with a brittle fracture. The activity in the cooling water from the reactor is not significant unless there has been a fuel element failure. There is, however, no reason to assume that a thimble fracture would produce a ruptured fuel element. The aluminum liner around the thimble is approximately three times as thick on the end (in the direction of the lattice) as on the side. (See sketch No. 1). Furthermore, data from the KAPL-30 loop indicates that the contamination present in the cooling water after a fission break would account for water activity from 200 to 700 m²/hr; even this level is not particularly hazardous.

Release of large amounts of fission gases is discounted because there is negligible chance of loss of sufficient reactor cooling water to cause a melt down of any of the fuel elements. The MTR hazard evaluation states that natural circulation of water in the reactor is sufficient to prevent such a casualty. The previous evaluation has shown that an adequate supply of cooling water is available to compensate for losses from a possible rupture of the aluminum liner. In addition, the reactor could be defueled (fuel removed to the canal) in a short time compared to the time required for loss of cooling water.

Loss of shielding is discounted because calculations show that the KAPL-30 thimble (loaded with test assemblies) will remain in place in the beam hole.

Personnel hazard because of missiles from the thimble is inconceivable because of its location in the center of the reactor where it is surrounded by concrete, steel, graphite, and aluminum.

The possibility of rupturing the aluminum housing is slight. If it were ruptured, however, it would probably mean loss of the beam hole for experimental purposes until a major maintenance shutdown were dictated for other reasons. Although rupture of the aluminum housing might cause an extended reactor shutdown, it is apparent that the consequences of brittle fracture would not be catastrophic.

F. APPENDIX:

1. CALCULATIONS

A. VOLUME OF WATER IN KAPL-30 THIMBLE, (WHEN ISOLATED BY STOP VALVES)

$$\frac{.785 (3.25)^2}{144} = .0573 \text{ ft}^2 \quad \text{Cross Sect. area}$$

$$14 (.0573) = .8 \text{ ft}^3$$

$$= .8 (7.48) = \sim 6 \text{ gallons}$$

FROM DRAWINGS, APPROX 62' 2" SCHED 160 PIPE, INLET & OUTLET.

transverse internal area = 0.0156
(Crane Handbook)

$$62 (.0156) (7.48) = \sim 7 \text{ gallons}$$

therefore $6 + 7 = 13$ gallons volume
in thimble and
piping

460 026

DMLEWIS
6/8/57

B. ENERGY AND VELOCITY CONSIDERATIONS
DURING HYDROSTATIC TESTS OF THE THIMBLE.

$$13 \text{ gallons water} = \frac{13/231}{1728} = 1.74 \text{ ft}^3$$

Assume 3300 psi test pressure -

$$\text{Compressibility} = \beta = \frac{\Delta V}{V_0 \Delta P} \approx 3 \times 10^{-6} / \text{psi}$$

Sound velocity in water =

$$C \approx 5000 \text{ ft/sec}$$

Energy stored in pressure

$$E_p = \frac{1}{2} \Delta V P_{\text{max}}$$

$$= \frac{1}{2} P_{\text{max}}^2 \beta V_0$$

$$= \frac{1}{2} (3300^2) (3 \times 10^{-6}) (1.74) (144)$$

$$= \frac{\text{lb}^2}{\text{in}^4} \cdot \frac{\text{in}^2}{\text{lb}} \cdot \frac{\text{ft}^3}{\text{ft}^2} = \text{ft} \cdot \text{lb}$$

$$= \sim 4000 \text{ ft} \cdot \text{lb}$$

Possible water discharge velocity:

1. Thimble end cut off at time zero and hemispherical cap mass neglected -

$$\begin{aligned}
 v &= \frac{P}{\rho C} \\
 &= \frac{(3300 \times 144) (32.2)}{62.5 (5,000)} \\
 &= \frac{\cancel{15} \text{ ft}^3}{\cancel{\text{ft}^3}} \frac{\cancel{\text{ft}}}{\cancel{\text{ft}}} \frac{\cancel{\text{sec}}}{\cancel{\text{sec}^2}} = \text{ft/sec} \\
 &= 49 \text{ ft/sec.}
 \end{aligned}$$

2. Small hole or orifice -

$$\begin{aligned}
 v &= \sqrt{2g \frac{\Delta P}{\rho}} \\
 &= \sqrt{64.4 \frac{(3300 \times 144)}{62.5}} \\
 &= \sqrt{\frac{\cancel{\text{ft}}}{\cancel{\text{sec}^2}} \frac{\cancel{15}}{\cancel{\text{ft}^3}} \frac{\cancel{\text{ft}^3}}{\cancel{\text{ft}^3}}} = \text{ft/sec} \\
 &= 700 \text{ ft/sec.}
 \end{aligned}$$

FROM THE ABOVE :

1. THERE IS A SUBSTANTIAL TOTAL AMOUNT OF ENERGY AVAILABLE TO DO DAMAGE.
2. A HEAVY MISSILE SUCH AS THE HEMI-SPHERICAL END OF THE THIMBLE WOULD HAVE A VELOCITY LESS THAN 49 ft/sec.
3. IF A SINGLE SMALL FRAGMENT WERE RELEASED BY VERY LOCAL BRITTLE FRACTURE (HIGHLY IMPROBABLE THAT

ONLY ONE SMALL FRAGMENT WOULD BE
EXPULSED) THE VELOCITY OF THE
FRAGMENT WOULD BE LESS THAN
700 ft./sec.

DR. MILLER
6/11/57

C. EVALUATION OF THE POSSIBILITY OF
RUPTURING THE ALUMINUM LINER ASSUMING
THE CARBON STEEL THIMBLE SPLITS.

$$\begin{aligned} OD &= 4.00 \text{ in} \\ ID &= 3.312 \text{ in} \end{aligned}$$

$$V_0 = 49 \text{ ft/sec}$$

$$\text{wall thickness} = \left(\frac{4.00 - 3.312}{2} \right) = 0.344 \text{ in}$$

$$D_{ave} = 3.65 \text{ in}$$

$$\begin{aligned} \text{K.E. per foot} &= \rho \times \pi (D_{ave}) \frac{V_0^2}{2} \\ &= \frac{500}{32.2} \frac{(0.344)}{144} \pi (3.65) \frac{(49)^2}{2} \\ &= \frac{15}{\text{ft}^3} \frac{\text{sec}^2}{\text{ft}} \text{ in} \text{ in} \frac{\text{ft}^2}{\text{in}^2} \frac{\text{ft}^2}{\text{sec}^2} \\ &= \frac{\text{ft} \cdot 15}{\text{ft}} \\ &= 51 \frac{\text{ft} \cdot \text{lbs}}{\text{ft}} \end{aligned}$$

ENERGY ABSORBING CAPACITY OF ALUMINUM LINER (6" ID)

Assume 20,000 psi hoop stress over a 5% increase in diameter

Energy per foot is -

$$W = \frac{20,000 (0.31) 12 (.05) \pi 6}{2}$$

$$\frac{16}{\text{in}^2} \left| \frac{\text{in}}{\text{ft}} \right| \frac{\text{in}}{\text{ft}} \left| \frac{\text{in}}{\text{ft}} \right| = \frac{\text{in } 16}{\text{ft}}$$

$$= 35,000 \frac{\text{in } 16}{\text{ft}}$$

$$\approx 3,000 \frac{\text{ft } 16}{\text{ft}}$$

FROM THE ABOVE IT APPEARS THAT THERE IS NO RISK OF PENETRATION OF THE ALUMINUM LINER DUE TO GROSS BRITTLE FRACTURE OF THE CARBON STEEL THIMBLE DURING A COLD HYDROSTATIC TEST. THE SAFETY FACTOR OF 3000/51 IS A GENEROUS ALLOWANCE FOR DEVIATIONS FROM THE CONDITIONS ASSUMED.

D. R. MILLER

6/20/57

A VERY CONSERVATIVE FOR ANNEALED 2S ALUMINUM.
SEE MTR TEST DATA, PAGE 3) THIS MEMORANDUM.

D. EVALUATION OF POSSIBILITY OF RUPTURE
OF 25 ALUMINUM LINER BY 700 ft/sec.
MISSILE.

For circular missiles of diameter
 = D , the punching shear force in the
 Aluminum liner would be

$$F = \tau_s \pi D t; \quad \tau_s = \text{ult. shear strength.}$$

assumed @ 20,000

$$= \frac{20,000}{\text{lb/in}^2} \pi D (0.31)$$

$$= \frac{15}{\text{in}^2} \text{ in in}$$

$$F(\text{lb}) = 19,500 D (\text{in})$$

If this force is developed through
 distance $t/2$, the work done is

$$W = F t/2 = 19,500 D \left(\frac{0.31}{2} \right)$$

$$W(\text{in lb}) = 3,000 D (\text{in})$$

$$\text{Thickness of steel thimble} = 0.344 \text{ in}_{(\text{max.})}$$

The diameter of a steel missile having a kinetic energy W @ 700 ft/sec is

$$W = \frac{1}{2} M v^2$$

$$= \frac{1}{2} \rho \pi \frac{\pi D^2}{4} v^2$$

$$3,000 D = \frac{1}{2} \frac{500}{32.2} (0.344) \frac{\pi D^2}{4} \frac{(700)^2}{144}$$

$$\text{in lb} = \frac{\text{lb}}{\text{ft}^3} \frac{\text{sec}^2}{\text{ft}} \text{in}^3 \frac{\text{ft}^2}{\text{sec}^2} \frac{\text{ft}^2}{\text{in}^2}$$

$$D = \frac{3,000}{500} \frac{2}{.344} \frac{4}{\pi} \frac{144}{700^2}$$

$$= 0.42 \text{ in}$$

Smaller missiles striking face on would not pass through, but larger ones at this velocity would (700 ft/sec).

As previously pointed out, however, it is extremely unlikely that only one small missile would be formed. It is much more probable that larger missiles having velocities approaching 49 ft/sec would be formed. As previously shown, these fragments would not penetrate the Aluminum Liner.

E. POSSIBILITY OF EXPULSION OF STEEL THIMBLE DURING COLD HYDROSTATIC TESTING.

If end cap cracks off, a pressure reduction wave will travel along the thimble at about 5,000 ft/sec.

$$\Delta t = \frac{14 \text{ ft}}{5000 \text{ ft/sec}} = 0.0028 \text{ sec.}$$

The force impulse on the thimble due to this transient unbalance of pressure would be

$$\begin{aligned} \int F dt &= F \Delta t = P \frac{\pi D^2}{4} \Delta t \\ &= 3300 \frac{\pi}{4} (3.312)^2 (.0028) \\ &= \frac{15}{\text{in}^2} \text{ in}^2 \text{ sec} \quad (\text{sec} = \text{time in seconds}) \\ &= 80 \text{ lb sec} \end{aligned}$$

Assuming the external piping to double the effective mass, the mass resisting the force impulse is

$$\begin{aligned} M &= 2 \rho \pi L D_{\text{(ave)}} L \\ &= \frac{2}{32.2} \frac{500}{\text{ft}^3} \frac{\pi}{\text{ft}^2} \frac{0.334}{\text{ft}} \frac{3.65}{\text{ft}} \frac{14}{\text{ft}} \\ &= \frac{15}{\text{ft}^3} \frac{\text{sec}^2}{\text{ft}} \frac{\text{in}^2}{\text{ft}^2} \frac{\text{ft}^2}{\text{ft}^2} \frac{\text{ft}^2}{\text{ft}^2} \end{aligned}$$

$$= 11.6 \text{ slugs}$$

$$V = \frac{F \Delta T}{M} = \frac{80 \text{ lb} \cdot \text{sec}}{11.6 \text{ lb} \cdot \text{sec}^2} = 6.9 \text{ ft/sec}$$

Displacement @ end of
0.0028 secs.

$$x = \frac{1}{2} (.0028)(6.9)(12) = 0.115 \text{ in}$$

seg $\frac{\text{ft}}{\text{sec}} \cdot \frac{\text{in}}{\text{ft}}$

$$\begin{aligned} KE_{\text{INITIAL}} &= \frac{1}{2} M V^2 \\ &= \frac{1}{2} (11.6)(6.9) \\ &= 40 \text{ ft lbs} \end{aligned}$$

The exterior piping will easily bring the thimble to rest after a small displacement

The 80 psi ΔP due to MTR coolant head will exert a force no higher than

$$F = \frac{\pi}{4} D^2 P = \frac{\pi}{4} (7)^2 80 = 3080 \text{ lb}$$

The force will probably be much smaller because it appears that any possible hole in the aluminum lever (thimble) will be small enough to cause a pressure drop through the hole with water leaking out through the annulus between the carbon steel and aluminum thimbles.

The exterior piping may be strong enough to hold the 80 psi (or lower) pressure. If not it appears easy to provide additional restraint.

DR MILLER
6/20/57

F. IRRADIATION DAMAGE DATA TO 25 ALUMINUM

Dose 2.6×10^{22} neut @ > 100 ev.

	<u>Before irradiation</u>	<u>After irradiation</u>
0.2 offset yield st.	18,500 psi	26,500 psi
Ult. tensile strength	20,000 psi	30,000 psi
Elongation	No change	
Reduction in area	81	73

per telephone call to E. E. Calderin
6/20/57

G. EVALUATION OF RESTRAINT OFFERED BY THIMBLE POSITIONING BRACKET.

Reference: NRL Drawgs D-26-101A
(sheets 1-3)

From inspection of the drawings the weakest point appears to be the weldment of the flange (positioning) to the thimble.

$$\begin{aligned} \text{shear area} &= .25(.62)(4) = .62 \text{ in}^2 \\ (.62)(\sim 20,000) &= 12,500 \text{ lbs} \\ \therefore 3,000 \text{ lb load safe by} & \text{ factor of } 4. \end{aligned}$$

$$\begin{aligned} \text{load per clamp} - \\ \text{shear area per clamp} &= 2(.94) = 1.88 \text{ in}^2 \\ 1.88(20,000) &= 37,600 \text{ lb} \\ \frac{37,600}{3,000} &= \sim \text{safety factor } 12 \end{aligned}$$

(assuming shear strength = 20,000 psi)

Inlet and outlet piping will also offer restraint $\therefore$ 3,000 lb load would not cause ejection.

DM Lewis
7/23/57
460 036

-33-
SKETCH #1

HB-1 BEAM HOLE
FOR KAPL-30

PARTIAL HORIZONTAL SECTION
MTR

BERYLLIUM REFLECTOR
PIECES

ENLARGED
SECTION INSIDE
REACTOR TK.

1" WALL
REACTOR TK.
(ALUMINUM)

COOLING WATER AROUND
ALUMINUM LINER

460 037

DML
6/20/57

I-IV AND
1-33

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