**Cover Sheet for a Hanford
Historical Document
Released for Public Availability**

Released 1994

**Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830**

**Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute**

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED DEC 13 1994

OSTI

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DECLASSIFIED

HW-16453

Classification Cancelled and Changed To

DECLASSIFIED

By Authority of CG-PR-2
CA. Bauman 2-13-92
By PM Eick 5-16-94
Verified By W. Wells 5-17-94

Approved for Release to U.S.A.F.C.
Date 8-3-50

- # 1. AB Greninger
- # 2. CN Gross
- # 3. WI Patnode
- # 4. AEC - HW - Att: DG Sturges
- # 5. JE Maider
- # 6. WK Woods
- # 7. EP Lee - JH Warren
- # 8. PE Lowe - D.C. Files
- # 9. RO Mehann
- #10. WW Windsheimer
- #11. PF Gast
- #12. R. Ward
- #13. WR Lewis
- #14. PH Reinker
- #15. CW Botsford - MW Carbon
- #16. EP Warekois
- #17. DH Curtiss - EA Baskin
- #18. SS Jones - HH Greenfield
- #19. IA McClaine - WC Riley
- #20. HH Burton - L. Bupp - R. Purcell
- #21. AB Carson
- #22. 700 File
- #23. 300 File
- #24. Pink Copy
- #25. Yellow Copy

July 24, 1950

SUBJECT: PILE GRAPHITE EXPANSION

COPY 1 OF 1

This document consists of
13 pages, including
1 of

Contents

Introduction

Summary

Details and Discussion

Temperature Coefficient of Damage

Nuclear or Pile Annealing

Graphite Mining

Tube Bowing Measurements

Tube Bore Mining

Location of Damage

Annealing Effects

Conclusions

Appendix - Tables I and II, Figures I to IV.

MASTER

DECLASSIFIED

~~RESTRICTED~~
This document contains restricted data as defined
in Atomic Energy Act of 1946.

DECLASSIFIED

HW-18453

-2-

INTRODUCTION

The purpose of this memorandum is to present and analyze, in terms of the current status of knowledge of radiation damage to graphite, the data available at the present time on the expansion status of the graphite in the piles, and suggest, in terms of this analysis, several possibly feasible curative and preventive measures. The portion of the data to be covered in this memorandum consists of that obtained during the last four years from pile motion measurements and from tube bowing measurements, and particularly that from graphite mining operations during the last six months. The objective to be attained is twofold: (1) the information developed here should permit a better understanding of the need for and development of future corrective measures to be applied to the present piles, and (2) this summary will serve as a basis for further experimental work necessary to place the conclusions on a more firm foundation. This memorandum is being issued at this time, although present ideas and conclusions are in a somewhat uncertain state, in the hope that the currently most feasible preventive measure might be applied to the DR Pile before startup.

SUMMARY

The analysis of the data presented in this memorandum is sufficiently firm to explain the trends of physical expansion of the pile packing with operation, in terms of what is known from laboratory studies.

The use of carbon dioxide in the pile gas atmospheres has resulted in temperatures sufficiently high to effect annealing of all the graphite in the lattice in the central zones of the piles, including that in the relatively cool bore region of the lattice. However, even a 100 percent concentration of carbon dioxide is not sufficient to stop the expansion in the cooler regions of the piles, and thus it is these regions which will become the critical regions in both the old and in the new piles. How serious this critical condition may become and the time when the condition may reach serious proportions can not be predicted with precision from the information currently available.

The only feasible curative measure consists of raising the graphite temperatures in the fringe zones. For the operating piles, this will probably involve expensive special loadings.

The only feasible preventive measure, which could be applied to the DR Pile prior to startup, consists of boring out the tube blocks to leave a larger annular gas space in the fringe zones.

The expense of taking corrective action in an operating pile has not been determined, but large investments of uranium 235 (probably well over 100 kilograms per pile) may be involved. An alternative would involve a major overhaul of the pile, with a complete tube replacement and boring of irradiated graphite blocks, representing possibly a year of pile outage. Boring of blocks in the DR Pile at this time would represent insurance against the possible necessity of taking these extreme measures several years from now. This insurance would probably cause a delay of several months in starting the DR Pile; the relative importance of early startup is not known.

DECLASSIFIED

DECLASSIFIED

HW-18453

-3-

DETAILS AND DISCUSSION

This section of the memorandum presents in narrative, tabular, and graphical form the more significant features of the graphite expansion problem as it applies to the physical condition of the piles. The general and extensive fund of information on graphite radiation damage which has been accumulated at Hanford in the last five years will be used implicitly in the analysis of the data presented here, but no explicit attempt will be made to review all of this information except that most pertinent to the present discussion. The pertinent facts regarding graphite radiation damage and its effects and control in the Hanford Piles were summarized in a recent report⁽¹⁾. Additional data and information obtained since that time have been reported in the Technical Activities Reports of the Engineering Section of the Pile Technology Division, and in the monthly reports on Pile Motion.

If the discussion is restricted to the most important effect of radiation damage, the physical expansion of the graphite, then the following very brief outline of the two most significant factors which control the physical expansion will provide a basis for the data analysis which follows.

1. Temperature coefficient of Damage - The rate at which graphite damage occurs is very strongly dependent upon the temperature of irradiation. At an exposure temperature of 250°C or higher, essentially no physical expansion occurs during exposures measured in years of time. The expansion rate at 250°C is almost certainly less than 5 percent of the rate at 25°C, under equivalent neutron flux conditions. Although low and high temperature limits have been determined, exact knowledge of the "temperature coefficient" is unavailable. Data obtained from monitoring work on the distortion of the pile packing have shown that a small temperature rise of the order of 25°C, produced by the heating of the cooling water in its passage through the piles, is effective in lowering the overall rate of damage by about 30 percent. This can be deduced from the type of data presented in Figure 1.

The rate of expansion, at least to the first approximation, is a linear function of the fast neutron flux, provided other variables, such as ambient exposure temperature, remain fixed. The physical expansion of the pile packing, from front to rear, should thus follow approximately a cosine function in line with the flux distribution from front to rear. The analysis to be presented will show that, except over a very short distance in the pile where the flux approaches zero, the variation in flux is not the significant factor in graphite expansion, and can be almost eliminated from consideration when large temperature differences exist.

-
1. "Graphite Radiation Damage - Its Effects and Control in the Hanford Piles", HW-16075, A. A. Johnson, W. R. Lewis, and P. H. Reinker, February 20, 1950.

DECLASSIFIED

2. Nuclear or Pile Annealing - Although it is impossible, in the present production piles, to raise the temperature of the graphite to a value high enough to effect any appreciably useful amount of thermal annealing, results have been obtained on a phenomenon of much more theoretical and practical interest, which indicate that expansion produced by radiation can also be annealed by radiation, if the temperature of exposure is raised to values which are operationally practical. A temperature rise during exposure will thus not only reduce the rate of expansion, but will, if high enough, reverse at a very appreciable rate the damage previously produced at the lower temperature. Other important physical properties such as thermal conductivity, stored energy, and X-ray expansion follow, with minor variations, the recovery of physical expansion. This, then, is the explanation, as proposed in previous memoranda, for the beneficial effects of carbon dioxide, which has principally the effect of producing higher temperatures in the bore of the tube blocks of the pile, the region in which most of the expansion has occurred.

Graphite Mining

Graphite mining operations were initiated early in 1949 to obtain direct information on the status of the graphite in the bore of the tube blocks of the piles; this method consists of scraping the surface of the bore with a cutter and removing the powdered samples for laboratory studies. The value of this technique was considerably enhanced during the last several months by extending the "spot mining" to a complete front to rear mapping of the tube block graphite. Additional information has been obtained from core samples which represent the cross section of the tube blocks from edge to bore. The nature of the samples obtained from these mining operations permits only X-ray and stored energy measurements, with any degree of convenience. Fortunately, X-ray expansion can be correlated very well with physical expansion by appropriate corrections obtained experimentally from laboratory studies.

Tube Bowing Measurements

The best overall distortion measurements of the packing are obtained from tube bowing measurements. With the recent development of the mercury manometer, traverses were obtained with considerably higher precision, and consequently the data obtained over relatively short periods of time can be analyzed with more confidence. Figure I is a composite representation of typical tube bowing measurements taken at the D Pile, in tube 4674, from July of 1946 to June of 1950. These curves show clearly the overall result of the expansion of the individual blocks of the packing, but the curves do not adequately represent the relative graphite damage from front to rear. The curves show that the rate of overall expansion of the pile decreased slightly, with increasing exposure, even before the addition of carbon dioxide to the pile atmosphere in February of 1948. This decreased rate was caused by the increase in graphite temperature as a result of the decrease in thermal conductivity with exposure. During this period prior to 1948, the distortion became progressively skewed about the centerline; this was caused by the temperature difference between the front and rear regions of the pile resulting from the heating of the cooling water on its passage through the pile. During the period of increasing carbon dioxide concentrations in 1948,

DECLASSIFIED

HW-10453

-5-

1949, and 1950, the expansion at the centerline (at 21 feet) decreased, while the point of maximum expansion moved toward the front face. Data taken during the last several months, with the D Pile at 100 percent carbon dioxide, have indicated a slight annealing even in the critical region at 10 to 12 feet from the inlet side. This is encouraging, but it is too much to hope that continued exposure will not result in continued expansion in the region closer to the front face.

The only available tube bowing measurement from the H Pile is included in Figure I. This represents the overall stack displacement caused by the filler layer and filler block expansion. Some expansion of this type was expected, but the shape of the curve points again to the influence of temperature in determining the rate of expansion. Unfortunately, it has not been possible to obtain mining data from the H Pile to ascertain the state of damage of the tube blocks because sufficient pile shutdown time has not been made available during the past two months.

Tube Bore Mining

Tube bore mining operations give the state of damage of the graphite along the length of an individual channel. Typical curves are given in Figures II and IV. An extreme gradient of damage has always been obtained at a distance 3 feet from the edge of the packing, which corresponds to a position opposite the edge of the first metal slug in the column. The influence of the cooling water in raising the temperature of the graphite in the rear zones of the pile is shown by the less sharply defined gradient of damage in this region. It is reasonable to assume, by comparing the shapes of these curves with those presented in Figure I, that the present "roller coaster" configuration resulted from the annealing of the central zone graphite by the introduction of carbon dioxide. The data from the F Pile, presented in Table I and Figure IV, show conclusively that this is the case.

Location of Damage

The data from positions 2279 and 2291-D, shown in Figure II, indicate that the damage to the graphite in the cooler regions of the pile, even though in a lower flux, is more extreme. This is indicated by the maximum expansion at approximately the 12 foot point in the process tube bores, and by the 15 percent crystal expansion in 2291 compared to 13 percent in 2279. The first three feet of the packing show practically no damage because, although the temperature is low, the fast neutron flux is essentially zero. This is important because it should be possible to take advantage of this extreme gradient in designing and planning curative and preventive measures.

Annealing Effects

Position 2286-D had been operated at ambient pile temperature for about 2 1/2 years following its use as a metal column for an exposure period of about the same length of time, and equivalent to 2486-B. These data are given in Figure II. If an initial state of damage is assumed for 2286-D to be that obtained for 2486-B, then the difference between the curves represents the amount of annealing accomplished by allowing 2286 to run at ambient pile temperature for 2 1/2 years. This is a conservative estimate, as the 2486-B position was mined when the B Pile gas was 100

DECLASSIFIED

percent carbon dioxide, and thus the centerline is probably lower than that of 2286-D prior to its use as a gas tube. Even so, the data show significant annealing effects in the central portion of the pile, but little or no annealing in the cooler regions near the front and rear faces. The low point at the centerline for the 2286 position may represent nearly the maximum amount of pile annealing possible at the temperature of exposure.

The gradients of crystal damage along two core samples removed from the D Pile in May, 1950, are less than the gradient of damage obtained from a core sample about 7 months previously. These data are shown in Figure III. During this period the increases in carbon dioxide concentration were effective in reducing the gradient of damage along the entire length of the core (from the tube block edge to the bore) but no significant annealing was observed for the tube block edge. The higher values for the core removed from 2291 compared to those from 2279 show again the influence of the lower temperature in the first case, which results in higher damage, although the neutron flux is about 40 percent lower.

Tables I and II summarize most of the data which show that the additions of carbon dioxide have raised the temperatures of the bore graphite to such an extent that significant pile annealing is occurring in this location in the central regions of the pile. Previously, it was thought that damage was continuing in the bore regions, and that the overall annealing effects caused by the carbon dioxide were the result of more rapid annealing in the outer regions of each lattice. The progressive annealing of the tube bore graphite over a seven month period is shown by the data in Table II on the D Pile. The recovery of 2273 compared to 2282 is of the same magnitude as the recovery of 2279 compared to 2273. A carbon dioxide addition occurred between each of the sampling dates, but the temperature rise itself would not result in any significant annealing. The recovery during the operating period between the mining of 2273 and 2282 was also shown by a decrease in total stored energy from 619 to 514 cal/gm. At the same time, measurements on 2290 and 2291 showed that expansion in this cooler region of the pile was continuing.

In Table I and Figure IV the data from the F Pile are summarized. Three tube positions were mined recently, all of which were nominally in the flattened zone, with 1387 lying on about the edge of the zone. Very good agreement of the mining data was obtained, with 1387 showing slightly higher values as it was from the edge of the flattened zone and thus in a slightly cooler region of the pile. The decrease in expansion with carbon dioxide additions at the F Pile is shown by the difference between 1884, mined in March of 1949, and the three tubes mined in July of 1950. During this time, the bore graphite recovered about 20 percent of the Co-spacing expansion.

DECLASSIFIED

-7-

HW-18453

CONCLUSIONS

The analysis of the data, although still uncertain in some respects and not quantitative in nature, is sufficiently firm to explain the trends of physical expansion with operation, in terms of what is known from laboratory studies. The use of carbon dioxide in the pile gas atmospheres has resulted in temperatures sufficiently high to effect annealing of all the graphite in the lattice in the central zones of the piles, including that graphite in the relatively cool bore region of the lattice. However, even a 100 percent concentration of carbon dioxide is not sufficient to stop the expansion in the cooler regions of the piles, and thus it is these regions which will become the critical regions in both the old and in the new piles. This is shown already at the H Pile by the one tube bowing measurement. The lack of mining data at the H Pile is a missing link in the analysis of these data, which could give an indication of the state of damage in a typical filler block and tube block position.

The only feasible curative measure consists of raising the graphite temperatures in the cooler fringe zones of the piles. Several suggestions have been made for accomplishing this. The most direct method consists of boring out the tube blocks to leave a larger annular space in the fringe zones of the piles, specifically in the front and rear regions of each tube position, and in the tube positions outside the flattened zone. This does not appear to be economically feasible on an operating pile. Other more practical suggestions involve special tube loadings with the use of enriched slugs in the fringe zones, or 235-aluminum slugs, to accomplish front to back flattening resulting in higher temperatures in the critical regions. Considerable effort will be necessary to determine the technical and economical feasibility of any of these techniques.

The only feasible preventive measure, which could be applied to the DR Pile prior to startup, consists of boring out the tube blocks to leave a larger annular space in the fringe zones of the pile. This would be a permanent cure which would not involve special loadings or operational procedures. This memorandum thus proposes that consideration be given to this preventive measure.

E. P. Warekois
E. P. Warekois
Pile Technology Division

P. H. Reinker
P. H. Reinker
Pile Technology Division

EPW:PHR:wj

DECLASSIFIED

DECLASSIFIED

TABLE I.

HW-18453

105-F PROCESS TUBES

PROCESS TUBE NO.	DATE MINED	SAMPLE POSITION IN TUBE	TOTAL POWER OUTPUT OF TUBE MW.	EXPOSURE	C. A	TOTAL STORED ENERGY CAL/GRAM	REMARKS
				MD/CT $= (MW)(8)(142)$			
0182 F	2-6-48	20-22'	—	325*	7.10	279	* 11-5-47 - METAL CHARGE PUSHED - EXPOSURE 325 CT 11-5-47 TO 2-6-48 H ₂ O COOLED DUMMY.
CO ₂ ADDITIONS STARTED 12-48 40% ON 2-15-49							
3169 F	2-19-49	20-22'	—	2390*	7.29	400	* 4-18-45 TO 7-20-45 METAL CHARGES EXPOSURE 850 MD/CT 7-20-45 TO 2-19-49 POISON CHARGES EQUIVALENT EXPOSURE = 2060 MD/CT
1884 F	3-15-49	20-22'	211.35	2400	7.57	566	3-15-49 - METAL CHARGE PUSHED - TUBE REMAINED EMPTY.
1884 F	5-5-49	20-22'	—	2495*	7.36	466	5-5-49 - 55 MD/CT EQUIVALENT EXPOSURE AT AMBIENT FILE TEMPERATURES.
CO ₂ INCREASED TO 60% 5-15-49 TO 6-1-49							
CO ₂ INCREASED TO 80% 4-18-50 TO 5-12-50							
2584 F	7-12-50	COMPLETE TUBE TRAVERSE	301.29	342.3	20' 7.39	---	---
2675 F	7-12-50	COMPLETE TUBE TRAVERSE	280.81	3190	20' 7.40	---	ONE CHARGE DURING HISTORY OF THIS TUBE CONSISTED OF A DEPLETED METAL CHARGE (43200) AND ORNL SAMPLES.
1387 F	7-19-50	COMPLETE TUBE TRAVERSE	257.88	2930	20' 7.41	---	---

DECLASSIFIED

DECLASSIFIED

-9-

HW-14413

TABLE II
105-D PROCESS TUBES

PROCESS TUBE NO.	DATE MINED	SAMPLE POSITION IN TUBE	MW. TOTAL POWER OUTPUT OF TUBE	EXPOSURE MD/CT MD/CT = (MW)(R)(1.42) ± 0.02	C ₀ A	TOTAL STORED ENERGY CAL/GRAM	REMARKS
CO ₂ ADDITIONS STARTED 2-48 40% ON 9-48							
3469-D	4-28-49	20'-22'	—	≈ 3300 SEE REMARK	7.14	237	3-29-45 TO 2-11-47 METAL CHANGE EXPOSURE = 1540 MD/CT 2-11-47 TO 4-28-49 GAS TUBE EQUIVALENT 21760 MD/CT METAL EXPOSURE
2282-D	10-26-49	20'-22' A' HOLE CORE	296.78	3370	7.57 7.12*	619	* FILLER BLOCK EDGE OF CORE
CO ₂ INCREASED TO 60% 11-1-49 TO 11-15-49							
2273-D	2-8-50	16'	321.55	3653	7.46	514	---
2290-D	2-8-50	16'	265.36	3014	7.47	552	---
CO ₂ INCREASED TO 80% 3-1-50 TO 3-15-50							
CO ₂ INCREASED TO 100% 5-1-50 TO 5-21-50							
2279-D	5-24-50	TRAVERSE TO "A" HOLE CORE	340.89	3873	7.36 7.15*	—	* FILLER BLOCK EDGE OF CORE
2291-D	5-24-50	TRAVERSE TO "A" HOLE CORE	251.12	2853	7.57* 7.45**	---	* MINED SAMPLE PROCESS TUBE END OF CORE = 7.72A ** FILLER BLOCK EDGE OF CORE
2286-D	6-14-50	COMPLETE TUBE TRAVERSE	183.80	2088 3288*	20' 7.09	—	* ESTIMATED 12-17-49 TO 2-16-48 METAL CHANGE = 2088 MD/CT 2-16-48 TO 6-14-50 GAS TUBE ≈ 1200 MD/CT
<u>105-B PROCESS TUBE</u>							
CO ₂ ADDITIONS STARTED 1-49 100% ON 2-50							
2486-B	4-13-50	COMPLETE TUBE TRAVERSE	187.34	2128	20' 7.26	—	---

DECLASSIFIED

DECLASSIFIED

DECLASSIFIED

DECLASSIFIED

DECLASSIFIED

CRYSTAL EXPANSION
ALONG PROCESS TUBE
GRAPHITE BLOCKS

DECLASSIFIED

DECLASSIFIED