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A PROPOSAL FOR THE CONTROLLED RELEASE OF STORED ENERGY IN THE MTR REFLECTOR GRAPHITE

E. Fast, E. O. Smith, and J. D. Ford

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A PROPOSAL FOR THE CONTROLLED RELEASE OF STORED ENERGY IN THE MTR REFLECTOR GRAPHITE

E. Fast, E. O. Smith and J. D. Ford

SUMMARY

A study of the stored energy buildup in the MTR reflector graphite and a program of controlled energy release is presented. Calculations, based on measurements of samples from the pebble zone show that an inadvertent spontaneous stored energy release would cause a temperature rise of 90° F in the pebble zone. The maximum transient structure temperatures resulting from a worst credible accidental release of energy would be less than allowable at present (except for possible damage to neutron detector chambers) but could exceed this value in five years.

It is proposed that the stored energy be released by thermal annealing. The reflector graphite is heated by reducing the air flow and operating the reactor at low power until a temperature of 500° F is reached, at which point the reactor is scrammed. Normal cooling is provided after 15 minutes at peak anneal temperature or if the temperature rises to 600° F. Health physics monitoring includes continuous measurement of particulate and of C^{14} activity. Sustained oxidation, if it occurs, will be detected with a CO_2 monitor and controlled by smothering.

An estimated 2 or 3 days of MTR operating time will be needed of which the anneal itself will require about one day.

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I. INTRODUCTION

In the design of the MTR, it was recognized that a problem might arise in irradiation damage to the graphite in the reflector region. As a precaution against physical distortion, a region near the tank was filled with graphite pebbles of one inch diameter, surrounded by block graphite. Provision was made to dump the pebbles and to replace them should they be damaged excessively.(1)

The graphite damage study program, started in 1953, was instituted in part to evaluate the condition of the MTR graphite. This phase included an analysis of samples taken from VG graphite plugs and of samples irradiated in VG-18 and in-tank facilities. A large proportion of the work was directed to measurement of the stored energy release at 200° C. Periodic reports are given in the MTR technical quarterly reports,(2) and others.(3,4) From the observed build-up of energy in VG-18 irradiated sample, it was considered probable that an energy release would need to be carried out. In support of such a study, it was desirable to sample graphite from the pebble zone near the tank. Thus, request was made and permission granted to remove the liner from VG-10 for this purpose.(5) Results of the analysis of balls from various levels near the tank are given in reference (4). These results along with a proposed increase in MTR power made it advisable to study the probable effect of an inadvertent stored energy release, and to outline a procedure for a controlled release. This report presents the results of this study and a proposed program of controlled stored energy release from MTR reflector graphite.

Although numerous planned releases have been made successfully on large graphite reactors,(6) the purpose here is different. Whereas the large graphite reactors are concerned with physical distortion of the graphite and consequently of the fuel or experimental tubes, the consideration here is to prevent possible structural damage due to excessive temperature differential which might be caused by an inadvertent energy release. The results of calculations indicate that a controlled energy release does not appear to be a serious problem at this time. However, extrapolated values for some years from now indicate that the energy build-up could become appreciable and a spontaneous release could possibly damage reactor components and/or experiments.

II. SUMMARY OF MEASUREMENTS AND CALCULATIONS

The data of Wheeler and Ryder(4) on stored energy and on x-ray diffraction measurements of inter-planar crystallite spacing is summarized in Fig. 1. The curve for stored energy was drawn conservatively to represent a maximum for the data rather than a best fit. The position of maximum effect is normally expected at the peak of fast flux, a few inches below centerline. This is the case for x-ray diffraction measurements. However, the stored energy peak appears to be at 18 inches below reactor centerline, which indicates that some anneal may have taken place. These two types of irradiation damage are not annealed at the same temperature.

In Fig. 2 the calculated maximum temperature rise upon release of stored energy is plotted as a function of MTR operating time. Three cases assumed are: (a) that all energy released remains in the pebble region now showing stored energy, (b) that the energy is uniformly distributed throughout the whole pebble zone, and (c) that the energy is distributed throughout all the graphite. Extrapolations were based upon an assumed 10,000 MWD operation of the MTR per year and the experimentally observed rate of stored energy build-up.(7) It was further assumed that an average heat capacity of 0.3 cal/g. °C was applicable and that the vertical stored energy distribution persisted throughout the pebble zone. These assumptions may appear excessively conservative, but are used to account in part for uncertainties in the information on stored energy distribution. The distance at which irradiation damage is observed also indicates that some stored energy should be present in the block graphite.

Calculations were also made to determine the effect of a thermal transient resulting from a stored energy release in the pebble zone on the reactor structure components. The worst credible conditions for the release to occur were assumed to be as follows:

1. All coolant fans failed.

2. No stack draft was available.

3. The reactor was scrammed.

4. The initial temperature condition for the reactor components were the equilibrium conditions for 40 Mw operation.

5. The total predicted stored energy content of the pebble bed was released instantaneously.

The transient temperatures and heat distribution rates for the various regions of the reactor were determined for the release of the total stored energy content existent at present, 5 years from now and infinite time from now (Figures 3, 4, and 5). A comparison of the maximum temperatures and temperature differences for the above cases and the maximum allowable are tabulated in Table II. The details of this calculation are presented in Appendix I.

A transient heat transfer analysis of the maximum pebble temperature to be expected has been made on the pebble zone for the proposed anneal scheme. The details of calculations and results have been issued as a separate report.(10) Results from heat balance equations programmed on the IBM-650, show that although the transient is rapid, peak temperatures do not exceed 501° F. This is far below temperatures considered hazardous due to graphite combustion.

III. PROGRAM FOR ANNEAL

The program for anneal of MTR reflector graphite as outlined below includes pre-anneal preparation, the procedure during anneal and post anneal activities. The program in principle was approved by representatives of Reactor Physics and Engineering Branch, Division

Engineering and MTR Operations. Any significant departures from this program should receive further considerations. Details of instrumentation are listed in Appendix B.

A. Pre-anneal Preparation

1. Check out of thermocouples presently in the graphite and reactor structure is to be made.

2. Additional sampling of graphite balls from VG-10 will be done, as determined by Reactor Physics and Engineering, to improve the data plotted in Fig. 1.

3. Thermocouples are to be mounted in pebbles irradiated to maximum stored energy content and inserted in the VG-10, VG-14 and VG-19 locations. The liners will be removed to allow the pebbles to be in direct contact with the pebble bed. After these pebbles have been annealed to the normal graphite temperature, they should record the maximum transient temperature during the stored energy release.

4. Three thermocouples each are to be placed into the permanent graphite of VG-35, VG-55, and VG-9. Of the three in each hole, one will be placed in the centerplane and the other two symmetrically above and below.

5. If possible, thermocouples will be mounted on the thermal shield, biological shield and in beam holes.

6. Monitors are to be provided for measuring air flow.

7. Monitors in the exit air stream will be provided for continuous record of particulate and C-14 activity.

8. Automatic power scram should be instrumented to actuate at the pre-determined maximum temperatures specified below.

9. Adequate health physics monitoring around the MTR should be provided by MTR Health Physics.

10. Precautionary measures for fire protection should be provided. Experience at Brookhaven(6) indicates that smothering is the most effective graphite fire control technique. Accordingly, all experimental holes should be sealed to the extent practicable. The inlet air ducts should be provided with means for sealing quickly in event of fire. A CO_2 monitor should be used in the exit air stream to monitor any excessive oxidation.

11. Equipment should be provided for measuring and controlling air flow remotely. A flow metering system and remotely operated control valve should be installed on the electrically powered auxiliary blower.

12. Experiments which might be damaged by heat during anneal must be removed.

B. Anneal Procedure

1. With the reactor scrammed, cut out all air flow except for one auxiliary fan delivering 300 lbs/min.

2. Bring the MTR power up to 2.5 megawatts. Observe the temperature rise during a 30 minute period which should be sufficient to establish a rate of rise or to come approximately to equilibrium.

3. Reduce air flow to 200, then 100 lbs/min with 30 minute observation periods following each change by adjusting the remotely operated control valve.

4. Raise power level step-wise one or two megawatts at a time up to a total of 10 megawatts with a 30 minute observation period between changes.

The above steps are designed to increase the temperature of the graphite zone gradually until the stored energy has been released. The procedure will be terminated or reversed subjected to the following conditions which will be instrumented where possible.

5. The maximum rate of temperature rise shall be 400° F per hour before stored energy release begins at about 300° F.

6. At 350° F reduce the power 50 per cent.

7. At 500° F the reactor should be scrammed. This should be instrumented to the temperature recorder for automatic action.

8. At 600° F the fans should be turned on. This should also be instrumented.

9. In case the temperature remains below 600° F continue anneal for 15 minutes after maximum temperature is reached, then turn fans on to cool graphite. A maximum temperature of at least 400° F is desired for the graphite zone.

10. If the temperature reaches 600° F, the main air blowers will start automatically within 15 seconds. If the temperature continues to rise to 1000° F, the fans will be turned off automatically which will actuate audible alarms to signify that fire fighting procedures are to be carried out.

C. Post-anneal Procedures

1. Analyze the results of the temperature charts obtained during the anneal.

2. Obtain sample graphite pebbles from representative regions and test for residual stored energy.

3. If appreciable stored energy is found in these samples, the person or persons in charge will determine whether a second anneal should be attempted. If so, they will establish the procedure based on the analysis of all data obtained.

4. The VG liners will be restored and excess instrumentation removed.

D. Time Required

Actual MTR down time required is estimated at 2 to 3 days depending on how much can be done with the reactor operating. Of this, less than one day will be needed for actual anneal and the rest for preparation and restoration. Possibly most of the preparation could be done during a scheduled shut down.

IV. DISCUSSION

In considering a program of stored energy release, a few further facts and observations may be noted.(8)

1. The measured stored energy per gram of MTR graphite is in the range found in other graphite reactors when planned anneal program was considered desirable. The total energy involved is, however, much less in the MTR.

2. The rate of stored energy build-up (of that which anneals at 200° C) decreases after about 50 cal/g and reaches a maximum at about 110 cal/g(7) after which it decreases slowly.

3. Oxidation of the graphite should present no serious problem at the temperatures anticipated. The rate of oxidation per unit weight will probably be slightly greater than in large graphite reactors under the same temperature conditions because of the greater relative surface area of the balls. Calculations based on heat transfer considerations indicate that a temperature on the order of 1100° C are required before oxidation heat generation is greater than the maximum heat removal rate.

4. Temperature due to spontaneous stored energy released is generally easily held to below 400° C by adjusting the air flow.

5. The thermal release of stored energy in graphite begins approximately 50° C above its normal operating temperature. A sufficient increase in power level or change in air flow could initiate a spontaneous energy release.

6. An instantaneous release of the maximum credible stored energy available now or during the next 5 years in the pebble zone would probably cause no permanent damage to the major structural components in the MTR when accompanied by a total loss of pebble stored energy content.

7. Preliminary results indicate that the maximum pebble temperature during the anneal is below the allowable maximum operating temperature. As the transient duration is very short in comparison to the case in Appendix I, it is believed that no damage will occur to the structural components during the anneal.

8. Operational experience gained through a planned release would provide a basis in experiment for estimating frequency of such operations in the future and in planning the proper procedure for furture energy release.

An alternative procedure for releasing energy would be to discharge the pebbles, anneal them outside, and then replace them in the reactor. A study of this procedure indicated that considerable more down time would be required. The discharge chutes are not readily accessible due to experimental construction. There would be potentially a much greater radiation hazard both from direct irradiation and contamination from dust. This procedure was generally considered much less desirable and is therefore not advocated.

V. REFERENCE

1. Buck, J. H. and Leyse, C. F., "Materials Testing Reactor Project Handbook" TID-7001, 1951

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3. Wheeler, G. V., Boyes, G. W., and Wilson, H. J., PHILLIPS INTERNAL REPORT

4. Wheeler, G. V. and Ryder, W. A., PHILLIPS INTERNAL REPORT

5. Private Communications, Smith, E. O.; deBoisblanc, D. R.; Phillipson, J. B.

6. BNL-4124 "Stored Energy, Growth and Annealing Status of Graphite Moderator in the BNL Research Reactor, Final Report" Brookhaven National Laboratory, Upton, New York

   Dickson, J. L., B.E.P.O. "Manual for Second Wigner Energy Release", P.O.C. Memo 89, 1958

7. Fast, E., "Graphite Damage as an Index to the Integrated Damaging Neutron Flux" IDO-16182 Sept. 28, 1954

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APPENDIX A

TRANSIENT STRUCTURAL TEMPERATURES IN THE MTR CAUSED BY STORED ENERGY RELEASE

I. Introduction

It is considered that one of the worst possible effects of a spontaneous release of stored energy in the MTR would be permanent damage to the structural components due to thermal stress or excessively high temperature. It is not credible that a total loss of coolant flow would occur as the system is sufficiently backed up with emergency auxiliary fans. Also it is not credible that the reactor would not shut-down in event of fan or power failure. However, to illustrate the potentials of an instantaneous release of the stored energy, existent at present and in the future, during a total failure of coolant flow, the following study is presented.

II. Calculations

The thermal transients which would occur in various reactor components due to the instantaneous release of stored energy were calculated assuming the following conditions:

1. Total loss of coolant flow has occurred, i.e., the auxiliary fan also failed.
2. No stack draft cooling is available.
3. The reactor is scrammed.
4. The release of stored energy occurred just slightly after the reactor scram occurred resulting in equilibrium 40 Mw structure temperatures.
5. The energy released is uniformly distributed throughout the pebbles.
6. The heat is transferred to the structure by two mechanisms.
    a. Conduction and convection from within the pebble bed.
    b. Convection circulation due to density difference in the air (see Fig. 6).

Figures 3, 4, and 5 are the transient curves for stored energy release due to neutron damage buildup at present, five years from now and infinite years from now.

Table I is a list of the heat distribution rates for the various components affected by the energy release.

III. Discussion

Table II is a listing of operating and maximum allowable operating temperature and/or temperature differences for the reactor structure. Included also is the results of the above transient analysis.

Note that the peak temperature, for the infinite time stored energy damage case (Fig. 5) temperatures in the pebbles, bean hole liners, and VG holes exceed the maximum allowable operating temperatures.

For the five year and present cases, however, (Fig. 4 and 3) only the level chambers temperatures are excessive. The chambers should be instrumented with thermocouples and thermally insulated or cooled to maintain temperature below 200° F.

It is believed that an increase in coolant flow would tend to reduce the maximum temperatures and make the situation more tenable.

IV. Conclusions

No structural damage will occur to the MTR due to the sudden release of the stored energy available in the pebble zone for the next 5 year period. However, the situation should be re-evaluated if further data indicate more stored energy than presently anticipated is being built up.

TABLE I

MAXIMUM HEAT DISTRIBUTION IN THE MTR STRUCTURE DUE TO AN INSTANTANEOUS RELEASE OF STORED ENERGY IN THE MTR PEBBLE ZONE WITH ZERO COOLANT FLOW

Exchange Region	Present Damage Maximum Heat Gain or Loss Rate Btu/hr	5 Year Future Damage Maximum Heat Gain or Loss Rate Btu/hr	Infinite Time Damage Maximum Heat Gain or Loss Rate Btu/hr
Pebble zone to natural air circulation (loss)	11,000	19,200	54,000
Pebble zone to permanent graphite (loss)	35,800	62,000	175,000
Air to upper thermal shield (lower plate) (gain)	6,900	12,000	33,700
Air to biological shield through upper thermal shield (gain)	270	500	1,370
Air to permanent graphite (gain) (difference)	3,900	6,700	19,000
Total stored energy released	6.74×10^5 Btu	1.25×10^6 Btu	3.3×10^6 Btu

TABLE II

COMPARISON OF ALLOWABLE, OPERATING AND CALCULATED TRANSIENT TEMPERATURES

Item	40 MW Max. Operating Temperature $^{\circ}$F	Maximum Transient Temperature $^{\circ}$F			Max. Allowable Oper. Temp.	
		At Present	In 1964	Time ∞	Temp. $^{\circ}$F	Reference
Pebbles	264	355	460	699	570	ORNL-50-3-102 p. 3
Beam hole liners	264	355	460	699	500	TID-7001, p.84
Permanent graphite	100	110	140	204	500	ORNL-50-3-102 p. 3
Biological shield	100	100.1	100.5	101	120 (50 Δt)	TID-7001, p.76
VG hole liners	264	355	460	699	500	
Reactor tank "D"	3.74(Δt) *	3.80(Δt)	3.94(Δt)	4.04(Δt)	23.55(Δt)	ASME Code Sec.8
Thermal shield plates	30 (Δt)	90 (Δt)	145 (Δt)	300 (Δt)	350 (Δt)	Blaw Knox Eng. 25 Report ECR-1
Reactor instrument level chambers	100	355	460	699	200	

* The symbol Δt indicate the quantity is a temperature differential.

APPENDIX B

PRELIMINARY SUMMARY OF INSTRUMENTATION REQUIRED TO CONTROL A PLANNED STORED ENERGY RELEASE IN THE MTR

I. Pebble Zone

The thermocouples in the pebble zone will be connected to a rapid response scanner device.(9) An alarm, scram system, and automatic reactor air blower start-up system will operate on the output of the scanner at preset maximum temperature signals.

A. Thermocouple Scan System

The thermocouple scanner device will be a dual channel system operating at a scan rate of 5 thermocouples per second. Rapid chart speed recorders will record temperature scan data on two speeds. The system will be capable of scanning 50 thermocouples.

1. Intermittent Fast Speed

This system will record quantitatively the thermocouple output for several scan cycles intermittently on a one to ten minute period with a chart speed of 5 inches per second. An additional stepping trace will be recorded to identify each thermocouple deflection.

2. Continuous Slow Speed

This system will record scan data continuously to indicate maximum temperatures. A fast response recorder (5 cps) will be operated at 0.2 inch per second.

B. Control Circuits

Fast response voltage sensitive relays will operate alarm, scram, and blower start-up circuits at preset voltages associated with setpoint temperatures.

C. Thermocouples

Thermocouples will be light gage (for fast response) clad with metal for strength. The new thermocouples will be mechanically fitted into irradiated pebbles by attaching the cladding to a threaded sleeve which screws into the pebble and presses the junction against the center of the pebble.

D. Single Point Recorders

The hottest pebbles will be connected to a fast (full scale travel 0.25 second) single point recorder instrumented with alarm, scram, and blower start-up setpoints.

II. Permanent Graphite

The permanent graphite thermocouples will be connected to a 16 point Multipoint recorder with a chart speed of 6 inches per hour and a print speed of one per minute. Alarm and scram setpoints will be attached.

Ten new thermocouple probes will be installed at locations close to the pebble zone. Several of these will be connected to the scanner system outlined in Section I.

III. Reactor Structure Temperatures

The existing reactor structure thermocouples will be monitored by three Multipoint recorders (16 point 6 in/hr chart speed, 1 print per minute).

Several thermocouples in the beam hole liners will be placed on the scan system outlined in Section I.

Blower start-up and scram setpoints will be provided for the recorders.

IV. Reactor Air Control System

The reactor air system will be modified to include an automatic blower start-up system, an auxiliary flow meter system and a flow control system. The gasoline motor blower will provide backup protection for the electric auxiliary blower.

A. Automatic Blower Startup

The manual start buttons in the fan house will be by-passed by a start-up relay with the coil actuated by automatic start-up mercoids listed in the above sections. The relay contacts will operate the blower starter circuits.

B. Auxiliary Blower Meter System

An orifice meter, DP cell, and flow control valve will be installed on the discharge of the electric auxiliary blower. A controller-recorder system is also required.

V. Control Panel

A central control panel will be located in the reactor control room. The panel will house thermocouple scanners and recorders, reactor air flow controls and recorder, alarm lights, annunciators, and control relays. Junction boxes will be installed for new thermocouples on the reactor top. A temporary conduit system will carry thermocouples wiring to the panel.

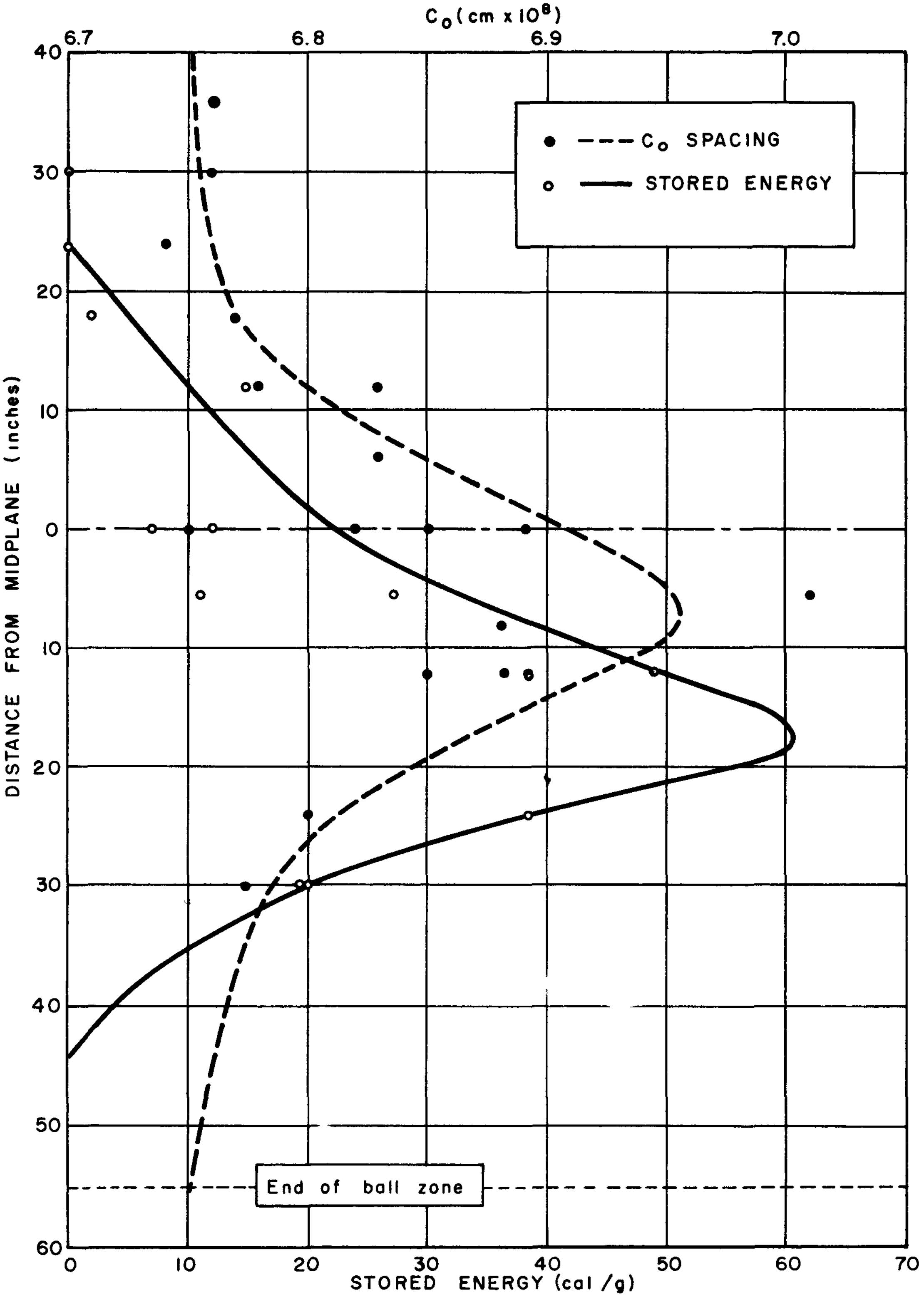

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FIG. 1

SUMMARY OF MEASUREMENTS ON GRAPHITE FROM VG-10

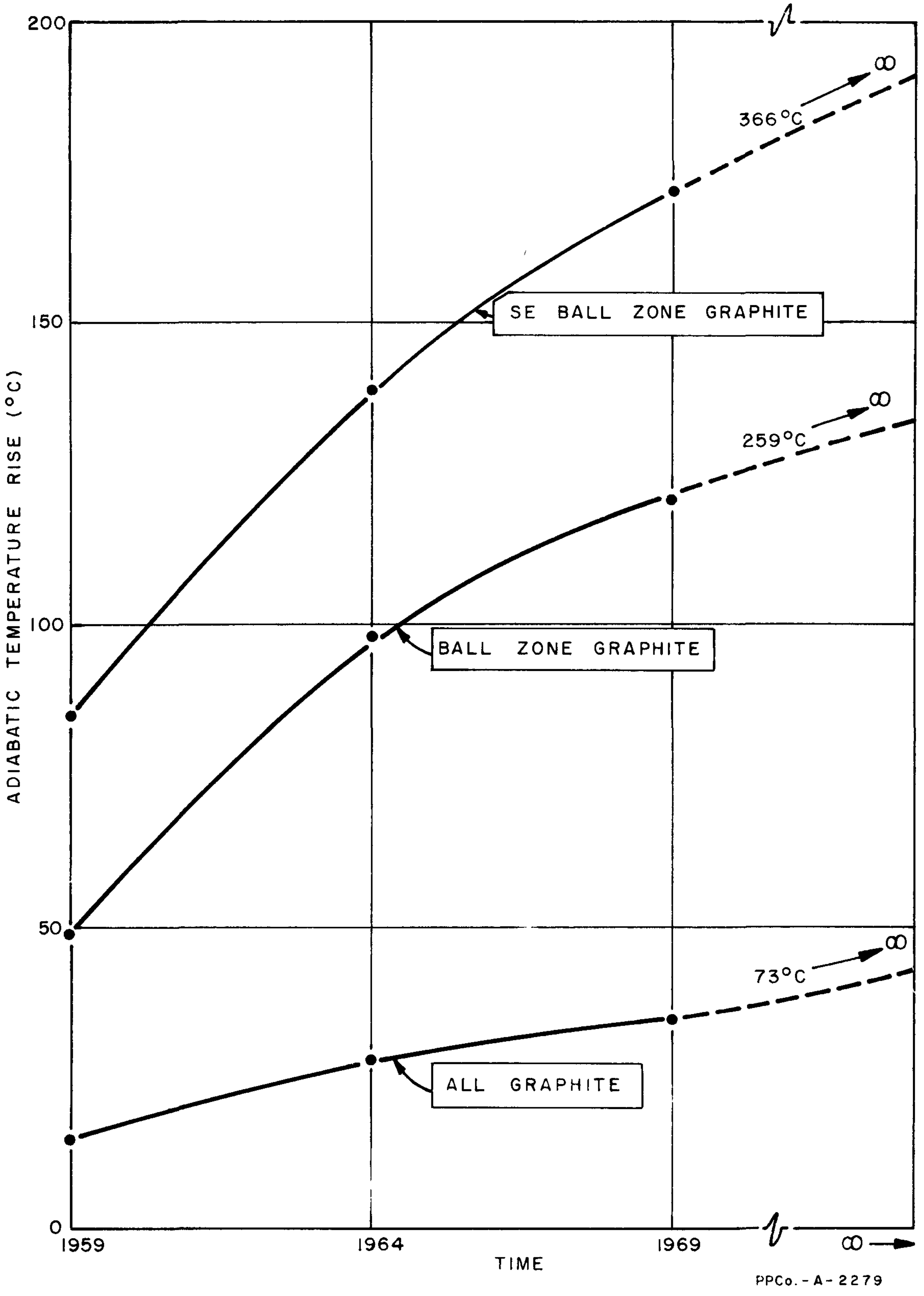


FIG. 2

MAXIMUM TEMPERATURE RISE IN MTR GRAPHITE DUE TO STORED ENERGY RELEASE

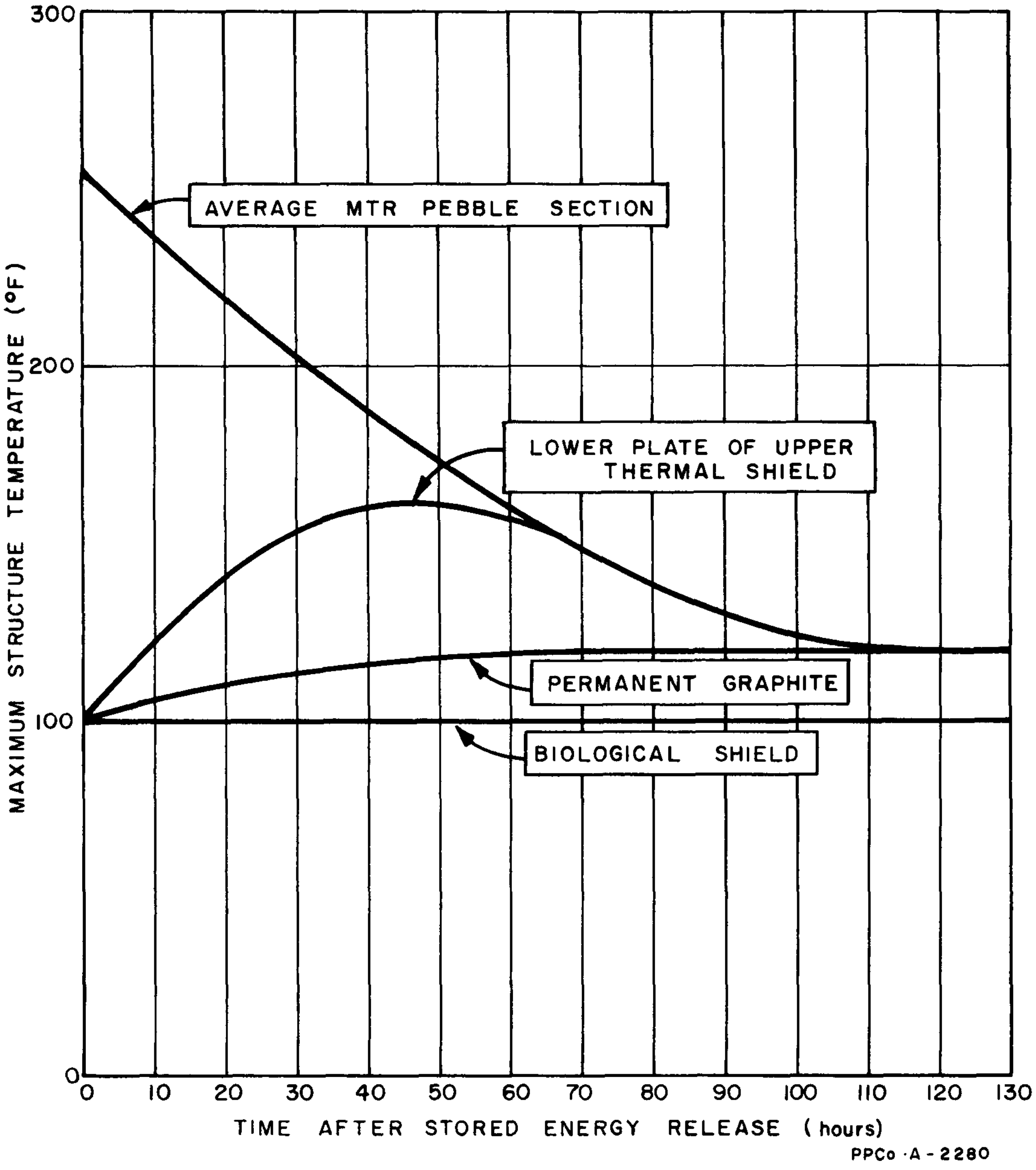


FIG. 3

MTR STRUCTURE TEMPERATURE TRANSIENT DUE TO THE WORST CREDIBLE ACCIDENTAL RELEASE OF STORED ENERGY IN THE PEBBLE ZONE

(STORED ENERGY CONTENT AT PRESENT)

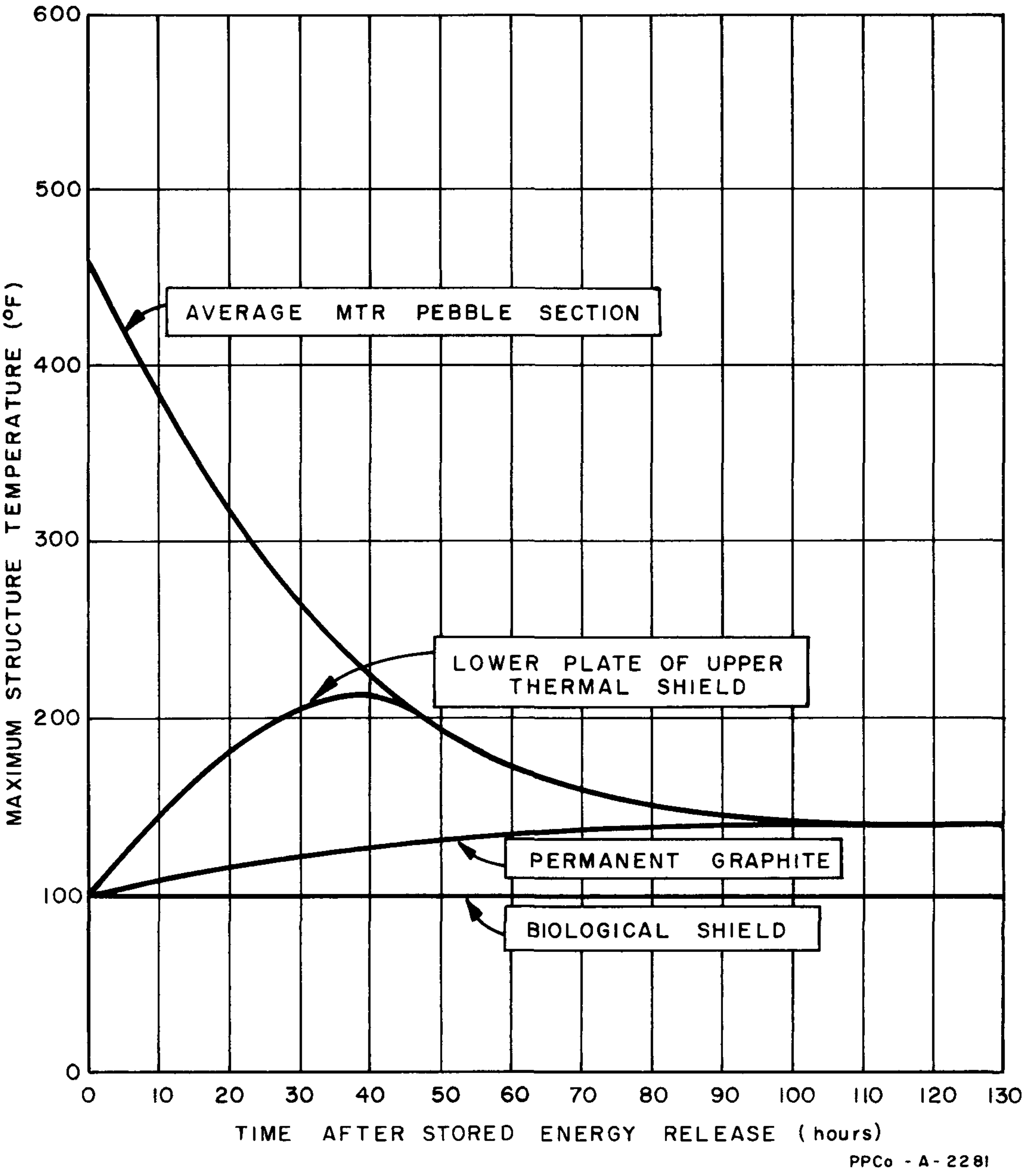


FIG. 4

MTR STRUCTURE TEMPERATURE TRANSIENT DUE TO THE WORST CREDIBLE ACCIDENTAL RELEASE OF STORED ENERGY IN THE PEBBLE ZONE

(STORED ENERGY CONTENT 5 YEARS FROM NOW)

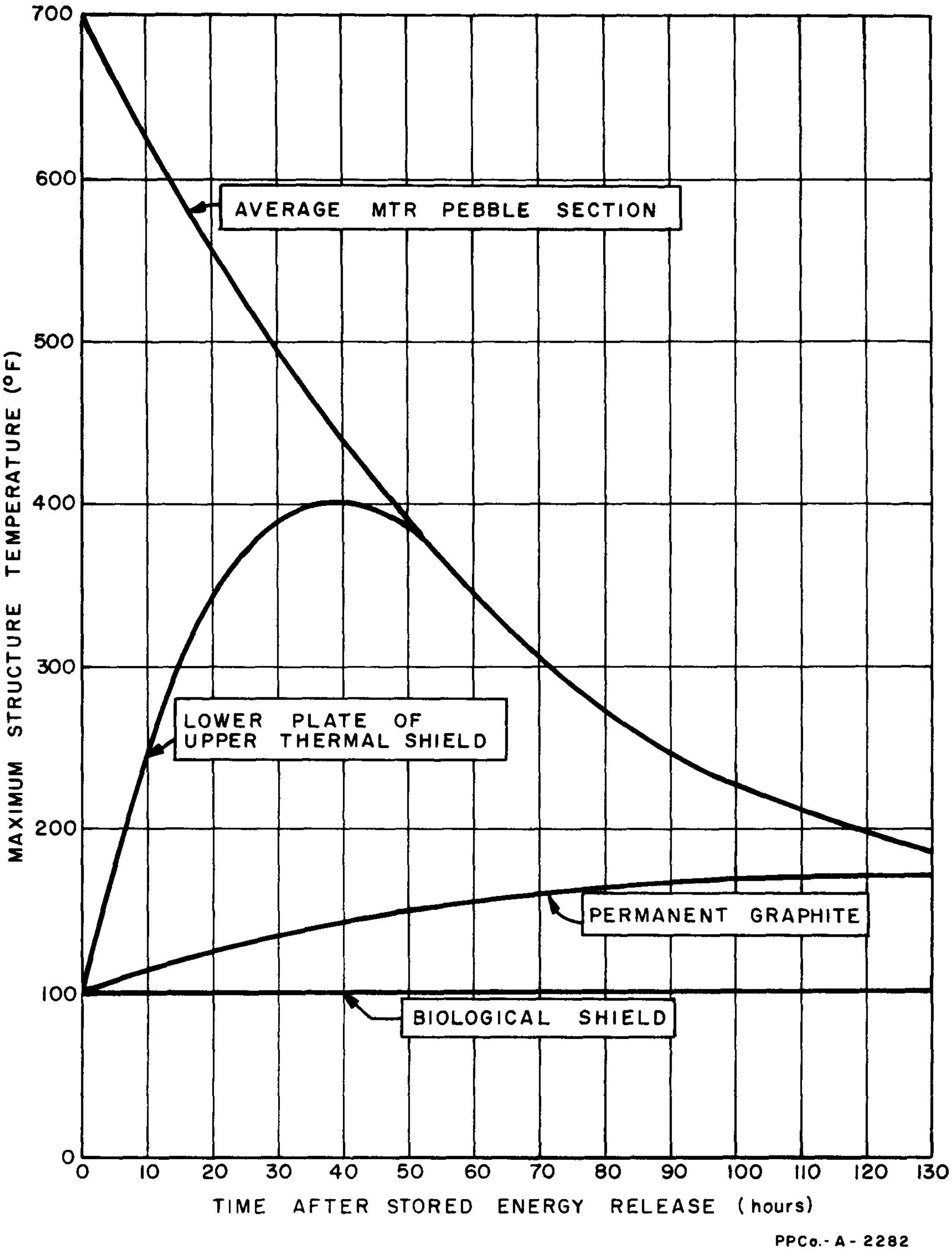
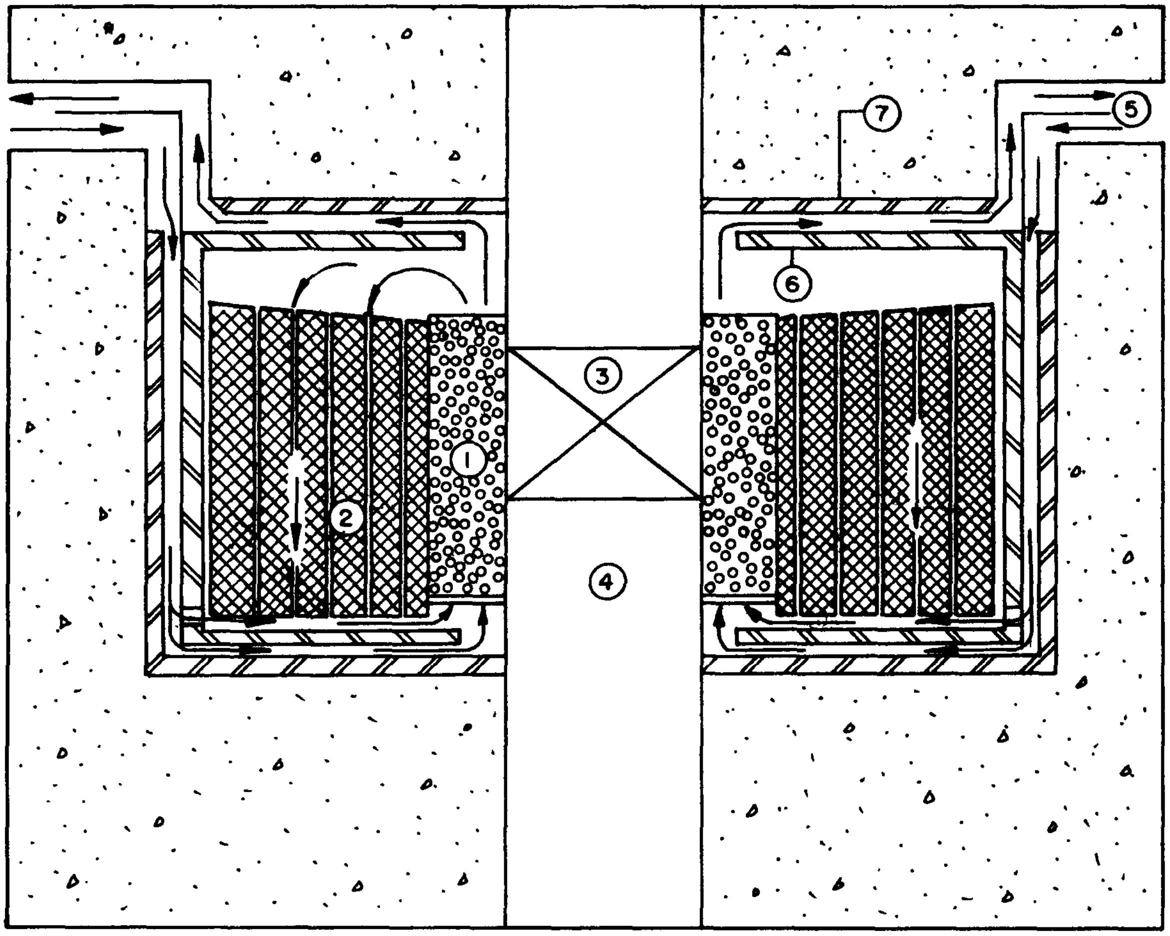


FIG. 5

MTR STRUCTURE TEMPERATURE TRANSIENT DUE TO THE WORST CREDIBLE ACCIDENTAL RELEASE OF STORED ENERGY IN THE PEBBLE ZONE

(STORED ENERGY CONTENT AT INFINITE TIME)



1.	PEBBLE ZONE	5	INLET AIR DUCTS
2.	PERMANENT GRAPHITE	6.	INNER THERMAL SHIELD PLATE
3	REACTOR CORE	7.	OUTER THERMAL SHIELD PLATE
4.	REACTOR TANK		

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FIG. 6
SCHEMATIC DIAGRAM OF CIRCULATION CURRENTS IN THE MTR WITHOUT FORCED AIR FLOW