[redacted] UNCLASSIFIED

SC-CR-66-2052X

MONTHLY PROGRESS REPORT NO. 1

to

SANDIA CORPORATION

SANDIA SYSTEMATIC DECLASSIFICATION REVIEW
DOWNGRADING OR DECLASSIFICATION STAMP
CLASSIFICATION CHANGED TO: U
AUTHORITY: K. D. Smith
Emelda Selph 05/20/96
PERSON CHANGING MARKING & DATE
RECORD ID: 96SW034
Carmela Gallegos 5/20/96
PERSON VERIFYING MARKING & DATE
DATED: 01-24-96

RECORD COPY
Do Not Take From This Room

on

A FEASIBILITY STUDY OF RADIOISOTOPE THERMOELECTRIC GENERATORS FUELED WITH KRYPTON-85 [redacted]

WORK PERFORMED UNDER BMI-SANDIA AGREEMENT SERIAL NO. 1221 (SANDIA PO ASB 48-3356)

SANDIA SYSTEMATIC DECLASSIFICATION REVIEW
1st Review Date: 1-18-96
Authority: ☐ADC ☒ADD W Loyne
Name:
2nd Review Date: 1-24-96
Authority: ADD
Name: K. D. Smith
Determination (Circle Numbers):
1. Classification Retained
2. Classification Changed to: U
3. Contains No DOE Classified Information
4. Coordinate With:
5. Contains UCAI?
6. Comments:

[redacted]

This report contains progress of the work performed under Contract ASB 48-3356 commencing April 5, 1966, and ending April 29, 1966.

[redacted]

BATTELLE MEMORIAL INSTITUTE
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

[redacted]

UNCLASSIFIED

Log No. 253

[redacted]

SC-CR-66-2052X

MONTHLY PROGRESS REPORT NO. 1

on

A FEASIBILITY STUDY OF RADIOISOTOPE THERMOELECTRIC GENERATORS FUELED WITH KRYPTON-85 (C)

INTRODUCTION

Re-entry and burnup of a radioisotope thermoelectric generator is a means of diffusing the radioactive fuel into the atmosphere so that the concentration is reduced to negligible levels.

Krypton-85 is an inert gas with half-life of 10.3 years. The physical state and inert characteristics of this radioisotope provide the basis for several desirable safety features when it is considered as a fuel for radioisotope thermoelectric generators. If the krypton is released to the atmosphere, it is feasible to assume that it will diffuse rapidly assuring worldwide dispersal at a negligible radiation level. Further, it can be assumed that the gas will not adhere to surfaces as a contaminant or enter the body as a biological threat.

Krypton-85 is a by-product of the fissioning of several isotopes such as U-233, U-238, and U-235. This material should become available when it is recovered by isotopic separation. Assuming that the separation can be accomplished, a feasibility study of RTG design with Kr^{85} as the heat source is desirable.

Work on this engineering study program was initiated on April 5, 1966. The program will be concluded by June 30, 1966. Within 30 days after the conclusion of the study, a final report will be issued. Monthly progress reports will be issued at the close of each calendar month.

[redacted]

UNCLASSIFIED

Objectives

General

To determine the feasibility of using krypton-85 as a fuel for radioisotope thermoelectric generators.

Specific

The specific objectives for the first month were:

(1) Determine pertinent tradeoffs which will affect feasibility and generator weight

(2) Investigate heat-source designs to minimize pressure vessel weight and scope the heat source for thermal power level

(3) Prepare design equations for incorporation into parametric RTG study

(4) Determine expected magnitude of radiation dosage.

Work Accomplished

(1) Tradeoffs

The design of the heat source as a pressure vessel constitutes the major factor in determining the feasibility of Kr^{85}-fueled generators. The primary interplay is the design of the pressure vessel as it affects the power density of the heat source and the weight of the device. System variables which are being considered are operating pressure and temperature, size and configuration, and time.

[redacted]

The relation between these variables and the feasibility and weight of the RTG is illustrated in Figure 1. The interactions are as follows:

(a) Higher pressures mean higher gas power density but also heavier vessels

(b) Higher heat-source operating temperatures mean lower gas power density and higher vessel weight but improved thermoelectric efficiency

(c) Lower cold-side temperatures mean higher thermoelectric efficiency but higher radiator weight

(d) Longer lifetimes mean higher vessel weight and possibly prohibitively high early-life temperatures

(e) Size and configuration generally affect device weight.

(2) Heat Source

Preliminary investigations of heat-source design will center around two heat-source operating temperature levels, 1800 F and 1200 F. These temperatures are to be associated with GeSi and PbTe thermoelectrics, respectively. The thermal power density of Kr^{85} in this temperature range is presented, as a function of pressure, in Figure 2. This represents the perfect gas law including the gas compressibility factor. The gas power is that for an isotopic separation of 50 wt percent Kr^{85}, 0.312 watt/gm in the liquid state.*

---

* Handbook of Shielding Requirements and Radiation Characteristics of Isotopic Power Sources for Terrestrial, Marine, and Space Applications; ORNL-3576.

UNCLASSIFIED

[redacted]

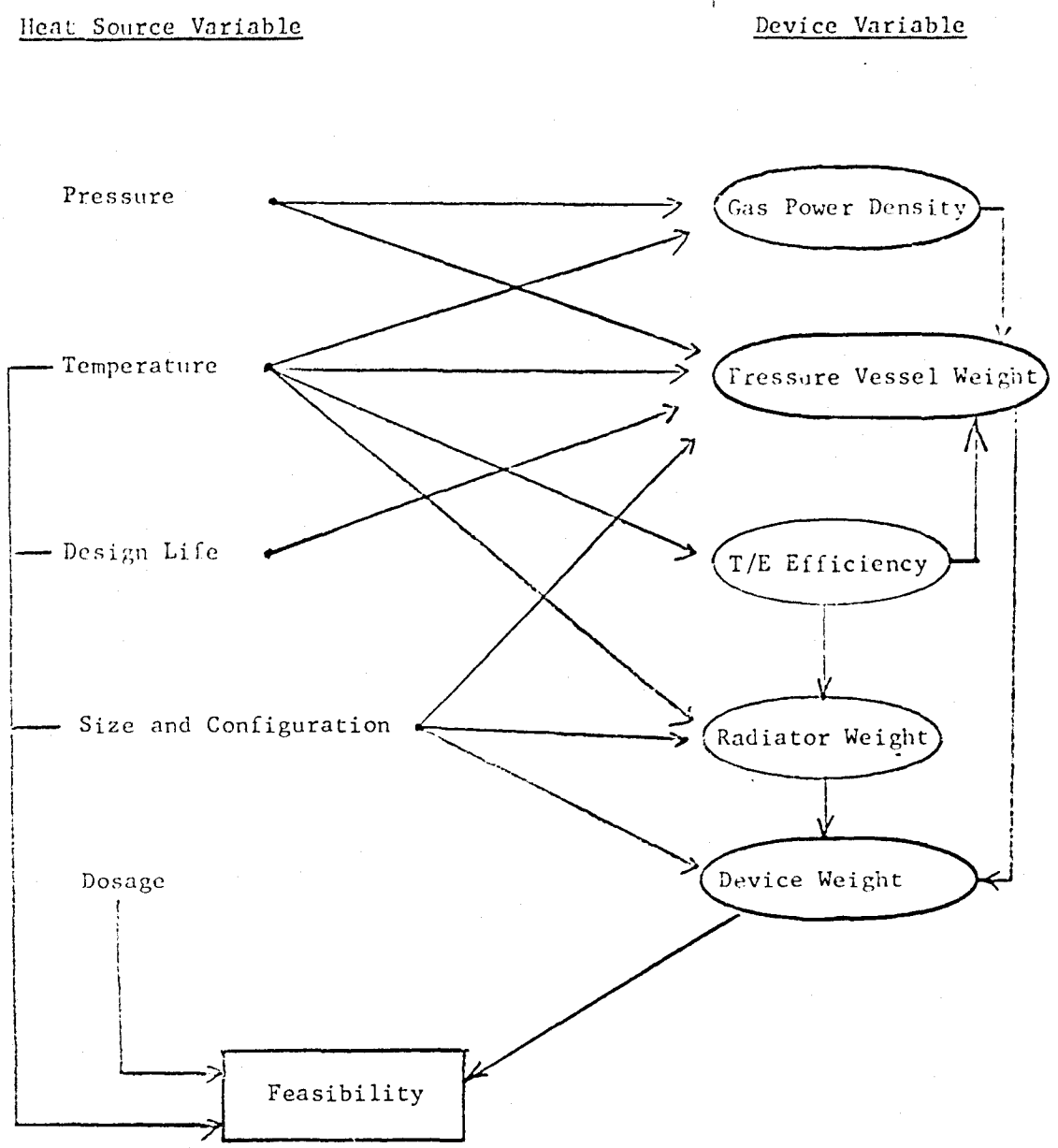


FIGURE 1. TRADEOFFS

LOGARITHMIC 46 7320
KEUFFEL & ESSER CO.

[redacted]

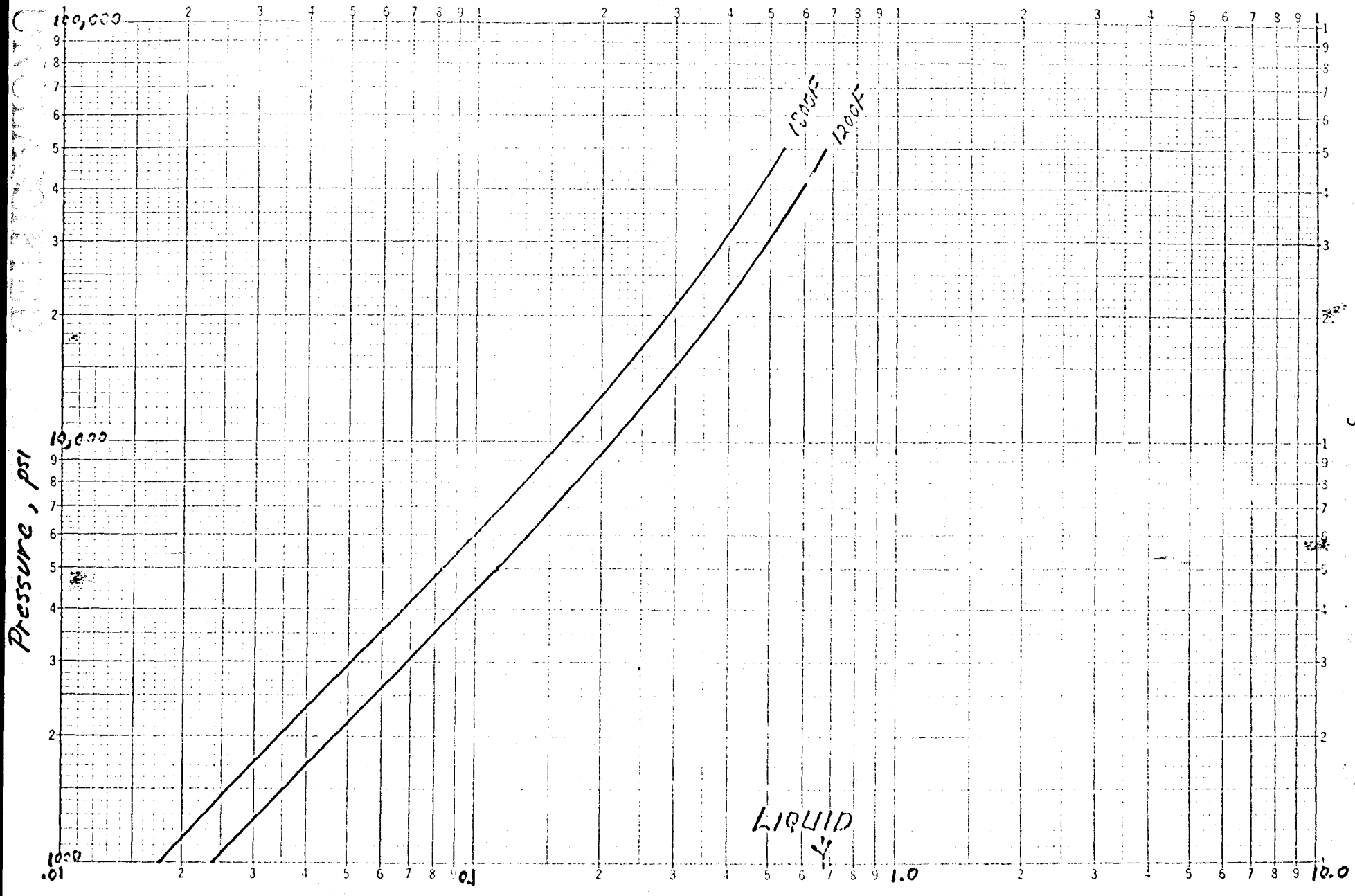


Figure 2. GAS POWER DENSITY - WATTS/cm³

[redacted]

UNCLASSIFIED

[redacted]

Essentially all of the thermal power is generated in the gas itself, as verified by calculations of β particle penetration distances, and because of the low thermal conductivity of the Kr^{85}, a unique problem is encountered in heat-source design. It is found that large temperature gradients in the gas may be expected when only gas heat conduction is considered. Within a vessel with a gas-temperature gradient the pressure will be at a constant level; however, the density and thus the power density will vary from point to point with the temperature. Thus, if high centerline temperatures exist, higher heat generation density will be found near the walls. Sample calculations accounting for variation of power density and thermal conductivity with temperature show that the expected centerline temperature, for the cylindrical heat source presented below, is of the order of 5000 R. In the presence of such a temperature gradient the vessel pressure is roughly 1-1/2 to 2 times that given by the perfect gas relation (including compressibility). The results of the calculations were gained from direct digital solutions of the heat conduction equation in cylindrical coordinates. These calculations do not account for gas radiation. Indications are that Kr is a poor radiator and therefore appreciable temperature gradients may still be expected in the gas. A possible corrective measure which will level the temperature distribution and reduce the mean pressure is the inclusion of conducting fins or screens within the vessel. The temperature gradient problem discussed above is not present if a gravity field of any magnitude is present because of convective effects.

[redacted]

UNCLASSIFIED

Heat sources in the form of spherical-ended cylinders and spheres have been considered assuming the internal pressure is that given in Figure 2. There are three criteria for pressure vessel design. The relationship between these criteria and the design is as follows:

Criterion	Design Factor
Short-Time Collapse	Initial Yielding
Long-Time Collapse	Creep-Rupture Strength
Excessive Deformation	Percent Creep Limitation

The creep-rupture properties and short-time yield strengths of several alloys under consideration are presented in Figures 3 and 4. Very few materials offer any substantial creep-rupture strength in the 1800 F temperature range. This may preclude the use of Kr^{85} with high-temperature (GeSi) thermoelectrics.

Example vessels have been designed using Udimet 500 which identifies creep-rupture strength as the governing criterion. The design equations are presented in the next section. Typical conditions associated with RTG design were selected as follows:

Life	-	30,000 hours, 3.4 years
Material	-	Udimet 500
Temperature	-	1200 F
Pressure	-	10,000 psi
Device Power	-	100 w(e) at 5 percent total efficiency.

Dimensions of sample vessels are shown in Figure 5 where multiple sphere heat sources are compared in length and diameter to a given cylinder. The spherical vessels are lighter because lower wall thickness-to-diameter

[redacted]

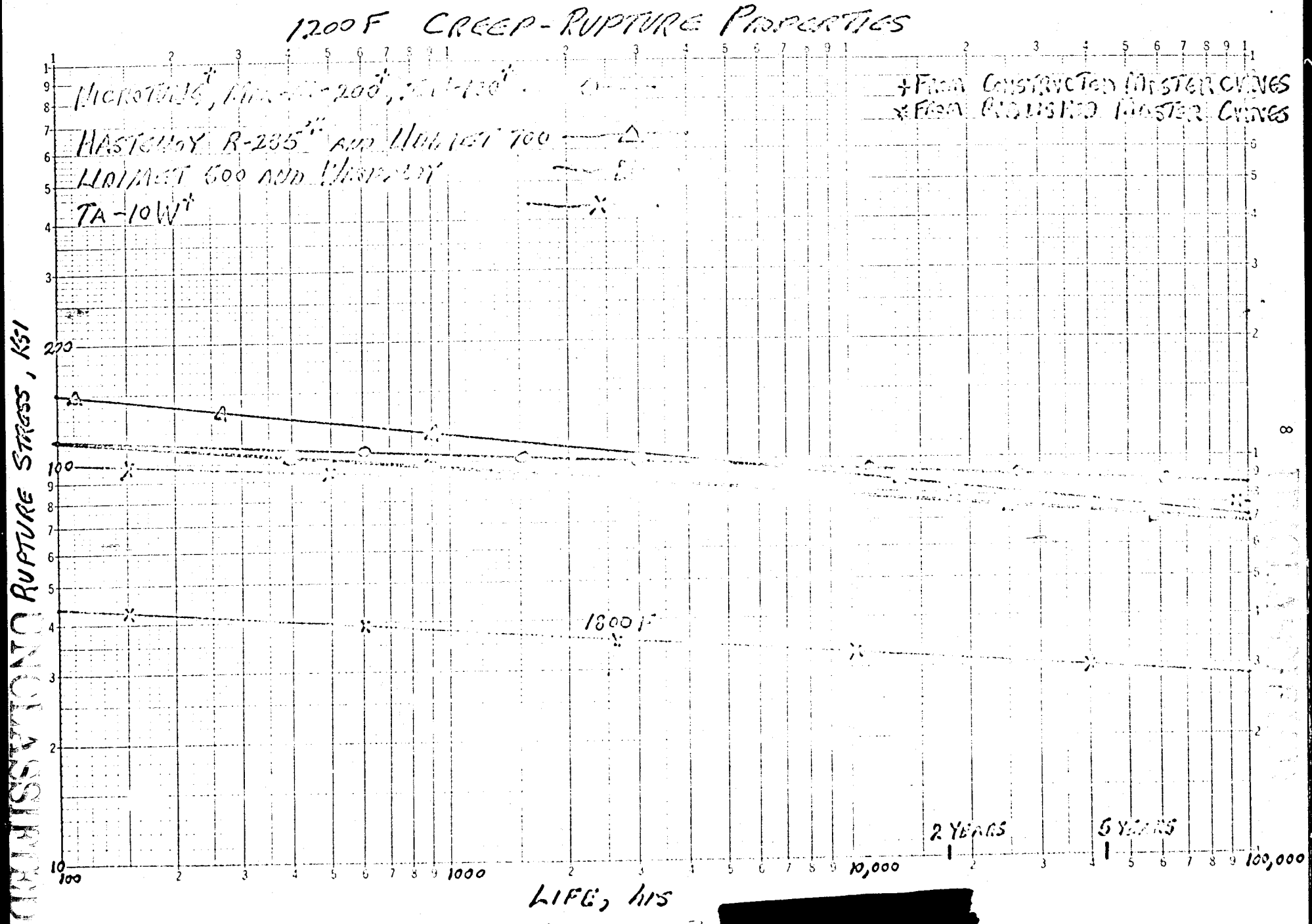


FIGURE 3.

[redacted]

UNCLASSIFIED

10 X 10 TO THE ½ INCH 359-11
KEUFFEL & ESSER CO. MADE IN U.S.A.

[redacted]

COMPARISON OF YIELD AND ULTIMATE STRENGTHS

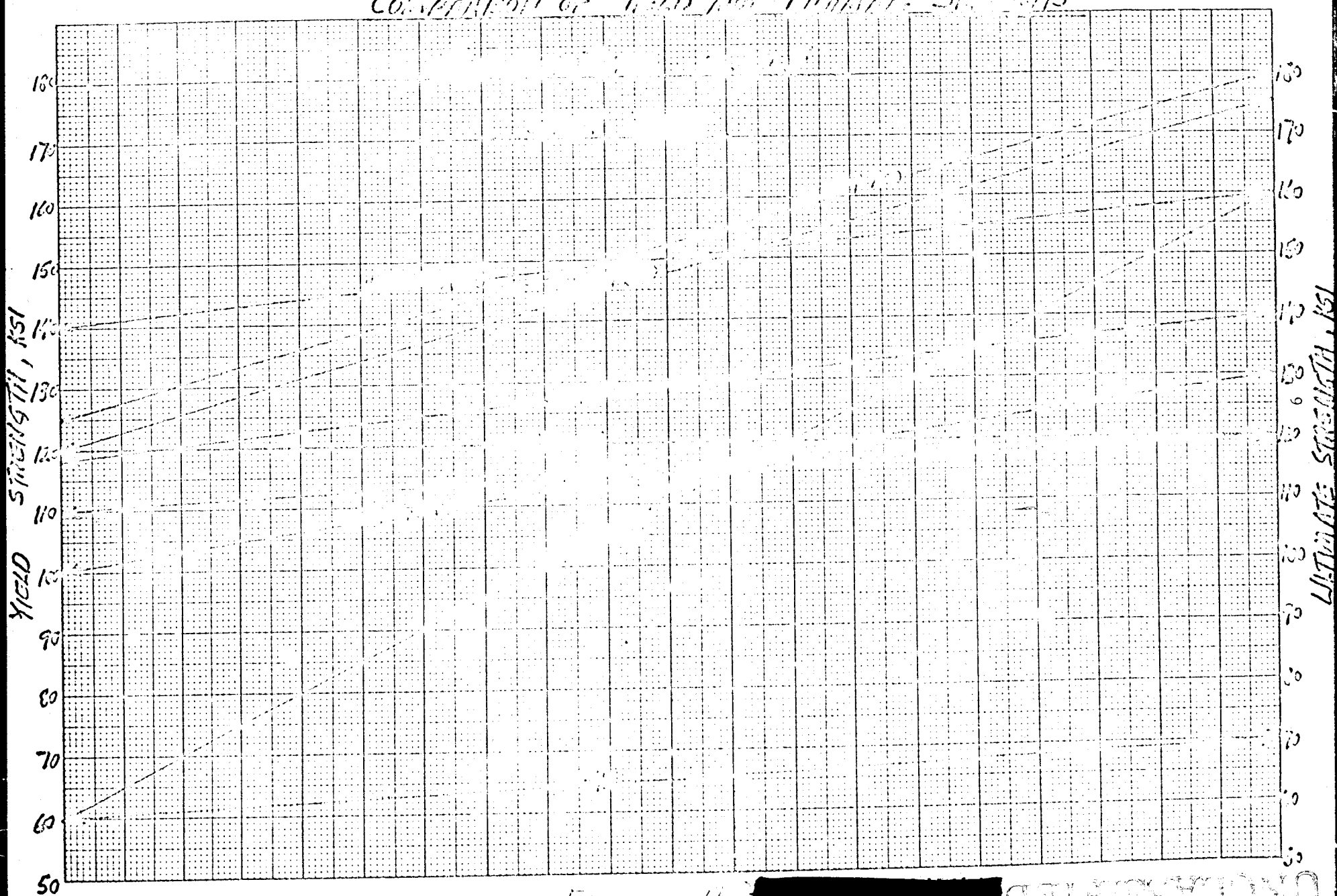


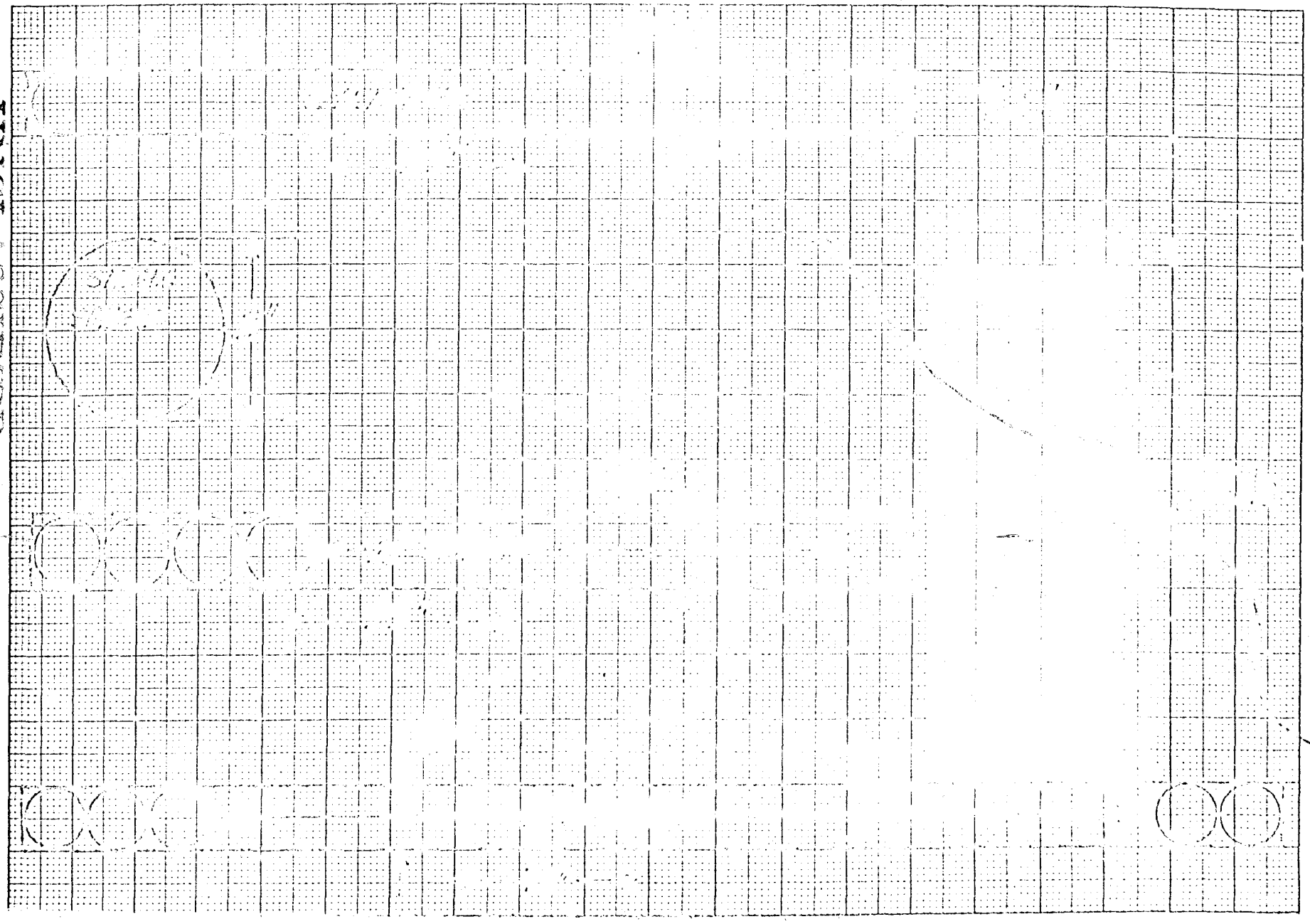
Figure 4. [redacted]

UNCLASSIFIED

K+E 10 X 10 TO THE ½ INCH 359-11
KEUFFEL & ESSER CO. MADE IN U.S.A.

[redacted]

EXAMPLE VESSELS



UNCLASSIFIED

ratios result from the stress calculations. Configuration and thermal power level will be investigated parametrically using the "RTG Analysis Code".

(3) Design Equations

Equations for designing a cylinder or sphere based on a creep analysis may be found in advanced tests on strength of materials (Marin, "Mechanical Behavior of Engineering Materials"). The relations determine a minimum wall thickness ratio, K (see Figure 6) for a given pressure and allowable stress on allowable creep rate. For a cylinder these are:

$$\frac{\sigma_\theta}{p} = \frac{\left[\frac{2-n}{n}\right] + 1}{K^{2/n} - 1}$$

$$\frac{\dot{\varepsilon}}{p^n} = B \left(\frac{3}{4}\right)^{\frac{n+1}{2}} \left(\frac{\sigma_\theta}{p}\right)^n$$

and for a sphere:

$$\frac{\sigma_\theta}{p} = \frac{\left[(3-2n)/2n\right] + 1}{K^{3/n} - 1}$$

$$\frac{\dot{\varepsilon}}{p^n} = \frac{B}{2} \frac{\left[3/(2n)\right]^n}{(K^{3/n} - 1)^n}$$

where p = internal pressure

σ_θ = loop stress at outer surface (critical)

$\dot{\varepsilon}$ = creep rate-percent elongation per unit time.

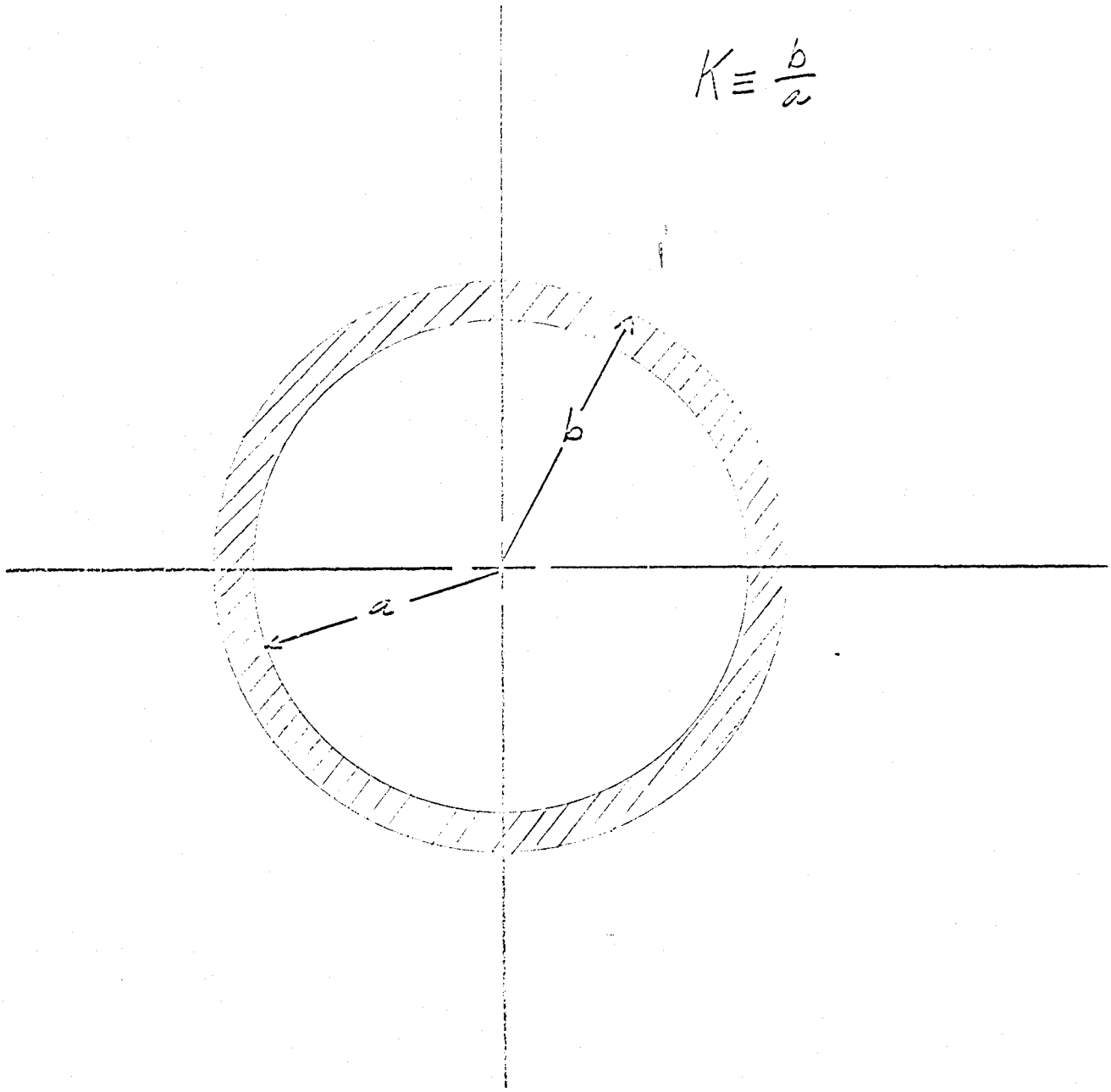


FIGURE 6. WALL THICKNESS RATIO, K

[redacted]

The creep behavior of the material is described by known material constants B and n as follows:

$$\dot{\varepsilon} = B\sigma^n.$$

It should be noted that B, n, and $\sigma_{\theta_{MAX}}$ are functions of temperature and material. Equations for initial yielding at the inner bore are:

$$p\ \text{yield} = \frac{\sigma_{\text{yield}}}{\sqrt{3}} \frac{(K^2 - 1)}{K^2} \quad \text{cylinder}$$

$$p\ \text{yield} = \frac{2}{3}\,\sigma_{\text{yield}} \frac{(K^3 - 1)}{K^3} \quad \text{sphere}.$$

Using these sets of equations, the design criterion which demands the largest wall ratio, K, may be determined for various materials, temperatures, pressures, and design lives. This will be performed by the RTG Analysis Code.

(4) Dosage

For the example cylinder shown in Figure 5 a dosage calculation may be made assuming that the vessel wall provides the only shielding. If iron is taken as the shielding medium, 0.6 cm thick, the gamma plus Bremsstrahlung dose rate at 1 meter from the geometric center of the cylinder is approximately 1260 rad/hr (see Figure 7). Surrounded by a generator the external dose rate from the heat source will be lower. If one assumes the generator will afford shielding which will increase the effective iron-shield thickness threefold, the dose rate is then about

 [redacted]

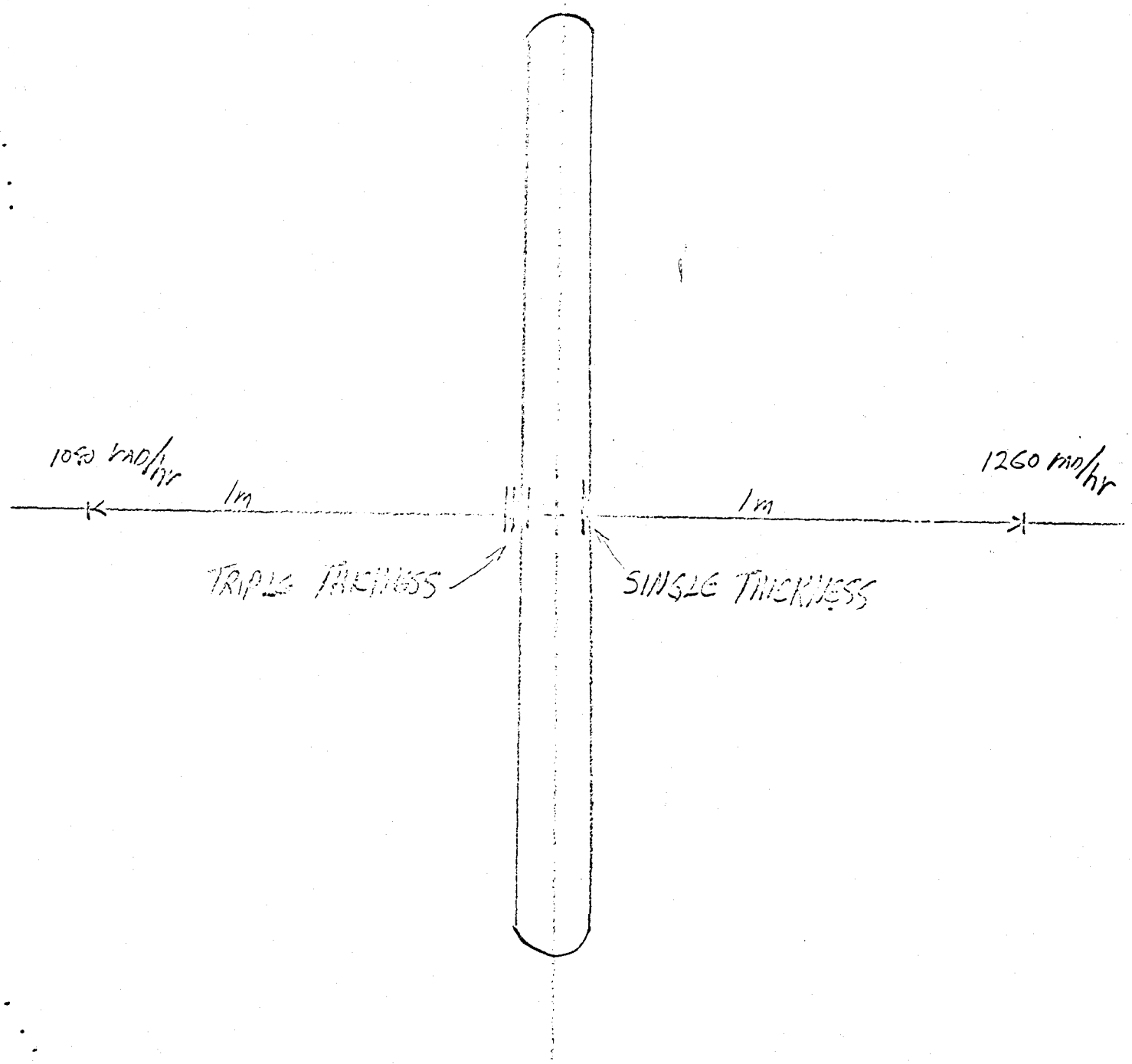


FIGURE 7. CYLINDER DOSE RATE

[redacted]

1080 rad/hr at one meter. Thus, it appears that the dose is relatively insensitive to changes of shielding thickness of the order of several centimeters. The dose rate for an actual device will depend on the material layers within the generator in addition to the specific configuration. These computations are intended to illustrate the magnitude of expected dose rates. Definitive dose rate levels will be computed for each final generator design.

Work Planned

(1) Continue investigation of the Kr gas-temperature gradient with respect to gas radiation, internal heat conductors and gravity effects.

(2) Program the heat-source design equations into the "RTG Analysis Code".

Project Appraisal

The program for evaluating the feasibility of Kr^{85} as a fuel for radioisotope thermoelectric generators has been initiated. Preliminary design studies on the heat source - pressure vessel have progressed to the point at which the over-all size and power density have been shown to be comparable to other low-power-density fuels and therefore useful in this application. This conclusion must be temporarily held in abeyance until a solution to the problem of the undesirable temperature distribution within the gaseous fuel is found. This problem exists only in the

[redacted]

UNCLASSIFIED

[redacted]

zero-G environment and the most obvious expedient at the present time is to place heat-conducting fins or screens within the vessel.

Design equations governing the pressure vessel have been established and work has been initiated to program these relationships into the "RTG Analysis Code".

[redacted]