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Historical Document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

Released 1995

**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**

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

H. W. NO.	
HW-27575	
COPY NO.	SERIES
PAGES	COPIES
12	

300-1

CRITICAL MASS INFORMATION APPLIED TO
PUREX AND RECUPLEX DESIGN

By

D. D. Lanning

April 1, 1953

This document classified
by W. J. Ozeroff

INVENTORIED
AUG 14 1953
DOCUMENT AUDIT AND OPERATION OF THE ATOMIC ENERGY COMMISSION BY THE GENERAL ELECTRIC COMPANY UNDER CONTRACT NUMBER W-31-109-ENG-52.

HANFORD WORKS
RICHLAND, WASHINGTON

RESTRICTED DATA

DOCUMENT CONTAINS RESTRICTED
DATA AS DEFINED BY THE ATOMIC ENERGY
ACT OF 1946. IT IS TRANSMITTED OR THE
DISCLOSURE OF ITS CONTENTS IN ANY
MANNER TO AN UNAUTHORIZED PERSON
IS PROHIBITED.

THIS MATERIAL CONTAINS INFORMATION
AFFECTING THE NATIONAL DEFENSE OF
THE UNITED STATES, WITHIN THE MEAN-
ING OF THE ESPIONAGE LAWS, TITLE 18,
U. S. C., SECS. 793 AND 794, THE TRANS-
MISSION OR REVELATION OF WHICH IN ANY
MANNER TO AN UNAUTHORIZED PERSON IS
PROHIBITED BY LAW.

ROUTE TO	READ BY	DATE	ROUTE TO	READ BY	DATE
GM Muller	314	9/14/51			
N. Koblach	13059	326			
C. L. Brown	525	326 JUL 2 1953			
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED					

DECLASSIFIED

MASTER

DISTRIBUTION

C: 1. AD Callihan, ORNL

INTERNAL

C: 2. TW Hauff
3. VR Cooper
4. OF Hill
5. FW Woodfield
6. AG Blasewitz
7. AE Smith
8. RE Tomlinson
9. RJ Sloat
10. ER Irish
11. HG Johnson
12. WB Webster
13. FA Hollenbeck
14. PF Gast
15. OH Greager
16. RH Beaton
17. WK Woods
18. WH Mobley
19. J Ozeroff
20. GM Muller
21. DD Lanning
22. EF Kurtz
23-26. GR Graham
27. JE Faulkner
28-30. Extra
31. 300 Files
32. 700 Files
33. Yellow Copy

CLASSIFICATION CANCELLED AND CHANGED TO
DECLASSIFIED

BY AUTHORITY OF RM Iken
CG-PR-2 5-13-92
BY DA Bink 8-15-92
VERIFIED BY J.V. Wells 8-15-92

NOT UCNI

MASTER

WARNING - PRELIMINARY REPORT

THIS REPORT CONTAINS INFORMATION OF
A PRELIMINARY NATURE AND IS PREPARED
PRIMARILY FOR THE USE OF PERSONNEL WORKS
TECHNICAL SECTION PERSONNEL. THIS RE-
PORT IS SUBJECT TO REVISION ON FURTHER
CHECKING OR COLLECTION OF ADDITIONAL DATA.

DECLASSIFIED

CRITICAL MASS INFORMATION APPLIED TO PUREX AND RECUPLEX DESIGNI. Introduction

Some time ago, a series of experiments (the P-11 project) were conducted to determine the critical mass of plutonium in variously sized and shaped vessels and with various solution concentrations. These experiments were rather general in nature, hence, it is necessary to interpret the data to the specific critical mass problems of interest in separation processes. The design of new continuous flow separation processes calls for even further extrapolations of these data to vessel geometries far from the range of present experimental knowledge. The purpose of this report is to review for reference the estimates used in the design of the critically safe portions of Purex and Recuplex. This report is compiled for engineering use in approximate design; however, any design of vessels involving criticality hazards will be reviewed by the Critical Mass Group.

II. Cylinders

Extrapolations of presently known critical mass data for plutonium solutions have been made to find the "always safe" cylinders. Such cylinders can not be made critical with an effectively infinite solution height and a very large concentration of plutonium. The inside diameter of these cylinders will depend upon (1) the MWD/T of Pu used, (2) the hydrogen concentration of the solution, (3) the macroscopic absorption cross section of the solution (4) the thickness of neutron reflectors such as water or stainless steel which surround the cylinder. For the critical mass considerations at Hanford, a conservative MWD/T of ~ 400 (2.95% Pu²⁴⁰) has been assumed, and since solution concentrations cannot always be known, the hydrogen concentration and macroscopic absorption cross section have been taken to be nearly that of water. Thus to apply the information in this report, the plutonium must be 400 MWD/T or greater and no moderators better than water can be present in the solution or the reflector. Then if the cylinder can be considered to be completely water reflected, the extrapolation indicates an inside diameter of 5.7 inches as the "always safe" cylinder.

At Hanford, some of the safe cylinders to be used in processes such as Purex and Recuplex need to be as large as possible. Design considerations for these plants have been made on the basis of unreflected cylinders. However, completely unreflected cylinders are impossible since the cylinder must have walls, piping and some means of support. The effect of the cylinder walls and surrounding steel objects can be seen from Figure 1 which shows a plot of the "always safe" cylinder diameter as a function of the thickness of a stainless steel wall surrounding the cylinder. This plot is based on some experiments with U²³⁵ solutions at Oak Ridge reported in K-643 and has been converted approximately to plutonium as explained in Section VIII.

DECLASSIFIED

FIGURE 1

SECRET

III. Interaction

The reduction in critical mass of a single cylinder due to neutron interaction between two critical cylinders has been studied experimentally for U^{235} solutions as reported in K-406. This report shows that when two cylinders, with effectively infinite water reflection, are separated from edge to edge by 12 inches or more, the neutron interaction is small enough to be negligible in most cases. If the cylinders are not surrounded by water, the unreflected case, interaction is somewhat more complicated since there is very little absorption of neutrons between the cylinders. Thus, the interaction distances become greater. The interaction data have been studied by G. M. Muller as reported in HW-26864, where he shows that at a distance of 18 inches the interaction between two unreflected 8" cylinders decreases the critical diameter of these cylinders by about 3.7%. Since interaction will take place with all Pu bearing vessels around a particular cylinder, a minimum of 2 feet from edge to edge has been required between safe vessels for design of Purex. The interaction distance for neutron reflection of supports, walls and other objects near Pu bearing vessels is assumed to be the same as the unreflected cylinder interaction.

IV. Piping Attached to Critically Safe Cylinders

Any piping which is to be used around the safe cylinders will have the interaction effects mentioned above. Hence, such pipes cannot come directly into the side of the maximum-sized always safe cylinder. The effect of piping around critical cylinders has not been investigated experimentally. Thus a reasonable but conservative method of changing the effect of the piping into something which can be compared with experiment must be used. Following a procedure suggested by C. L. Schuske in Document Y-853, the critically safe design for the size of cylinders which can be joined is calculated as shown in Figures 1a, 1b and 1c, provided that each cylinder is always subcritical by itself.

Figure 1a

Figure 1b

Figure 1c

Consider two pipes, whose outside diameters are D_1 and D_2 , that are joined at some angle ($\theta \leq 90^\circ$) as shown in Figure 1a. It can be assumed that the interaction between these two pipes will be no greater than the interaction between the same two pipes in contact edge to edge as shown in Figure 1b. Since it has also been assumed that 24" is the limit of effective interaction around "always safe" cylinders, then the length of joining pipe interacting with this cylinder becomes $24" \csc \theta$. If D_1 and D_2 are always subcritical cylinder diameters, then the cylinders in contact can be conservatively treated as a single pipe whose cross sectional area over the range of interaction is increased to the sum of the cross sectional areas of the two pipes as shown in Figure 1c, where $D_3 = \sqrt{D_1^2 + D_2^2}$. The design is considered critically safe when D_3 is an always safe diameter.

This means that any maximum-sized "always safe" cylinder (D_3) must have its outside diameter reduced to D_1 for a distance of $(24 \csc \theta)$ inches before a pipe of outside diameter D_2 joins the cylinder at an angle θ .

V. Structural Supports

The effect of near supports, walls and other such objects has also not been investigated experimentally.

Until better information is available, conservative estimates of the reflection effect from these objects must be made for design purposes. Assuming that no reflectors better than water or stainless steel are present, one method of calculating the reflection effect is as follows:

Consider a plane perpendicular to the axis of a very long cylinder with a support parallel to the axis of the cylinder and running the length of the cylinder, as shown above. Let x be the thickness of the support whose surface (s) faces the cylinder. The effect of the support can be thought to be the same as some thickness (t_e) of reflector surrounding the cylinder, and this thickness is found conservatively from:

$$2 \pi \gamma t_e = Sx$$

hence

$$t_e = \sum_{i=1}^n \frac{S_i X_i}{2 \pi \gamma_i}$$

where n is the number of such objects within 2 feet of the edge of the cylinder.

Also consider a support in the form of a rod or bar approaching the cylinder at an angle θ . The reflection effect of such an object is regarded to be the same as piping which has already been explained except that now the cross sectional area of the bar is added to the outside of the cylinder increasing (t_e). If there are M such bars approaching the cylinder in a region 2 feet above and below the plane considered in the diagram, then the effective thickness, t_e , in this plane becomes:

$$t_e = \sqrt{\frac{D_o^2 + \sum_{j=1}^M D_j^2}{2}} - D_o + \sum_{i=1}^n \frac{S_i X_i}{2 \pi \gamma_i}$$

with D_j is the outside diameter of the supporting bar and D_o the outside diameter of the cylinder.

The total thickness of reflector surrounding the cylinder is the wall thickness plus t_e , or $t = t_w + t_e$. This value of t from the graph in Figure 1 will give the inside diameter of the always critically safe cylinder for the particular design. It should be noted that t_e involves the cylinder diameter so that the calculation for the maximum safe cylinder in this design involves some trial and error, however, the effect of supports will in general be small so that the cylinder diameter can be chosen and the above method used as a check on the critically safe design of the support for the cylinder.

VI. Slabs

In the Purex process, it is desirable to have some vessels of considerable volume at the end of certain columns. These vessels have to be always critically safe and the use of large slabs seems reasonable. This involves extrapolation of the critical mass data to find the cylinder height which cannot be made critical for an infinite cylinder diameter and a very large concentration of plutonium. All of the considerations mentioned for the safe cylinder apply in general also for the safe slab. Figure 2 is a plot of the always safe inside height of the infinite slab as a function of reflector thickness on either side of the slab.

FIGURE 2

VII. Critical Concentrations

In certain processes, the necessity for vessels larger than the "always safe" vessels has arisen. This creates the problem of how to keep such vessels critically safe in a continuous flow process where batch size limiting is difficult. One possible method of doing this is to limit the maximum possible concentration of plutonium in the tank. Some insight into this method may be seen from Figure 3. This is a plot of the critical concentration versus the inside radius for two infinitely high cylinders, one cylinder is surrounded by an effectively infinite water reflector and the other is a bare cylinder with a 1/4" stainless steel wall. The diameter at which the critical concentration becomes infinite is the always safe inside diameter for the particular cylinder and any similar cylinder with a smaller diameter will always be subcritical. For diameters larger than the always safe diameter, if the Pu concentration is above the line on the graph, the cylinder will be super-critical, and if the Pu concentration is below the line, the cylinder is critically safe, or subcritical. As is shown on the graph, the critical concentration for these infinite cylinders falls rapidly to the asymptotic value as the diameter is increased. This asymptotic concentration is about 8 grams per liter and for concentrations of 400 MWD/T plutonium in water below this, any vessel will be subcritical no matter what its size.

VIII. Method of Extrapolation

The critical mass data for these estimations are reported in HW-24514, however, these particular problems are far from the range of geometries and solutions actually used in the experiments. In order to make these extrapolations, an empirical formula has been found which fits the experimental data for the various geometries and solutions used. This formula involves the use of the geometric buckling (B) calculated from the vessel shape with an extrapolation length (L) which depends upon the reflector thickness. Since the actual value of the extrapolation length has been somewhat uncertain, the constants of the empirical formula have been found for two different values of the infinite water reflector extrapolation length. These two equations are discussed in HW-25374 where it is shown that both equations will fit the experimental data within the experimental error, however, outside of the range of experiments in the direction of particular interest, one equation predicts somewhat lower values of the critical mass of cylinders and smaller diameters of the "always safe" cylinders. This is the equation used for these extrapolations and for solutions of 400 MWD/T plutonium in water, it can be written as :

$$\text{Critical Mass (in grams)} = \frac{7.667V}{14.127B + 0.51272} - 1.02434$$

with (V) as the volume in liters and (B) the geometric buckling of the vessel in cm^{-2} .

The extrapolation lengths used for various thicknesses of stainless steel and water reflectors are based on experiments made at Oak Ridge as reported in Document K-643, where for a fuel of a given material buckling, different amounts of lateral reflector thicknesses were used and critical height (H_x), of the right cylinders, was measured. Thus assuming a value of the extrapolation length with no reflector (ℓ_0), ℓ_x is found approximately by the formula:

$$\ell_x = \frac{2.4048}{\sqrt{B_0 - B_{H_x}}} - R$$

where R is the radius of the cylinder, B_0 is the buckling with no reflector and $B_{H_x} = \left(\frac{\pi}{H_x + 2\ell_0} \right)^2$

Figure 4 is a plot of the results where $\ell_0 = 2.68$ cm, which gives for the effectively infinite water reflector $\ell = 6.1$ cm. The value of ℓ_0 is used in order to make ℓ_x at 0.05 inches of stainless steel be 2.84 cm, a value predicted by the 16" bare stainless steel sphere data reported in HW-24514, using the conservative formula made with $\ell = 6.0$ cm for an infinite water reflector around a stainless steel sphere.

The "always safe" vessels are then estimated by calculating from the empirical formula the buckling which takes an infinite critical concentration. Using this buckling as the geometric buckling, the inside dimension of the "always safe" vessel can be found as a function of the reflector thickness around the vessel by taking extrapolation lengths from Figure 4.

Some of the material discussed in this paper has been collected in cooperation with W. J. Ozeroff and G. M. Muller.

References:

- HW-26864 - "Technical Activities Report, Physics Research", by J. E. Faulkner, D. E. Davenport and G. E. Duvall, December, 1952.
- K-406 - "Critical Mass Studies, Part IV", by D. Callihan, D.F. Cronin, J.K. Fox, R.L. Macklin, J.W. Morfitt, November 28, 1949.
- K-643 - "Critical Mass Studies, Part V", by D. Callihan, D.F. Cronin, J.K. Fox, J.W. Morfitt, June 30, 1950.
- Y-853 - "Application of Criticality Information to Y-12 Plant Problems" by C.L. Schuske, March 11, 1952.
- HW-24514 - "Critical Mass Studies of Plutonium Solutions", by F.E. Kruesi, J.O. Erkman, D.D. Lanning, May 19, 1952.
- HW-25374 - "Critical Mass Study of 231 Process Tanks" by D.D. Lanning, August 19, 1952.

David D. Lanning
 PHYSICS UNIT
 APPLIED RESEARCH SUB-SECTION

DD Lanning:as