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Neutron Prompt Burst Assembly Proposal

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NEUTRON PROMPT BURST ASSEMBLY PROPOSAL

Chronology: The development of new techniques of initiating nuclear weapons has amplified the requirement for an accurate knowledge of the probability of initiation as a function of the various parameters involved. The results of the codes presently used to calculate these probabilities are self-consistent, but have been shown to be quite sensitive to the value of fission cross section used. Accordingly the critical assemblies group was requested informally by small weapons division to investigate the feasibility of providing a prompt critical assembly which could give an experimental basis for normalization of the code results. A study of the various assemblies which met the requirements of this experiment was therefore conducted to determine which was best suited. The conclusion of the study is that a bare spherical oralloy assembly similar in operation to that of the Los Alamos Godiva would be the most suitable device with which to make these measurements. This conclusion was based on the fact that the prompt critical behavior of such a bare oralloy sphere is well understood and further, this behavior can be calculated by means of the present weapons codes. Such an assembly could be in operation in less than six months and would require an estimated total expenditure of $70,000 exclusive of the oralloy components. Safety of operation could be insured by proper design of components, interlocks and operating procedures. The proposed assembly would be housed in the West Vault in Building 110 which can be made available in the near future. Much of the present instrumentation in the vault can be used for the new assembly. Some modification to the vault will be necessitated by the higher shielding requirements of the prompt assembly. Cost of these modifications is included in the basic cost estimate.

Experimental Requirements: Given the e-folding rate, α, for an arbitrary weapon assembly as a function of time, it is believed that the probability of a delay of g or more generations in initiating an infinite chain by a steady source is equal to:

$$e^{-asg}$$

when s = steady source strength
$g = \int \alpha dt$
a = constant of the system

Since the yield of a fission bomb is directly related to the α at initiation (or more properly, explosion) time, it is essential that the variation of initiation time be bounded within reasonable limits. The purpose of the experiment is therefore to obtain a value of the constant a in the expression above. The requirements for the experiment are:

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1. An accurate knowledge of the α-time history and a measurement of g.

2. The prompt α of the assembly must be high enough to give some measure of confidence in the constancy of "a" when the results are extrapolated to weapon α's.

3. To provide a normalization, the results of the prompt assembly must be amenable to calculation by the same codes used to predict weapon behavior.

Prompt Burst Assembly Feasibility Study: Various methods of attaining a controlled prompt critical configuration were investigated. Each method was then analyzed with respect to the experimental requirements of the previous section. A description of the possible methods and comments concerning their applicability to the present experiment are given below. In all the methods listed a positive α is attained by the rapid introduction of fissionable material into an already near-critical assembly. After super-criticality is achieved, the system is driven sub-critical by some mechanism inherent in the particular assembly.

1. Moderated Systems: The systems investigated consisted of a homogeneous moderator-fuel mixture(i.e. $ZrH_{1.7-2}$, BeO) combined with a selected poison(i.e. Er^{167}) having a less than 1/v variation of absorption cross section. The shutdown mechanism depends on the large negative temperature coefficient due to the rise of the thermal neutron temperature (moderator) which causes the poison to be proportionately more effective. These systems were rejected for the following reasons:

   a. Calculation with weapons codes except by Monte Carlo methods not possible.

   b. Analogy to weapons not clear.

   c. Extensive development required.

   d. Prompt neutron lifetimes are 10^2 to 10^3 times those of metal systems. Thus a proportionately larger amount of reactivity would have to be added to achieve α's comparable to those of unmoderated systems.

2. Fast Neutron Systems:

   a. Rapid Disassembly, Dragon, type. In this all oralloy system, assembly to a super-critical condition is achieved by firing an oralloy projectile through an annular ring of the same material. Shutdown is effected by a combination of thermal expansion and physical disassembly as the projectile passes on through. This system was rejected for the following reasons:

[redacted]

1. Difficulties of accelerating and decelerating the projectile.

2. Lack of reproducibility of α-t curve due to variation in assembly parameters.

3. The modest increase in $\alpha_{max.}$ attainable with this system, $\sim .5\ \mu sec^{-1}$, as compared to the "Godiva" type described below is not significant enough to warrant the greater complexity of the dragon type assembly.

b. "Godiva" type. Assembly to prompt critical is achieved by rapid insertion of an oralloy control rod into a delayed critical assembly. Shutdown is achieved by thermal expansion to a below prompt critical configuration. This system appears to be the most desirable for the initiation experiment:

1. Simple geometry is possible.

2. Theory of operation is well understood.

3. Results of Los Alamos experience with Godiva I and II are available.

4. Engineering and design expenditures in time and dollars are less than for the other assemblies investigated.

CHARACTERISTICS OF THE PROPOSED ORALLOY ASSEMBLY

1. Description: The design criteria for the assembly is to achieve a final prompt critical configuration as nearly spherical as possible. A perfect sphere will not be possible since it is desirable that additional rod reactivity still be available for all foreseeable situations to permit flexibility as well as to allow for small uncertainties in critical mass calculation. Crevices and holes will be kept to a minimum and will be located near the outside of the sphere if possible. Two 3/4" control rods are planned. Each of these would have a reactivity worth about $1.70 - 2.00; i.e. 1.2 - 1.4%. A third oralloy rod ~1" in diameter would be used to produce prompt bursts. The spherical portion of the assembly would be machined in three approximately equal slices and held together with oralloy bolts. A large oralloy plug of approximately 10 kg mass completes the sphere when inserted from below. This large plug is used as a safety block and is the major component in the scram system. A horizontal axial hole of 5/8" diameter extends through the sphere. For the initiation experiments, this tube will be used to position the neutron source. The remaining volume will be filled with oralloy plugs. It is proposed that a skull cap of oralloy be fabricated to compensate for the reactivity loss when the tube is used as a sample transfer tube and is essentially empty during later experiments. A sketch of the oralloy assembly is shown in Figure 1.

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The outer spherical surface of the oralloy components is to be plated with 5 mils of cadmium to reduce the effects due to room return and to lessen the effects of hydrogeneous materials placed near the assembly for irradiations. All exposed surfaces are to be nickel plated to reduce the possibility of surface oxidation and subsequent contamination.

2. Operation: With all control rods and the safety block fully withdrawn, the burst rod is adjusted to yield the desired α for the subsequent prompt burst. The burst rod setting is calibrated so that full insertion from its preset position will cause an increase in reactivity from delayed critical to approx. 5 - 8 cents above prompt critical ($1 = reactivity increase from delayed to prompt critical). After the burst rod has been adjusted and with the control rods fully withdrawn, the safety block is inserted. The control rods are then adjusted to delayed critical. After this adjustment, the safety block is lowered to allow the neutron population to decay and the assembly to cool. After a period of 10 - 15 minutes the safety block is reinserted and the burst rod is fired into the assembly. A neutron burst with an essentially pure exponential rise develops and is self terminated by thermal expansion of the assembly. Typical neutron bursts are approximately 80 μseconds wide at half maximum amplitude. Peak fission rate attained is about 10^{20} fissions per second. The scram circuit is energized by a radiation level detector during the exponential rise; however, no physical movement occurs until after the maximum fission rate has been achieved. Although below prompt critical, a residual power level persists due to delayed neutron activity. Since this power level results in a temperature rise of $\sim 100^{\circ}C$ per second, fast scram is desirable.

3. Applicability to the Initiation Experiment: It is anticipated that burst rod insertion can be accomplished in less than 5 milliseconds. Since only the final 10% of the ~1" of travel is in the positive α range, an α-t curve similar to that shown in Figure 2 should be possible. The following measurements pertinent to the initiation experiments may be made during an excursion. Time is measured from $t = 0$ at $\alpha = 0$.

   a. Burst rod position as a function of time.

   b. Initial α of the assembly.

   c. Fission rate as a function of time.

   d. Fission yield during the excursion.

These measurements can be used to determine the variation in time of some fiducial point such as maximum fission rate ($\alpha = 0$). Knowing the variation of α with time and the fission yield to this point the time of initiation may be inferred assuming negligible initial power. Repetition of the experiment should yield the statistical variation of initiation time and provide the needed normalization. The assembly could be used for other experiments pertinent to initiation probability wherein the strength and position of the steady source might be varied or a short pulsed source might be used to study the fluctuation in the build-up of individual chains.

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HAZARDS ANALYSIS OF THE PROPOSED ASSEMBLY

1. General: Only the safety aspects peculiar to the proposed assembly are considered in this analysis. Such problems as security, fire prevention and effects of terrain and weather are identical in all respects to those associated with the critical assembly work normally carried on in Building 110. A more detailed and rigorous hazard report will be submitted prior to any actual assemblies.

2. Safety During Normal Operation

   a. Maximum Energy Release: It is essential that energy release during normal excursions be restricted to some practical limit. This limit is set by the stipulation that during normal operation we will not allow any oxidation, bending or melting of the oralloy components. Shielding and containment requirements are then based on this value.

   The characteristics associated with the self-disassembly of a bare oralloy assembly which is undergoing a constant rate of addition of reactivity have been studied. This study indicates that for an assembly rate of \$100 per second, the temperature at the center of the sphere will not exceed ~210°C and the subsequent tension at the surface of the sphere will not exceed ~4100 atmospheres during the disassembly pulse. The tensile strength of uranium is ~5000 atmospheres. Since 210°C is well below the melting point of the oralloy, \$100/second is set as the upper limit for assembly rates of highly reactive components.

   Since the control rods will necessarily be moved slowly to provide adequate control sensitivity, the safety block is the only component for which this limit must be examined in detail. The reactivity worth of oralloy at the center of the assembly is \$1.40 per gram atom. Movement of the safety block at a final velocity of 7.5 in/sec. would result in a final assembly rate of less than \$100/sec. The actual assembly rate will be considerably less than this value.

   The response of an oralloy assembly to step inputs of reactivity has also been studied. Maximum fission rate, reciprocal period, burst yield and central temperature rise are shown in Figures 3 - 6 as a function of step input of reactivity. Initial excess reactivities of ~\$.15 above prompt critical will result in rupture of the oralloy assembly. This input corresponds to fission yield of about 4×10^{16}. One accidentally intense burst at Los Alamos resulted in 6×10^{16} fissions and did cause rupture of the assembly.

   Since the burst rod is the only component that may be added, effectively, as a step input, the maximum amount of reactivity to be added in this manner will be restricted to less than \$.10 above prompt critical. This amount of initial reactivity will result in a fission burst of ~2×10^{16} fissions, central core temperature rise of ~ 120°C and a subsequent parting pressure of less than 1800 atmospheres.

The entire assembly is to be viewed through an observation window during assembly to ensure that no changes in the experimental set up occur during remote operation. The 1.2 x 10^{17} burst which forced the retirement of Godiva I is attributed to a small furnace falling to rest against the assembly after the assembly area had been vacated. In view of the Los Alamos experience, special precautions will be taken to preclude the possibility of accidental changes in tamping caused by loose apparatus in the vicinity of the assembly.

b. Interlock Sequence: The sequence of events preceeding a prompt critical burst can be arranged to prevent inadvertent or unsafe assembly procedures. The proposed sequence of events is given below:

BR = Burst Rod
Cl_1, CR_2 = Control Rods
SB = Safety Block
Source = External neutron source if no source is already present for the experiment.

1. Reset interlocks, (radiation monitors, scram power (air) and scram circuit must be on)

2. Introduce source (source must be at "IN" limit before any components may be moved in)(BR inoperative)

3. Raise SB (CR, CR_2 and BR must be at "OUT" limit)

4. Run CR_1 in (CR_2 inoperative until CR_1at "IN" limit)

5. Run in CR_2 and adjust for delayed critical.

6. Drop SB for delayed neutron cool off (CR_2 cannot be moved)
   (CR_1 can be adjusted for temp. correction)
   (BR circuit is now reset, but cannot be activated)

7. Remove source(CR_1 and CR_2 cannot be moved)

8. Raise SB (BR circuit now fully armed)

9. Insert safety key and fire (Monitor operated fast scram retracts SB and BR after burst)

10. Activate auto run out circuit to retract CR_1 and CR_2.

c. Shielding: Modification to the West Vault to accommodate the proposed assembly would consist primarily of replacement of the timbered roof with 2 feet of concrete. Empirical data from the Bulk Shielding Facility indicates that the attenuation factor of the water window provides adequate shielding. Calculated values of the attenuation factor indicate that shielding is marginal; however, the calculation may be unnecessarily pessimistic in view of the assumptions used. It is planned to measure the attenuation of the window with the assembly at low power. Should additional shielding be required, it can be easily added by using a more dense viewing liquid or by adding leaded glass on the side of the window.

The measured dose at one meter from a 2×10^{16} fission burst at the Los Alamos Godiva is approximately 60 rads from gammas plus 740 rads from fast neutrons. The calculated dose received at the exterior of the assembly vault would be:

surface of 6' water window	- $\sim$ 0 (neutrons)
	.3 mr (fission γ)
surface of 5' concrete wall	4 mrem (neutrons)
	.3 mr (fission γ)

air scattered radiation - receiver
2.5 feet from the exterior wall
at the same height as the assembly - 75 mrem (neutrons)
- 5 mr (fission γ)

3. Maximum Credible Accident

a. Magnitude: It is difficult to envision the mechanism or series of events which would give rise to a damaging burst. This section does not consider the cause of such an accident, but merely the effects arising from some reasonably large accident. Dependent on the assumptions one is willing to make, the magnitude of an accident can be made as large or as small as one desires. It seems reasonable to assume that the intense burst that severely damaged Godiva I represants a near limit on the energy release of a bare oralloy assembly. In this approximately 1.2×10^{17} fission accident, the assembly violently disassembled itself and it is estimated that the center of the sphere was only 50° short of the melting point. For the purpose of determing the damage resulting from some maximum credible accident, assume an accident of 2.4×10^{17} fissions, twice the size of the Godiva I accident. Such an accident would result from a step input of reactivity of ~27 cents above prompt critical. The initial value of α for this case would be $\sim .29\ \mu sec^{-1}$.

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b. Contamination: The energy released during a 2.4×10^{17} fission excursion corresponds to that released by 3.25 lbs. of high explosives. Calculations, in agreement with available experimental data, predict that only 3% of this total fission energy would occur as kinetic energy. Thus the blast from such an accident would be roughly equivalent to that from ~.1 lb. of high explosive. The temperature of the central region of the assembly would exceed the melting point and the oralloy components would be ruptured. Considerable contamination would be expected. The contamination from the Godiva accident was estimated to correspond to ~ 10 grams of fine oxide.

The walls, roof and water window could contain a blast of this magnitude; however, it is likely that the air filters for the air exhaust system would be blown out. It may be desirable to close the air exhausts ducts during the short periods required for assembly.

It is conceivable that the vault side of the water window could be pierced by shrapnel of some sort. It is highly improbable that the control room side of the window would be broken.

In view of the above, it appears that most of the initial blast and all of the initial radioactive contaminants could be contained within the assembly vault.

c. Radiation Exposure: Applying the attenuation factors previously used to a 2.4×10^{17} fission accident:

Dose at surface of water window	3.6 mr.
Dose at surface of concrete wall	52 mr.
Max. air scattered radiation at assembly height	.85 r.

Should the water window shielding effects be lost, the control room would be exposed to quite a high radiation flux. A radiation level of ~ 1000 r per hour persists at a distance of 1 meter from the Los Alamos Godiva for greater than a minute after a normal excursion. Radiation levels at the control room window could reach the 1000 r per hour level in the event of such an accident.

SUPPORT REQUIREMENTS

1. Manpower: Design, installation and operation of the proposed assembly, in support of small weapons division, could be accomplished by personnel presently assigned.

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[redacted] [redacted]

2. Money: The present best estimate of the cost of installing such an assembly is $70,000. This includes construction of the assembly machine, interlocks, instrumentation and modification to the assembly vault.

3. Oralloy: Approximately 60 kilograms of normal enrichment oralloy would be required.

/khs

Distribution:

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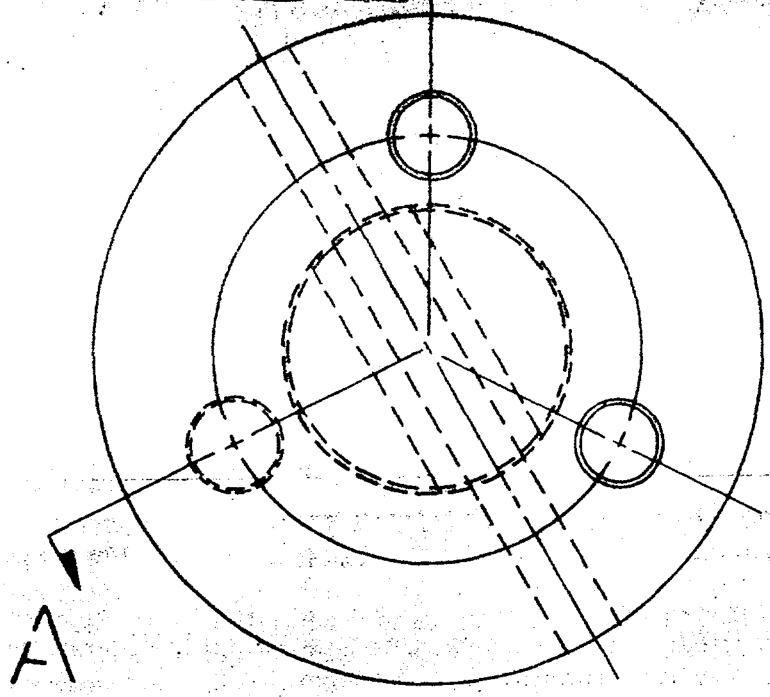

PROMPT BURST ASSEMBLY
1/2" = 1"

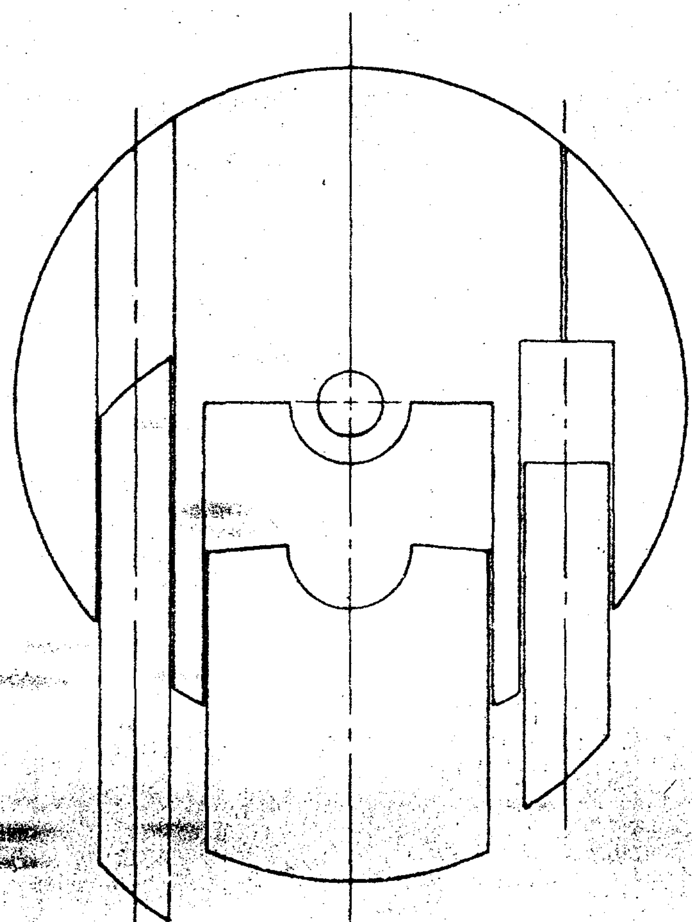

FIGURE I.

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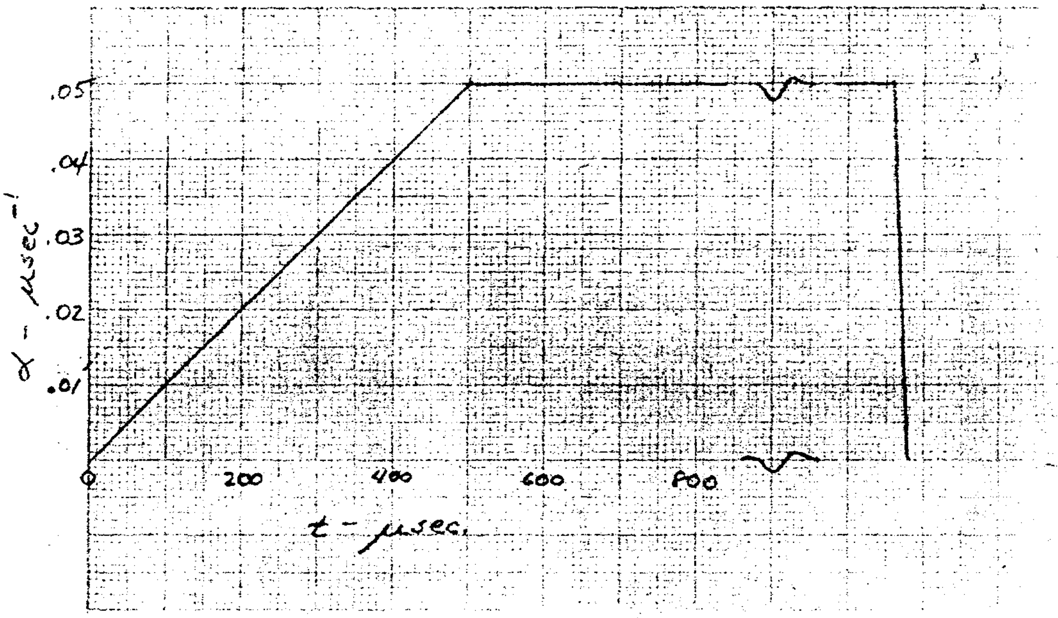

FIGURE 2.

IDEALIZED α VERSUS t HISTORY
PROMPT BURST ASSEMBLY

[redacted]

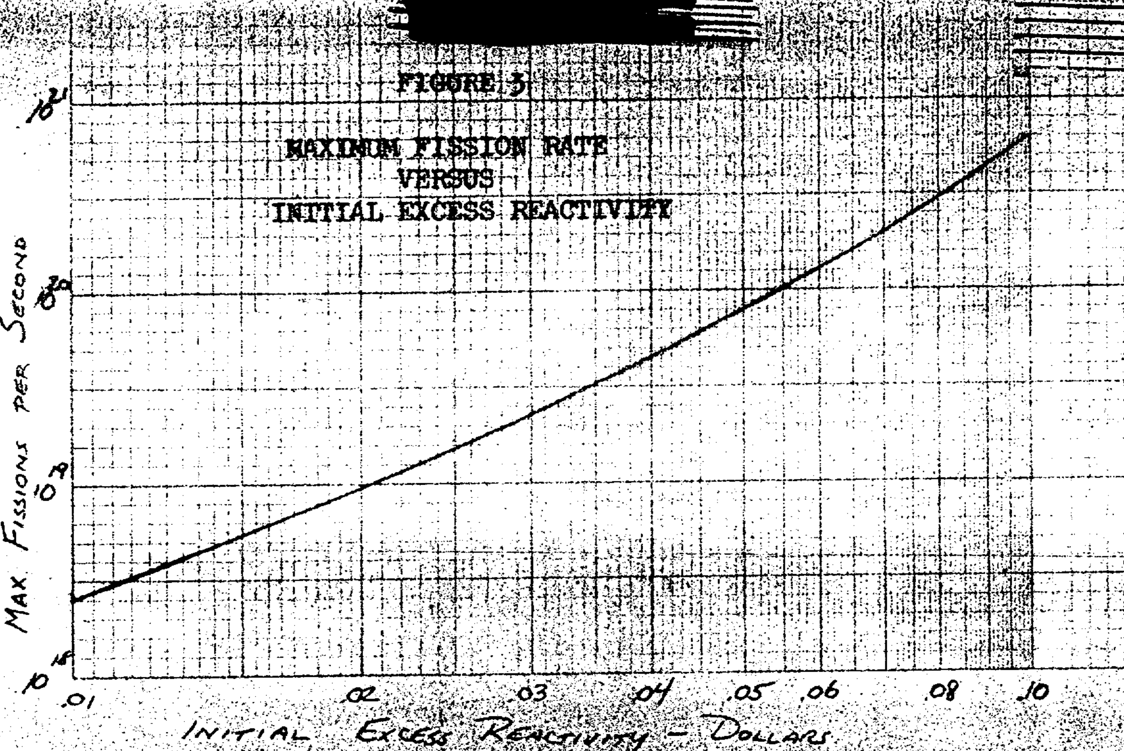

FIGURE 3

MAXIMUM FISSION RATE
VERSUS
INITIAL EXCESS REACTIVITY

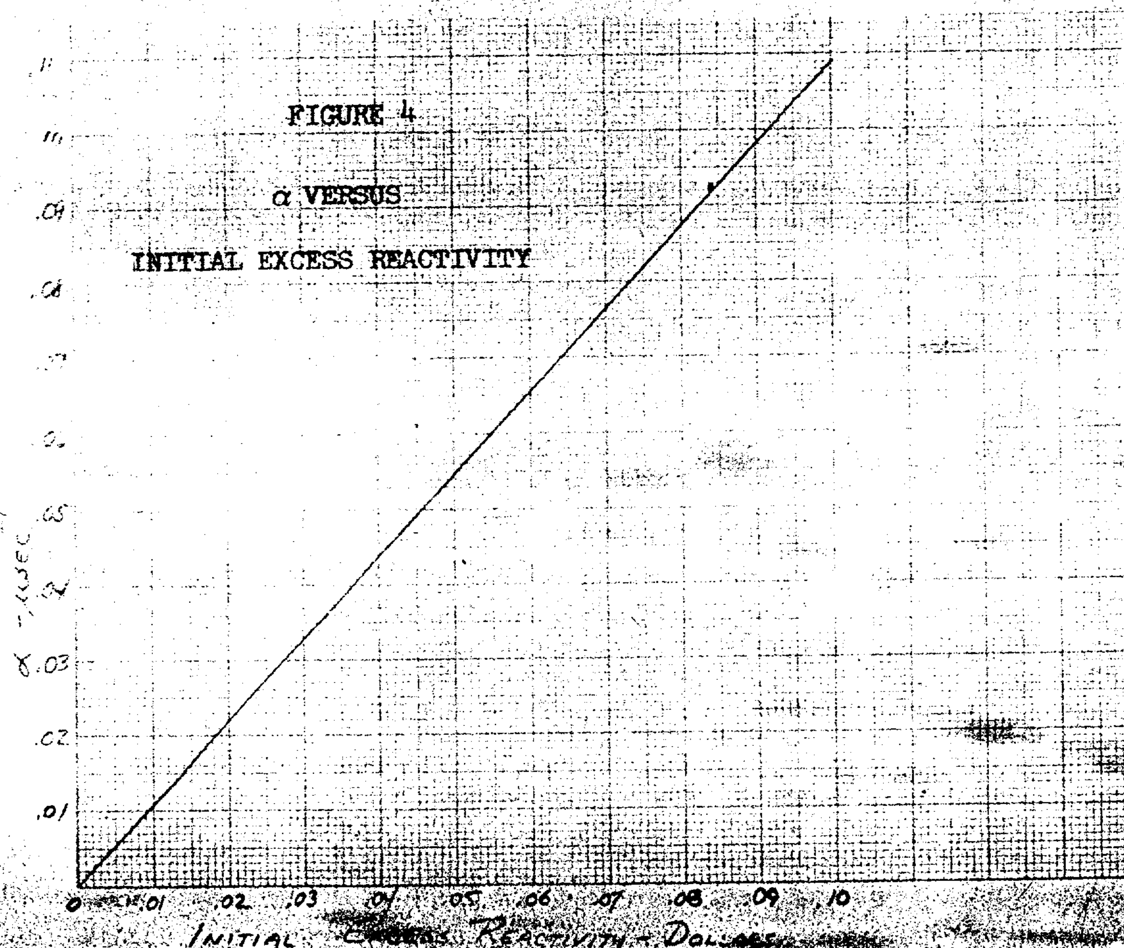

FIGURE 4

α VERSUS

INITIAL EXCESS REACTIVITY

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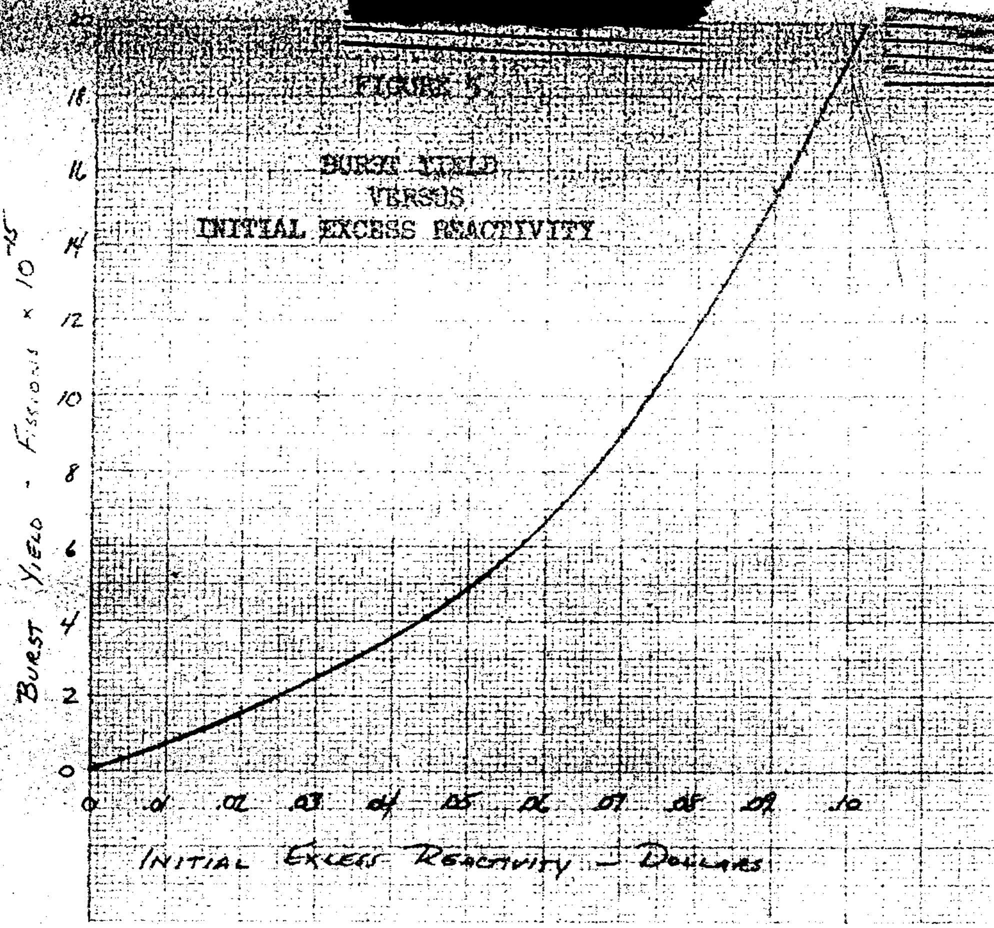
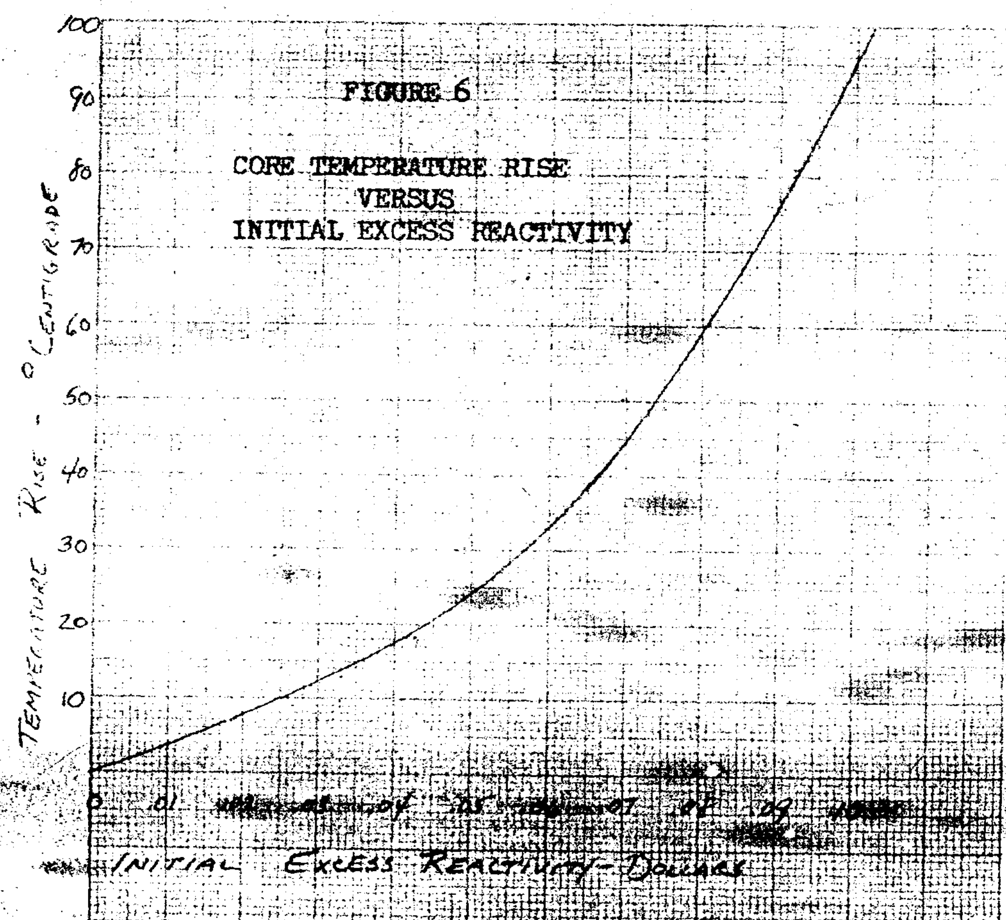
[redacted]





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