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Measurement of the Critical Size of Solutions of Plutonium and Natural Uranium Nitrates with Pu/U = 0.3

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AWRE, Aldermaston

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CONTENTS

1. INTRODUCTION

This report describes part of an experimental investigation, carried out while AWRE were part of the UKAEA, of the critical size and other reactivity parameters of mixtures of plutonium and natural uranium having a plutonium content of $\sim$ 30%. Measurements of the critical size, neutron spectrum and prompt decay constant of a mixture of PuO_2 and UO_2 at a density of 1 g (Pu)/litre, moderated by polythene to give H/Pu = 18.6 have been reported [1,2]. The present work extends the critical size measurements to essentially thermal cores which are more conveniently studied using solutions of the fissile isotopes in nitric acid.

Four concentrations of fissile solution were used. The highest (330 g (Pu + U/litre) was chosen as being close to maximum at which accidental precipitation would not occur under any reasonable conditions [3]. The second (32 g (Pu)/litre) is close to that for minimum mass, and the concentrations of the two remaining solutions (18.6 and 17.5 g (Pu)/litre respectively) were chosen as being close to that which could be made critical with the total available stored volume.

2. GENERAL DESCRIPTION OF THE SCAMP RIG

SCAMP (Solution Criticality Assembly Machine - Plutonium), shown diagrammatically in figure 1, consists essentially of a means of remotely filling a cylindrical core vessel with fissile solution under controlled conditions, with facilities for rapid dump of the solution in case of an unexpected reactivity increase. The core vessel is reflected with effectively infinite water, the removal of which provides a secondary reactivity shut-down mechanism.

This apparatus, together with the necessary storage vessels, pumps and other ancillary equipment, is mounted within two inter-connecting glove boxes. These are constructed from fibre glass panels moulded to steel frames. A general view of the rig in an advanced stage of construction is shown in figure 2.

2.1 Upper glove box

The upper box houses the core and reflector vessels and top reflector plugs. It is provided with a 600 mm diameter bag-port to enable core vessels to be removed from the box, a light electric hoist, and a traversable gantry used to suspend the top reflector above the core. Both the core and reflector vessels are fitted with sight glasses to enable solution and water heights to be read by a remotely controlled television link.

2.2 Core and reflector vessels

Core vessels of diameters 254, 306, 380 and 507 mm were used, the first three being 1070 mm high and the last vessel 915 mm high. They are constructed from stainless steel of wall thickness 2 mm for the smallest vessel and 2.5 mm for the remainder. All have a base flange approximately 10 mm thick with a 100 mm diameter hole made to suit the core dump valve. Steel cylindrical shells, 2.5 mm thick, may be clamped to any vessel to estimate the effect of the vessel walls on critical size.

The core vessel is bolted to a rigid mounting plate carried on a web from the bottom of the reflector tank, as shown in figure 3. It has double O ring seals to ensure that the fissile solution and reflector water are isolated. The annular gap between the seals is monitored by a pneumatic pressure sensor which initiates a trip signal to dump fissile solution and reflector water should either seal leak.

The water reflector vessel has an internal diameter of 840 mm. It is assembled from aluminium alloy ring sections to facilitate changing the core vessel. It is bolted to a fixed stainless steel base section which supports the core vessel and provides a 150 mm water reflector below the core.

2.3 Top reflector plugs

Each core vessel is supplied with a 150 mm thick polythene plug to provide an effectively infinite hydrogenous reflector on the top face of the core. Each plug has a 3.17 mm stainless steel plate on its lower face and is supported from above by two independent chains connected to a motor driven sprocket which, when operated under remote control, drives the plug in an upward direction only. The sprocket drive can be overridden manually to allow the plug to be lowered to the starting position when the core vessel is empty. The sprocket drive is counterweighted to ensure that under fault conditions, the plug will always move upwards.

In addition, the 380 mm diameter core vessel has a mock up of the dump valve mechanism in steel and polythene to estimate the effect of this on the critical height, and a water filled stainless steel tank 150 mm in height to help estimate the difference in reflector saving of polythene and water. This plug has facilities for doubling the thickness of its steel base.

A 2 mm wide annular gap between the plug and the core vessel is provided to admit air to the core vessel when fissile material is dumped. PTFE buttons are fitted to the plugs to reduce the maximum tilt to ± 1 mm.

Each plug is fitted with two conductivity probes, one of which is used to indicate that the bottom face of the plug has been wetted by the fissile material, and the other to measure the "dumping" time of 10 mm of fissile solution as a check on the operation of the dump valve mechanism.

2.4 Lower glove box

The lower glove box houses storage tanks for fissile solution and reflector water, pumps and other equipment.

The fissile solution is stored in two 50 litre slab tanks separated by 200 mm of polythene. Each tank is 63 mm thick surrounded by a 0.6 mm thick cadmium sheet.

An orbital lobe mixing pump recirculates the whole contents of both slab tanks 5 times per hour.

A Watson-Marlow peristaltic flow inducer is used to pump the fissile solution to the core vessel. This type of pump has a rotor carrying three rollers which squeeze a PVC tube against an anvil. Pumping speeds are controlled between 6 and 54 litres/hour by a continuously variable hydraulic motor drive. Within this speed range the volume delivered was found to be proportional to the pump speed.

The reflector water storage tank has a capacity of 800 litres. The reflector vessel is filled from it by pressurising the air space above the water thus forcing the water upwards into the reflector vessel. The compressed air line is fitted with solenoid valves which enable the height of the reflector to be adjusted.

The fissile solution and reflector water circuits are shown diagrammatically in figure 4. Figure 5 shows the fissile solution and water reflector storage tanks, measuring cylinders and valves.

3. REACTIVITY SHUTDOWN MECHANISMS

There are two independent devices, each of which will remove reactivity much more rapidly than the maximum addition rate.

3.1 Fissile solution dump valve

Figure 6 shows the general arrangement of the fast-acting dump valve. The valve head is fitted with an O ring seal and is held in the closed position by compressed air acting against the compression of two springs. De-energisation of an electro-magnetic clapper valve releases air rapidly from the system and either the action of the springs or that of the hydrostatic pressure head opens the valve. The fissile solution drains through a 75 mm diameter dump line to the slab tanks. Dump rates were 9 litres/s.

The total time from operating the shut down button to opening the dump valve was found to be 350 ± 12 ms. High speed ciné film showed that a maximum acceleration of 3 g is reached during the valve stroke.

3.2 Water reflector dump valve

This consists of a venting pipe situated in the top of the water storage tank, closed by an electro-magnetic clapper valve opening under gravity. Reflector water returns to the tank at a rate of 41 litres/s. The delay time is about 18 ms.

4. HEIGHT MEASUREMENT AND CONTROL

A cursor linked by a chain system to the top reflector plug is fitted over a height scale between two sight glass tubes to show the position of the top reflector. The bracket carrying the cursor also carries three photo-electric cells and their associated lamps. One cell is fitted just above the cursor line and straddles the fissile solution sight tube. Interruption of its light beam stops the fissile liquid pump from delivering more solution. Interruption of the light beam from a second cell fitted just above the first causes the safety lines to break and the fissile solution and water dump valves to open.

A similar cell straddles the water sight tube at the same height as the top of the reflector plug. Interruption of its light beam stops the supply of water to the reflector vessel. Additionally, the fissile solution cursor indicates the position of the top reflector plug to ± 0.1 mm.

5. DETAILS OF FISSILE SOLUTION

The fissile solution for the highest concentration was obtained by mixing plutonium nitrate with natural uranium nitrate in the rig, and adding sufficient nitric acid to give a 1.5N solution. For the other solutions the mixture was diluted with nitric acid to give the required concentration and a normal solution.

The material was carefully mixed for several days after each change of concentration and was circulated between the two slab tanks for 1 hour before each experiment. Testing for uniformity of mixing was by measurement of normality, Pu/U ratio and density.

Plutonium and uranium were determined by controlled potential coulometry. The NO_3^- content was estimated by passing a sample aliquot through a column of cation exchange resin, the eluate, essentially HNO_3, being titrated with N/10 NaOH solution using methyl orange.

For solution A (the highest concentration), the data indicated an increase in density of 0.002 kg/litre during the experiment probably due to loss of water by evaporation. The remaining solutions showed no differences between samples greater than those expected from the errors of analysis.

The metals had the following isotopic composition:-

Plutonium	Pu-239	93.95% (w/w)
	Pu-240	5.63%
	Pu-241	0.42%
Uranium	U-235	0.72%
	U-238	99.28%

The remaining analytical data are reproduced in tables 1 and 2 based on the mean value and errors of all 8 samples.

6. EXPERIMENTAL METHOD

The core and reflector vessels were mounted onto the base plate and the top reflector plug suspended inside the core vessel and lowered to the bottom.

Two BF_3 proportional counters and two lithium glass scintillators were suspended inside the reflector tank with a further two BF_3 counters placed in the through tube passing below the core vessel. A third lithium glass scintillator was situated below the core and reflector vessels, just outside the box (figure 7).

TABLE 1

Analytical Data

Solution	A	B	C	D
Runs No.	5 - 15	16 - 28	35 - 43	44
H/Pu (by atoms)	224 ± 1	795 ± 2	1372 ± 5	1461 ± 6
Pu/(Pu + U)	30.7 ± 0.2	30.7 ± 0.2	30.6 ± 0.2	30.6 ± 0.2
Density (g/ml)	1.524 ± 0.001	1.184 ± 0.001	1.1185 ± 0.001	1.113 ± 0.001
Conc (mg/ml) Pu	101.3 ± 0.2	31.58 ± 0.06	18.61 ± 0.07	17.50 ± 0.08
U	228.5 ± 1	71.3 ± 0.2	42.2 ± 0.1	39.6 ± 0.1
NO_3	319 ± 3	132 ± 1	97.5 ± 1	94.7 ± 1
H_2O	857 ± 2	947 ± 2	962 ± 2	963 ± 2
Normality	1.60 ± 0.03	1.10 ± 0.07	0.95 ± 0.03	0.93 ± 0.03
N/Pu (by atoms)	12.1 ± 0.1	16.1 ± 0.2	20.2 ± 0.2	20.9 ± 0.2
Atoms per ml × 10^{20}				
Pu-239	2.396 ± 0.006	0.747 ± 0.002	0.440 ± 0.002	0.414 ± 0.002
Pu-240	0.144	0.045	0.026	0.025
Pu-241	0.011	0.0033	0.0020	0.0018
U-235	0.042	0.012	0.0076	0.0076
U-238	5.739 ± 0.02	1.791 ± 0.005	1.060 ± 0.003	0.995 ± 0.003
H	573 ± 2	633 ± 1	643 ± 1	644 ± 1
N	31.0 ± 0.3	12.8 ± 0.1	9.5 ± 0.1	9.2 ± 0.1
O	386 ± 1	362 ± 1	349 ± 1	349 ± 1
Fe	0.0002	0.00007	0.00004	0.00004

TABLE 2

Results of Spectrographic Analysis

Solution	A mg/l	B mg/l	C and D mg/l
Be	< 5	< 1	< 0.5
B	< 5	< 1	< 0.5
Mg	5	22	10
Al	40	35	40
Ca	40	< 5	10
Ti	20	5	< 5
V	< 5	< 1	< 0.5
Cr	20	8	< 5
Mn	< 5	< 1	< 1
Fe	190	68	40
Co	< 5	< 1	< 0.5
Ni	10	8	5
Cu	< 30	< 10	< 5
Ga	< 5	< 1	< 0.5
Ge	< 5	< 1	< 0.5
Mo	< 5	< 1	< 0.5
Cd	< 5	< 1	< 0.5
In	< 5	< 1	< 0.5
Sn	< 5	< 1	< 0.5
Sb	< 5	< 1	< 0.5
Au	< 5	< 1	< 0.5
Tl	< 5	< 1	< 0.5
Pb	< 5	1	< 0.5
Bi	< 5	< 1	< 0.5

The top reflector plug was raised to half the height conservatively estimated to be critical and water raised in the reflector vessel until it was level with the top of the upper reflector. Fissile solution was then pumped into the core vessel until it just made contact with the bottom of the reflector plug. The polythene reflector plug, reflector water and fissile solution were then raised in at least three further steps, the rate of injection of fuel being reduced as the end-point was approached.

At each height, the neutron count rates were fed on-line into a Ferranti ARGUS computer via Harwell type 2000 Scalers and a Teletype AR33 terminal. This arrangement was used to predict the delayed critical height, to advise the operating team on the next step and to estimate the expected neutron count rate.

The computer program used for this purpose is described in appendix B.

Figure 8 shows how the reciprocal count rate per unit volume varied with fissile liquid height during experiment 26. The figure also shows the critical heights estimated by the computer during the actual experiment.

Safety considerations limited the maximum multiplication to 100, and hence the critical height was estimated by extrapolation over the last 3% of the core height.

The form of the approach curve was found to be independent of concentration or vessel shape. Figure 9 illustrates this for five typical experiments. In plotting this figure, use was made of the technique for extrapolation (or interpolation) described in appendix B.

The core vessels could each be fitted with an extra layer of steel 2.5 mm thick to estimate the effect of the vessel walls. A partial void exists in the axial reflector in the region of the solution dump valve. Its effect was estimated (using the 380 mm diameter core vessel) by comparing the height obtained by the normal polythene top reflector plug against that obtained using a plug which simulates the solution dump valve mechanism. Correction was also made for the difference between water and polythene by the use of a water filled plug. This has an additional steel plate which could be lowered to enable the effect of the steel plate on the base of the polythene plug to be estimated.

7. EXPERIMENTAL PROGRAMME

The experiment was carried out between 11 October 1968 and 20 January 1969. An extract from the SCAMP log is given in table 3. It will be seen that several experiments required two days for their completion. On these occasions all the measurements required for extrapolation to the critical height were made in one day. Certain runs were repeated with a 10^6 n/s Po(α,n)Be chemical source in the reflector water. The increased count rate from this source markedly changed the shape of the inverse count rate curve. The results were used to check that the extrapolation to critical was unaffected by the shape of the curve.

TABLE 3

Experimental Log

Date	Run No.	Concen-tration	Core Vessel Diameter, cm	Comments
11.10.68 - 18.10.68	1 - 4	A	25.4	To check experimental procedure.
22.10.68	5	A	25.4	Core vessel thickness increased.
23.10.68	6	A	25.4	
24.10.68	7	A	30.5	
25.10.68	8	A	30.5	Core vessel thickness increased, chemical source.
25.10.68	9	A	30.5	Repeat of run 8 without chemical source.
28.10.68	10	A	38.1	
29.10.68	11	A	38.1	Core vessel thickness increased.
31.10.68	12	A	38.1	Water reflector plug, 0.317 cm steel base.
31.10.68	13	A	38.1	Water reflector plug, 0.634 cm steel base.
1.11.68	14	A	38.1	Dump valve mock up reflector plug.
4.11.68	15	A	50.8	
25.11.68	16	B	38.1	Core not completely assembled.
26.11.68	17	B	38.1	Continuation of run 16.
26.11.68	18	B	38.1	Core vessel thickness increased, core not completely assembled. Chemical source.
27.11.68	19	B	38.1	Continuation of run 18.
27.11.68	20	B	38.1	Water reflector plug, 0.317 cm steel base.
28.11.68	21	B	38.1	Water reflector plug, 0.634 cm steel base.
28.11.68	22	B	38.1	Dump valve mock up reflector plug.
2.12.68	23	B	50.8	
3.12.68	24	B	50.8	Repeat of run 23 with chemical source.
4.12.68	25	B	30.5	Core not completely assembled.
5.12.68	26	B	30.5	Continuation of run 25.
5.12.68	27	B	30.5	Repeat of run 26 with chemical source.
5.12.68	28	B	30.5	Core vessel thickness increased.
6.12.68 - 17.12.68	29 - 31	-	38.1	Intermediate concentration.
18.12.68 - 20.12.68	32 - 34	(C)	38.1	Concentration undefined (see text).
6.1.69	35	C	38.1	Core vessel thickness increased.
7.1.69	36	C	38.1	
8.1.69	37	C	38.1	Water reflector plug, 0.317 cm steel base.
8.1.69	38	C	38.1	Water reflector plug, 0.634 cm steel base.
9.1.69	39	C	38.1	Dump valve mock up reflector plug.
16.1.69	40	C	50.8	
20.1.69	41	D	50.8	

Runs 32 - 34 gave slightly different critical heights when repeated three weeks later. The earlier results were rejected on the assumption that a small concentration change occurred during this time.

8. ERRORS

8.1 Cylinder height

Measurement of critical height of the plug was observed using a long focus lens television system positioned to give a field of 50 mm on the screen. The accuracy of observation of the critical height on the screen was ± 0.1 mm. The errors of setting up the cursor and scale were each ± 0.1 mm. Stretch in the plug suspension chain was found to be 0.1 mm. No correction was made for this in estimating the critical heights, but an error of ± 0.17 mm, common to all measurements, was therefore taken to allow for this and for calibration of the sight glass scale.

The base of the core vessel had a ½° slope to facilitate drainage of the fissile solution. This decreased the volume and height of the core by the quantities given in table 4.

TABLE 4

Decreased Volume and Height due to Sloped Core Vessel Base Shape

Nominal Diameter, mm	Volume, ml	Height, mm
250	16.1	0.32 ± 0.01
300	33.7	0.46 ± 0.01
380	76.0	0.67 ± 0.02
510	209.0	1.00 ± 0.03

The temperature at which the measurements were made was 26 ± 2°C. Differences in temperature between experiments would give rise to errors in the critical height due to:-

(a) The change in density of the solution. (The critical height was assumed to vary as the ratio of the densities to the power of - $(1 + \gamma^*)$.

(b) Difference in the effective diameter of the stainless steel core vessel. This was taken as zero, ie, the expansion was assumed to take place in a vertical direction only, thus increasing its effect on the critical height.

(c) Difference in length of the top reflector plug supporting chain (approximately 1 m long).

(d) Distortion of the mild steel framework of the box and gantry supporting the plug raise mechanism.

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* γ is the mass density exponent for the reflected core [3]. An approximate value is 1.65 [4].

Measurements showed that the standard deviation due to these effects was not more than 0.14 mm. In view of the heavy tampering by the reflector water, the temperature was assumed not to vary during an experiment.

The effects of differences of box pressure and distortion due to the weight of core and reflector were less than 0.01 mm over the range involved in the experiment.

8.2 Core vessel volume

The diameter of the core vessels was estimated by measurements using an internal micrometer at intervals of 60° in diameter (36° on the 507 mm vessel) and 150 mm in height. The average values obtained were as follows:-

254.25 ± 0.05 mm
306.2 ± 0.1 mm
379.9 ± 0.4 mm
507.2 ± 0.1 mm

8.3 Extrapolation error

The error caused by extrapolation using an exponential type of curve is deduced by extrapolating any three of the last four solution heights to critical. The effect of errors on the value of the shape factor B (see appendix B) chosen by the program is estimated by recalculating the value of B as described in appendix B.

8.4 Neutron counting

The output from each counting channel was fed to the computer terminal after a nominal 100 seconds. The timing period was measured using a crystal controlled timer feeding 100 pulses per second into the terminal. Count rates were typically 10^3 - 10^5 per second.

The errors of counting were found to be somewhat higher than those expected on the basis of the total events recorded. This is illustrated in figure 10 for experiment 41, in which the actual errors and those expected are shown multiplied by a factor of 10.

Figure 11 plots the excess error* against fraction of critical height of solution. The error has been normalised to take account of the changing neutron population due to the increased volume of solution present. This indicates that near critical, there is a small constant residual error above that due to the counting inaccuracies. Analysis of a high speed recorder trace of the ratemeter readings showed that the additional error varied as the square root of the time of counting between 0.1 and 10 seconds. This analysis indicates that this excess error is produced by spontaneous variations in the neutron source strength within the core. Observation of this effect was not expected in a system so far from critical, however, the efficiency of the neutron counting system was very high by usual reactor standards, and this has compensated for the reduced reactivity of the system.

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*Excess Error = $\sqrt{V_E - V_N}$, where V_E is the variance obtained experimentally and V_N is that calculated on the assumption that the events recorded by the neutron detectors vary according to a Poisson distribution.

The effect on the accuracy of the results quoted was taken account of in a subroutine (ALPHA) in TRACT. It was found to be negligible in comparison with the other errors present.

9. EXPERIMENTAL RESULTS AND THEIR CORRECTION TO "CLEAN" CORES

The count rates corrected for dead time and background, together with the critical height extrapolated for each counter channel, are given in appendix A. Table 5 quotes the weighted average critical heights and parameters for those runs using the normal polythene top reflector plugs.

These data require correction for the effect of the structural materials before they can be used for nuclear safety assessment. The magnitude of these corrections was estimated from subsidiary experiments in which parts of the structural materials were changed, and the critical height re-measured.

9.1 Corrections for effect of dump valve mechanism and polythene top reflector on reactivity

The subsidiary measurements using the water filled top reflector plug and the mock up of the dump valve mechanism were used to estimate the difference in reflector saving between the experimental environment and 150 mm water reflection. The effect of the steel base of the water tank was estimated by the difference in critical height of the core with the thick and thin bases in position. Since the correction was small (between 0.3% and 1.7% of the critical height), linear extrapolation is adequate.

The critical heights of the appropriate cores are given in table 6.

9.2 Corrections for steel of vessel walls

The effect of the steel walls of the core vessels was estimated from differences in heights for the normal and double thickness walled vessels quoted in table 5.

The normal core vessel wall thickness was 2.50 mm but the 254 mm diameter vessel had 2.00 mm thick walls. The addition of the steel cladding increased the wall thickness by 2.50 mm. Since the increase in critical height due to the change in wall thickness was small, the effective shape of the core was unaffected, consequently the corrections were obtained by linear extrapolation to zero thickness.

9.3 Corrected critical core sizes

Applying the corrections as described above yields the critical heights of "clean" cores reflected by effectively infinite water. Core parameters obtained in this way are tabulated in table 7.

Figure 12 is a plot of these data as a function of the core shape. The curves were drawn using one group diffusion theory. The Buckling (B^2) is given by the following relation for a cylindrical core:-

$$B^2 = \frac{\pi^2}{(H + 2\lambda)^2} + \frac{4J_o^{\,2}}{(D + 2\lambda)^2}, \qquad \ldots.(1)$$

where H and D are the height and diameter of a cylindrical core, λ is the extrapolation length (including reflector savings) and $J_o = 2.405$.

For a cylindrical core having a height equal to its diameter (E), the Buckling is given by

$$B^2 = \frac{\pi^2 + 4J_o^{\,2}}{(E + 2\lambda_{\frac{1}{2}})^2}, \qquad \ldots.(2)$$

where $\lambda_{\frac{1}{2}}$ is the extrapolation length of such a core.

In analyses using these equations, it is usual to assume that the extrapolation length does not vary with shape. However, Stratton [4] produces some evidence that the variation is approximately parabolic with the function (H/D)/(1.0 + H/D), H/D being the ratio of height to diameter of a cylindrical core. Since the variation of extrapolation length with shape is not very large, this assumption was taken as being a reasonable approximation to analyse the variations of the volume of SCAMP cores with shape.

Combining equations (1) and (2), the diameter of a critical cylinder is given by

$$E = \frac{1.0}{\sqrt{\frac{0.299}{(H + 2\lambda)^2} + \frac{0.701}{(D + 2\lambda)^2}}} - 2\lambda_{\frac{1}{2}}. \qquad \ldots.(3)$$

In the analysis of concentrations A and B, E and λ were varied to minimise the parameter $\Sigma(\Delta H)^2$, ΔH being the error on the critical height of the comparison cylinder based on a single estimate of critical size. The analysis of concentrations C and D assumed variations of extrapolation length with shape based on the values obtained from the other two concentrations.

The sizes of the reference cylinders determined by this method are given in table 8.

It is interesting to note that the constraints imposed by equation (3) induce the critical volume curves to have minima at a value of (H/D)/(1.0 + H/D) between 0.45 and 0.47, similar to that found by Paxton for uranium cores [5].

10. ACKNOWLEDGMENTS

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TABLE 5

Measured Critical Parameters for SCAMP Cores

Concentration	Run No.	Diameter, mm	Height, mm	Volume, litres	Plutonium Mass, g	Height / Diameter
Normal Core Vessel Wall						
A	6	254.25 ± 0.05	563.1 ± 0.6	28.59 ± 0.04	2896 ± 7	2.215 ± 0.002
	7	306.2 ± 0.1	298.9 ± 0.5	22.01 ± 0.05	2230 ± 7	0.976 ± 0.002
	10	379.9 ± 0.4	211.7 ± 0.4	24.00 ± 0.10	2431 ± 11	0.557 ± 0.001
	15	507.2 ± 0.1	160.5 ± 0.4	32.43 ± 0.10	3285 ± 12	0.316 ± 0.001
B	26	306.2 ± 0.1	461.8 ± 0.5	34.01 ± 0.06	1074 ± 3	1.508 ± 0.002
	27	306.2 ± 0.1	462.9 ± 0.8	34.10 ± 0.08	1077 ± 3	1.512 ± 0.003
	17	379.9 ± 0.4	282.4 ± 0.4	32.01 ± 0.11	1011 ± 4	0.743 ± 0.001
	23	507.2 ± 0.1	203.9 ± 0.3	41.21 ± 0.08	1301 ± 3	0.402 ± 0.001
	24	507.2 ± 0.1	203.5 ± 0.4	41.11 ± 0.10	1298 ± 4	0.401 ± 0.001
C	36	379.9 ± 0.4	728.6 ± 0.7	82.61 ± 0.25	1537 ± 7	1.918 ± 0.003
	40	507.2 ± 0.1	335.9 ± 0.3	67.86 ± 0.09	1263 ± 5	0.662 ± 0.001
D	41	507.2 ± 0.1	371.6 ± 0.3	75.08 ± 0.09	1314 ± 6	0.733 ± 0.001
Thick Core Vessel Wall						
A	5	254.25 ± 0.05	604.5 ± 0.8	30.69 ± 0.06	3109 ± 8	2.378 ± 0.004
	8	306.2 ± 0.1	300.8 ± 0.5	22.15 ± 0.05	2244 ± 7	0.982 ± 0.002
	9	306.2 ± 0.1	299.8 ± 0.4	22.08 ± 0.04	2237 ± 6	0.979 ± 0.001
	11	379.9 ± 0.4	211.8 ± 0.4	24.02 ± 0.10	2433 ± 11	0.558 ± 0.001
B	28	306.2 ± 0.1	488.4 ± 0.3	35.97 ± 0.05	1136 ± 3	1.595 ± 0.001
	19	379.9 ± 0.4	284.1 ± 0.5	32.21 ± 0.12	1017 ± 4	0.748 ± 0.002
C	35	379.9 ± 0.4	758.8 ± 1.3	86.03 ± 0.3	1601 ± 9	1.997 ± 0.004

TABLE 6

Data for Calculation of Reflector Saving Differences between 150 mm Water and SCAMP Upper and Lower Reflectors

Upper Reflector	Conc. A		Conc. B		Conc. C	
	Run No.	Critical Height, mm	Run No.	Critical Height, mm	Run No.	Critical Height, mm
1. Polythene	10	211.7 ± 0.4	17	282.4 ± 0.4	36	728.6 ± 0.7
2. Water (3.17 mm steel base)	12	209.6 ± 0.6	20	281.1 ± 0.5	37	732.8 ± 0.8
3. Water (6.34 mm steel base)	13	213.0 ± 0.4	21	283.1 ± 0.6	38	735.3 ± 1.0
4. Mock up dump valve	14	211.8 ± 0.5	22	280.1 ± 0.5	39	728.7 ± 0.8

TABLE 7

Critical Parameters for SCAMP Cores with Effectively Infinite Water Reflection

Concentration	Diameter, mm	Height, mm	Volume, litres	Plutonium Mass, g	Height / Diameter
A	254.25 ± 0.05	518.0 ± 2	26.3 ± 0.1	2669 ± 12	2.041 ± 0.008
	306.2 ± 0.1	286.4 ± 2	21.1 ± 0.1	2136 ± 16	0.935 ± 0.007
	379.9 ± 0.4	200.5 ± 2	22.7 ± 0.2	2302 ± 24	0.528 ± 0.005
	507.2 ± 0.1	149.4 ± 2	30.2 ± 0.4	3058 ± 41	0.295 ± 0.004
B	306.2 ± 0.1	432.0 ± 2	31.8 ± 0.1	1005 ± 5	1.411 ± 0.007
	379.9 ± 0.4	276.4 ± 2	31.3 ± 0.2	989 ± 8	0.728 ± 0.005
	507.2 ± 0.1	199.4 ± 2	40.3 ± 0.4	1272 ± 13	0.393 ± 0.004
C	379.9 ± 0.4	701.7 ± 3	79.5 ± 0.4	1480 ± 9	1.847 ± 0.008
	507.2 ± 0.1	339.2 ± 3	68.5 ± 0.6	1275 ± 12	0.669 ± 0.006
D	507.2 ± 0.1	375.0 ± 3	75.8 ± 0.6	1326 ± 12	0.739 ± 0.006

TABLE 8

Derived Critical Parameters of Water Reflected Cores having Equal Height and Diameter

Concentration	Diameter, mm	Volume, litres	Plutonium mass, kg
A	300.3 ± 0.3	212.7 ± 0.06	2154 ± 7
B	338 ± 3	303.0 ± 0.8	957 ± 24
C	441 -	674 -	1250 -
D	456 -	745 -	1300 -

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APPENDIX A

CORRECTED HEIGHTS AND COUNT RATES WITH EXTRAPOLATED CRITICAL HEIGHTS

Run No.	Height, mm	Count Rate, s^{-1}	Height, mm	Count Rate, s^{-1}	Height, mm	Count Rate, s^{-1}	Height, mm	Count Rate, s^{-1}	Critical Height, mm
5	520.3	2812.67	550.3	4491.19	570.1	7218.54	580.3	10445.06	603.4 ± 1.2
		2598.30		4134.45		6652.79		9605.18	604.0 ± 1.1
		1397.43		2231.56		3620.46		5218.91	604.7 ± 0.9
		23970.51		39653.80		64751.75		92825.79	605.0 ± 1.2
		23213.74		38786.64		64023.13		93307.33	604.2 ± 0.9
		4556.88		7214.48		12008.45		16280.45	608.5 ± 2.4
		45.59		77.21		118.71		161.25	600.7 ± 4.5
6	460.3	1899.35	520.3	4854.89	530.3	6514.37	540.3	9462.53	563.5 ± 0.9
		1748.35		4477.59		5998.90		8814.38	563.0 ± 0.6
		882.62		2308.03		3126.46		4555.42	562.7 ± 1.2
		14644.68		41703.14		56413.16		82583.79	562.5 ± 1.1
		14772.87		40076.86		56277.43		81254.12	561.4 ± 2.9
		2612.61		8307.47		10008.01		14724.14	568.9 ± 6.8
		40.69		83.12		106.91		145.42	570.6 ± 3.4
7	240.1	2728.37	270.1	5958.18	280.1	8957.49	290.1	18774.73	300.4 ± 1.0
		2536.77		5472.32		8207.84		17144.91	297.0 ± 0.9
		806.80		1884.24		2885.37		6146.15	299.9 ± 0.5
		2524.32		5661.46		8615.07		18637.05	299.8 ± 0.9
		2150.95		6048.28		9548.56		26063.30	296.7 ± 0.7
8	250.1	3400.40	270.1	5869.67	280.1	8956.22	290.1	17856.82	300.9 ± 0.4
		3165.18		5420.69		8245.68		16378.90	301.0 ± 0.4
		1008.90		1821.29		2822.49		5728.19	300.6 ± 0.3
		2943.44		5118.69		7652.39		15122.23	298.3 ± 3.4
		4327.40		11057.88		17216.25		35823.73	300.0 ± 1.3
		33.76		61.37		97.90		196.00	300.2 ± 0.9
9	250.1	1834.19	270.1	3160.43	280.1	4708.31	290.1	9418.57	299.3 ± 0.8
		1697.37		2924.07		4366.97		8704.71	299.9 ± 0.7
		593.42		1037.33		1552.74		3104.24	301.3 ± 0.8
		2920.97		5594.28		8811.68		18760.23	299.6 ± 0.3
		1967.11		3771.57		5923.65		12387.83	299.9 ± 0.4
10	169.9	1742.57	189.9	3682.31	199.9	7096.05	204.9	12431.48	212.0 ± 0.4
		1555.27		3292.07		6346.66		11105.26	212.0 ± 0.3
		266.26		575.30		1137.86		2003.82	211.7 ± 0.4
		880.63		1865.31		3666.89		6644.08	211.4 ± 0.4
		1609.91		4277.25		7471.72		16648.70	209.8 ± 1.3
		882.07		2178.28		4491.01		8134.92	211.6 ± 0.6
		19.40		39.97		74.04		131.24	210.5 ± 1.1
11	194.9	4752.85	199.9	6910.76	204.9	12279.06	207.9	21759.00	211.9 ± 0.3
		4299.60		6229.20		11070.99		19676.32	211.8 ± 0.3
		756.67		1097.23		1983.42		3515.51	211.8 ± 0.3
		1990.07		2802.84		4974.49		8845.13	211.9 ± 0.3
		47.37		70.68		126.99		228.69	211.8 ± 0.5
12	169.9	1796.41	189.9	3834.23	199.9	6966.73	204.9	15498.10	209.7 ± 1.8
		1636.76		3467.14		6315.44		14068.09	209.7 ± 1.8
		269.56		599.06		1103.46		2479.49	209.6 ± 1.5
		926.41		2023.90		3735.94		8660.94	209.3 ± 1.7
		605.02		1480.81		2808.38		6007.23	209.9 ± 0.8
		272.58		661.78		1272.24		2938.21	209.3 ± 0.9
13	149.9	1051.30	189.9	3373.01	199.9	6250.91	204.9	10244.85	213.2 ± 0.4
		954.99		3071.06		5678.53		9339.45	213.2 ± 0.4
		158.09		537.40		1010.94		1669.13	213.0 ± 0.3
		577.39		1863.42		3513.61		5839.92	212.9 ± 0.3
		150.00		645.39		1276.71		2173.46	212.8 ± 0.7
		135.12		579.58		1148.04		1952.94	212.8 ± 0.8
		8.82		32.94		64.87		106.14	212.8 ± 0.9
14	179.9	2377.64	189.9	3581.84	199.9	6722.00	204.9	11739.23	211.6 ± 0.7
		2160.52		3264.14		6127.00		10671.18	211.6 ± 1.0
		369.30		565.83		1070.90		1894.59	211.9 ± 0.4
		388.42		629.78		1264.15		2257.47	211.8 ± 0.5

Run No.	Height, mm	Count Rate, s^{-1}	Height, mm	Count Rate, s^{-1}	Height, mm	Count Rate, s^{-1}	Height, mm	Count Rate, s^{-1}	Critical Height, mm
15	119.5	1715.80	129.5	2413.27	149.7	7632.16	154.5	13902.34	160.6 ± 0.5
		1543.86		2169.91		6877.29		12496.56	160.7 ± 0.5
		9.74		12.44		41.98		77.96	160.6 ± 0.7
		26.61		38.40		124.00		236.81	160.2 ± 0.4
17	218.5	503.33	238.5	780.98	258.5	1530.74	268.5	2700.36	282.8 ± 0.5
		471.07		725.62		1433.58		2533.93	282.8 ± 0.5
		271.60		438.26		874.51		1571.36	282.2 ± 0.4
		79.62		123.95		247.77		443.34	282.4 ± 0.5
		194.84		390.51		881.81		1523.84	282.0 ± 0.5
		96.03		170.53		373.13		694.23	281.9 ± 1.5
		5.08		7.21		16.16		31.41	279.8 ± 1.1
19	218.5	846.33	238.5	1304.60	258.5	2529.21	268.5	4306.44	284.2 ± 0.4
		824.99		1268.71		2431.52		4138.48	284.1 ± 0.5
		422.16		718.91		1486.23		2631.64	283.2 ± 1.1
		299.97		381.47		609.35		929.44	286.0 ± 1.9
		146.69		284.69		647.63		1199.28	282.3 ± 2.6
		10.38		16.94		32.81		55.17	284.8 ± 1.5
20	218.5	505.96	238.5	784.43	258.5	1552.56	268.5	2884.83	280.8 ± 0.6
		464.69		721.16		1433.48		2647.40	281.1 ± 0.6
		275.15		438.95		882.91		1643.46	281.3 ± 0.4
		87.40		136.98		275.39		514.81	280.8 ± 0.6
		119.37		203.62		451.28		873.68	281.0 ± 1.2
21	238.5	732.45	258.5	1376.52	268.5	2395.86	273.5	3689.22	283.3 ± 0.5
		690.76		1306.53		2268.61		3488.39	283.3 ± 0.6
		408.58		792.61		1383.49		2142.54	283.1 ± 0.6
		143.82		201.33		402.07		638.11	282.2 ± 0.9
		377.71		684.17		1442.67		1988.42	284.2 ± 3.0
		191.82		400.91		733.58		1150.49	282.5 ± 1.1
22	218.5	510.42	238.5	803.52	258.5	1611.65	268.5	3062.60	280.0 ± 0.6
		475.89		745.08		1501.52		2861.91	280.2 ± 0.6
		251.98		397.73		818.48		1572.43	280.2 ± 0.4
		89.16		141.56		286.82		552.17	279.5 ± 0.8
		231.49		423.13		923.87		1614.31	284.5 ± 3.1
		210.01		366.50		822.42		1638.86	279.8 ± 0.9
23	158.2	641.27	178.2	1220.40	188.2	2073.17	198.2	5859.24	204.1 ± 0.3
		591.63		1138.11		1935.04		5490.90	204.1 ± 0.3
		94.73		206.13		361.95		1067.27	203.7 ± 0.3
		29.88		54.27		90.24		256.47	204.1 ± 0.4
		335.83		605.24		1165.98		3217.84	203.4 ± 1.1
		227.05		461.71		795.97		2305.19	203.9 ± 0.3
		6.58		11.75		21.01		60.45	203.7 ± 0.5
24	158.2	1156.12	178.2	2554.54	188.2	4656.92	198.2	14475.40	203.2 ± 0.3
		1364.78		2708.99		4710.57		13978.46	203.7 ± 0.2
		164.22		423.77		824.24		2692.09	202.7 ± 0.6
		570.35		1728.25		3325.27		8922.57	204.2 ± 1.1
		321.32		864.67		1687.33		5602.24	202.6 ± 0.6
		15.82		31.62		56.50		158.42	203.9 ± 0.6
26	418.7	1272.79	438.7	2357.73	448.7	4053.84	453.7	6497.80	461.6 ± 0.8
		1206.94		2235.04		3846.60		6165.94	461.6 ± 0.7
		1422.61		2655.47		4597.94		7564.17	460.6 ± 0.8
		436.56		817.76		1408.27		2296.24	460.4 ± 0.9
		951.75		1840.90		3222.02		5307.94	461.9 ± 0.5
		441.15		864.74		1516.46		2476.85	462.0 ± 0.4
		16.52		30.43		54.07		85.51	462.6 ± 0.6
27	418.7	2114.93	438.7	3872.08	448.7	6609.98	453.7	10308.65	462.7 ± 0.7
		2065.84		3733.57		6334.55		9823.38	462.8 ± 0.7
		2337.63		4395.81		7628.67		11961.46	462.8 ± 0.7
		927.00		1554.19		2537.11		3853.31	463.0 ± 0.8
		1618.88		3506.17		5256.89		8310.25	463.8 ± 1.6
		721.86		1402.19		2474.58		3891.62	463.0 ± 0.9
		28.71		52.02		88.12		133.32	463.8 ± 0.9

Run No.	Height, mm	Count Rate, s^{-1}	Height, mm	Count Rate, s^{-1}	Height, mm	Count Rate, s^{-1}	Height, mm	Count Rate, s^{-1}	Critical Height, mm
28	448.7	1622.60	458.7	2232.66	468.7	3382.49	478.7	7110.87	488.5 ± 0.4
		1535.28		2131.51		3208.60		6715.46	488.6 ± 0.4
		1905.04		2633.68		4008.65		8529.17	488.2 ± 0.3
		572.05		795.99		1209.76		2549.61	488.4 ± 0.3
		2190.13		1830.53		2879.22		6163.08	488.0 ± 8.6
		613.26		870.06		1344.16		2880.44	487.9 ± 0.4
		10.19		28.63		44.35		94.43	488.0 ± 3.2
35	548.5	500.21	648.5	1024.69	698.5	1846.68	723.5	3131.15	757.3 ± 2.3
		467.97		954.70		1725.52		2905.21	759.3 ± 2.1
		340.84		705.89		1298.39		2202.65	760.0 ± 1.8
		95.54		199.18		365.21		627.27	757.0 ± 2.4
		5.51		13.61		27.63		45.65	763.1 ± 5.8
36	598.5	819.10	648. 5	1382.48	678.5	2245.44	698.95	3818.37	727.6 ± 1.2
		768.40		1301.93		2115.16		3581.83	727.9 ± 1.2
		566.05		966.94		1606.24		2733.25	729.1 ± 0.7
		159.37		277.34		451.90		770.44	729.8 ± 1.3
		10.99		19.33		32.22		56.71	727.2 ± 1.6
37	598.5	796.18	648.5	1307.24	678.5	2080.04	698.5	3338.28	733.9 ± 1.1
		743.37		1223.68		1937.37		3134.68	732.1 ± 1.3
		558.62		932.05		1489.17		2408.98	732.9 ± 1.1
		156.24		257.56		413.85		672.56	732.9 ± 1.2
		10.28		17.31		28.68		48.68	729.3 ± 2.3
38	598.5	781.64	648.5	1285.23	678.5	2001.61	698.5	3154.45	733.8 ± 1.5
		730.17		1210.20		1886.79		2960.58	734.0 ± 1.7
		553.21		917.37		1452.19		2292.32	735.8 ± 1.0
		153.61		258.05		403.81		640.81	736.4 ± 1.6
39	598. 5	811.84	648.5	1375.94	678.5	2236.61	698.5	3803.73	727.4 ± 1.2
		766.79		1297.12		2124.38		3588.10	729.3 ± 0.9
		606.28		1060.59		1740.46		3017.08	728.6 ± 1.3
		157.99		275.21		450.38		777.55	728.9 ± 1.4
		10.29		19.75		33.09		54.89	721.6 ± 3.3
		339.08		716.66		1316.43		2380.36	726.2 ± 3.0
40	298.2	1133.77	308.2	1556.17	318.2	2502.49	328.2	5837.78	336.1 ± 0.3
		1108.97		1530.27		2458.02		5732.13	336.1 ± 0.3
		243.98		340.60		539.82		1290.88	336.0 ± 0.5
		64.03		88.89		139.66		342.58	335.8 ± 0.8
		1105.33		1643.40		2828.70		7072.00	335.3 ± 0.5
		1059.05		1559.36		2675.99		6655.56	335.5 ± 0.5
		13.17		17.78		29.21		72.86	335.2 ± 0.5
41	318.2	890.92	338.2	1477.64	358.2	3756.75	366.2	9289.13	371.7 ± 0.3
		878.49		1456.65		3708.42		9183.42	371.7 ± 7.7
		196.94		324.37		830.82		2119.45	371.5 ± 6.9
		52.70		87.39		225.56		567.22	371.6 ± 5.7
		1017.55		1906.69		5465.02		14049.05	371.5 ± 5.3
		956.44		1799.84		5117.92		13315.44	371.4 ± 4.6
		9.10		17.78		48.29		120.85	371.7 ± 2.5

APPENDIX B

EXTRAPOLATION TO CRITICAL USING THE COMPUTER PROGRAMS SCAMPER AND TRACT

B1. INTRODUCTION

Analysis of previous approaches to critical at Aldermaston involving a wide range of parameters, showed that they conformed to a curve of the form

$$y = A \exp(Bx) + mx + C, \qquad \text{....(B1)}$$

where $y = 0$ at criticality, and A, B, m and C are taken as constant for a particular approach. Equation (B1) was exploited using the program SCAMPER on line on the Ferranti ARGUS computer, to obtain safety information during the critical approach (see above), and off line using the program TRACT (exTRApolation to CriTical) written in Fortran, to obtain estimates of the critical height and their errors.

The value of the extrapolated critical parameter is relatively insensitive to the value of B, which is determined separately by a technique described below. The values of the remaining constants are evaluated as follows:-

Differentiating equation (B1) gives

$$y' = AB \exp(Bx) + m, \qquad \text{....(B2)}$$

Applying equation (B2) to sets of values of x and y labelled 0 and 2, (0 representing the most reactive position) gives

$$y_2' - y_o' = AB[\exp(Bx_2) - \exp(Bx_o)].$$

Hence
$$A = \frac{y_2' - y_o'}{B[\exp(Bx_2) - \exp(Bx_o)]}$$

$$m = y_o' - AB \exp(Bx_o) \qquad \text{....(B3)}$$

$$C = y_o - A \exp(Bx_o) - mx_o,$$

Changes in B affect the relative curvature of the line fitted to the three points. For example, if B is positive, the curvature will increase with x, or if B is small, $Bx \rightarrow 0$ and equation (B1) will reduce to a straight line. The value of B is calculated from the last four experimental points, so as to minimise the error of extrapolation between the four possible combinations of any three of those points.

This extrapolation technique was used for two different purposes, viz:-

(1) To estimate the (negative) reactivity of the next step of the assembly process. In SCAMP, this was done using the computer code SCAMPER.

(2) To estimate the critical height of the core, ie, the point where the count rate would become infinite. This was solved using the Newton-Raphson interpolation technique, by the computer code TRACT, which also produces an error analysis.

The slope of the curve at position (0) and (2) may be obtained by application of the Gregory-Newton interpolation formula for irregular differences to values of x and y at positions 0 and 2 and an intermediate position labelled 1.

ie, $$y_n' = \frac{y_1 - y_o}{x_1 - x_o} + \left\{\frac{2x_n - (x_o + x_1)}{x_2 - x_o}\right\}\left\{\frac{y_2 - y_1}{x_2 - x_1} - \frac{y_1 - y_o}{x_1 - x_o}\right\},$$

where n = 0 or 2.

B2. SCAMPER

SCAMPER is based on the Operating Instructions for SCAMP but could, with minor modifications, be applied to any critical assembly process. It is written in ASPAL and occupies approximately 1K of core store in the Ferranti ARGUS computer. The objects of using SCAMPER on-line during the SCAMP experiment were:-

(1) To provide the operating staff with up-to-date information and recommend the next stage.

(2) To be "aware" of the operating instructions, and be able to issue warnings of any impending breach of conditions.

(3) To avoid personal bias during extrapolation of the approach curves.

(4) To extrapolate pessimistically when the statistics of counting were inadequate in the early stages of the assembly.

(5) To avoid errors due to misreading data and its subsequent processing by dumping the counting channel scalers directly into the computer.

(6) To reduce time taken to carry out the assembly process.

(7) To provide an independent log of the experiment.

B3. TRACT

Although TRACT was designed for the analysis of SCAMP results, it may be used for any criticality parameters which vary according to equation (B1), eg, the separation between two cores, or a core and reflector, or the number of fuel elements in a reactor.

A data error would produce an extreme change of curvature. Consequently values of B outside the region $100 > Bx > 0.05$ produce diagnostic ERROR messages.

TRACT may be used to estimate the experimental errors on the critical parameter. This is achieved by calculating the standard deviation of the last 3 values of x and y and using EXTRA to extrapolate these data using all the $3^6 = 729$ possible combinations of x and y given by x, $x \pm \sigma$, y, $y \pm \sigma$ to derive a standard deviation of x. This operation is done twice, once to estimate the errors due to the statistics of counting, and again to estimate those errors wholly or partially common to all counting channels, eg, time measurement, height measurement, cross sectional area of core vessel and chemical analysis.

The error introduced by fitting the last four points to an exponential curve is estimated by including the residual error calculated when deriving B in the error analysis.

The error in x caused by the effect of errors in x or y on B is calculated by changing the values of x and y of the fourth highest point separately by one standard deviation, recalculating B and the predicted parameter in each case.

The program calculates the average value and errors for each counting channel and the weighed average dimension and its standard deviation, only the statistics of counting and extrapolation being considered independent.

An example of a TRACT output is given below. The neutron counts for counters 4 and 5 were modified to illustrate the rejection of unsuitable data. The program was thus unable to produce a smooth exponential curve through the four points for counter 4. Counter 5 was shown to have an unnacceptably large standard deviation.

SCAMP PU/U(NAT) EXPERIMENT OCT.68-JAN.69.

EXPERIMENT NO. 36

CONCENTRATION 3 18.6 GRAMS(PU)/LITRE
30.8 CM.CORE VESSEL
NORMAL CORE VESSEL WALLS
WATER FILLED TOP REFLECTOR
EXTRA STEEL ADDED TO BASE OF TOP REFLECTOR FOR EXTRAPOLATION PURPOSES

COUNTER NUMBER	HEIGHT (CM)	COUNT	HEIGHT (CM)	COUNT	HEIGHT (CM)	COUNT	HEIGHT (CM)	COUNT	BACKGROUND PER SECOND	DEAD TIME MICROSECS
1	60.00	78386	65.00	126479	68.00	199753	70.00	31301	2.80	3.00
2	60.00	73703	65.00	121469	68.00	188821	70.00	29440	7.30	3.00
3	60.00	56796	65.00	93234	68.00	146941	70.00	23070	13.90	0.20
4	60.00	15626	65.00	26079	68.00	30600	70.00	6440	2.40	0.20
5	60.00	1986	65.00	2694	68.00	3708	70.00	533	8.80	0.20

COUNTING TIME (SECONDS)

100.161	100.134	100.256	10.008

STANDARD DEVIATIONS

HEIGHT ERROR = 0.100E-01 CM AT EACH POINT

PARAMETER ERROR = 0.300E-04 FRACTION

COMMON HEIGHT ERROR = 0.140E-01 CM

CLOCK ERROR = 0.100E-02 SECONDS

PARAMETER PROPORTIONAL TO 1.00 POWER OF HEIGHT

CORRECTED COUNT RATES AND HEIGHTS

COUNTER NUMBER	HEIGHT (CM)	COUNT RATE	HEIGHT (CM)	COUNT RATE	HEIGHT (CM)	COUNT RATE	HEIGHT (CM)	COUNT RATE
1	59.85	781.64	64.85	1285.23	67.85	2001.61	69.85	3154.42
2	59.85	730.17	64.85	1210.20	67.85	1886.79	69.85	2960.54
3	59.85	553.21	64.85	917.37	67.85	1452.19	69.85	2292.32
4	59.85	153.61	64.85	258.05	67.85	302.84	69.85	641.17
5	59.85	11.03	64.85	18.10	67.85	28.19	69.85	44.46

JOB TERMINATED FOR COUNTING CHANNEL NO. 4
ERROR ON EXTRAPOLATED CRITICAL HEIGHT FOR LAST 4 POINTS = 4.549 CM.

COUNTING CHANNEL NO	1	2	3	4	5
AV.CRITICAL HT.(CM)	73.372	73.399	73.582	0.	73.359
SCALE FACTOR	2.27E-01	2.86E-01	-2.15E-03	-1.59E 00	2.23E-01
EXP.INTERCEPT (A)	-6.06E-10	-6.15E-12	-1.36E 01	-3.32E 43	-6.25E-08
GUIDE LINE INTERCEPT	3.54E-01	3.93E-01	1.41E 01	2.78E 00	2.49E 01
GUIDE LINE SLOPE	-4.68E-03	-5.25E-03	-3.33E-02	-3.82E-02	-3.29E-01

CRITICAL HEIGHT ESTIMATE BASED ON AVERAGE VALUES ONLY = 73.428 CM.

JOB TERMINATED FOR COUNTING CHANNEL NO. 5
MORE THAN 10 ITERATIONS REQUIRED ON AT LEAST 20 OCCASIONS DURING ERROR ANALYSIS

AVERAGE CRITICAL HEIGHTS AND ERRORS FOR EACH COUNTER
****

COUNTER NUMBER	AVERAGE CRITICAL HEIGHT (CM)	COUNTING AND EXTRAP ERRORS (CM)	OTHER ERRORS (CM)	TOTAL ERROR (CM)	DIFFERENCE FROM AVERAGE CRITICAL HT. (STANDARD DEVIATIONS)
1	73.373	0.139	0.063	0.153	-0.781
2	73.402	0.154	0.074	0.171	-0.534
3	73.582	0.093	0.046	0.104	0.858
4	0.	0.	0.	0.	0.
5	0.	0.	0.	0.	0.

WEIGHTED AVERAGE CRITICAL HEIGHT = 73.493 CM   TOTAL ERROR (INCLUDING COMMON ERROR) = 0.102 CM

THIS JOB REQUIRED 0 MIN 24.62 SEC

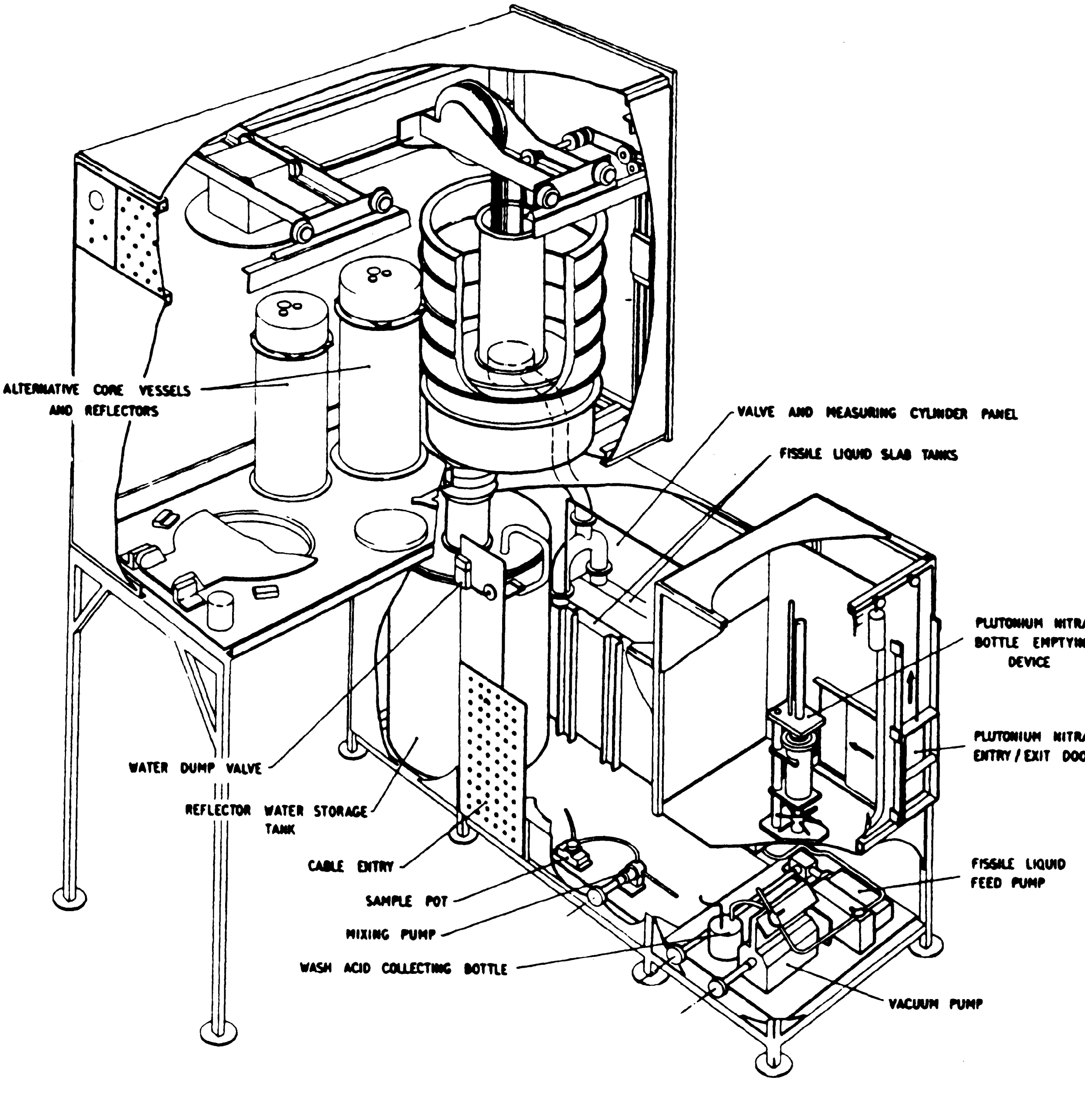


FIGURE I. GENERAL VIEW OF GLOVE BOXES

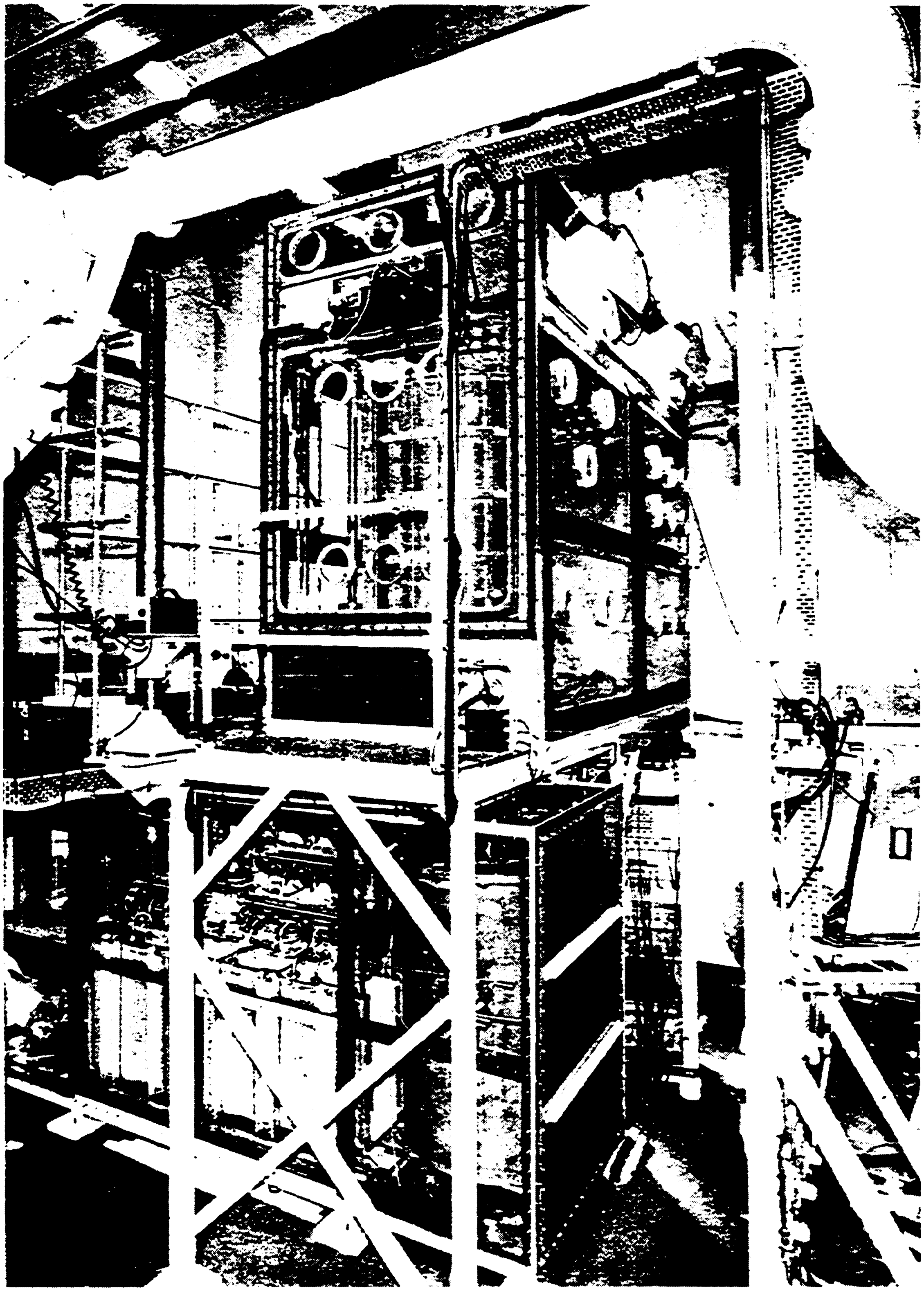


FIGURE 2. SCAMP RIG DURING CONSTRUCTION

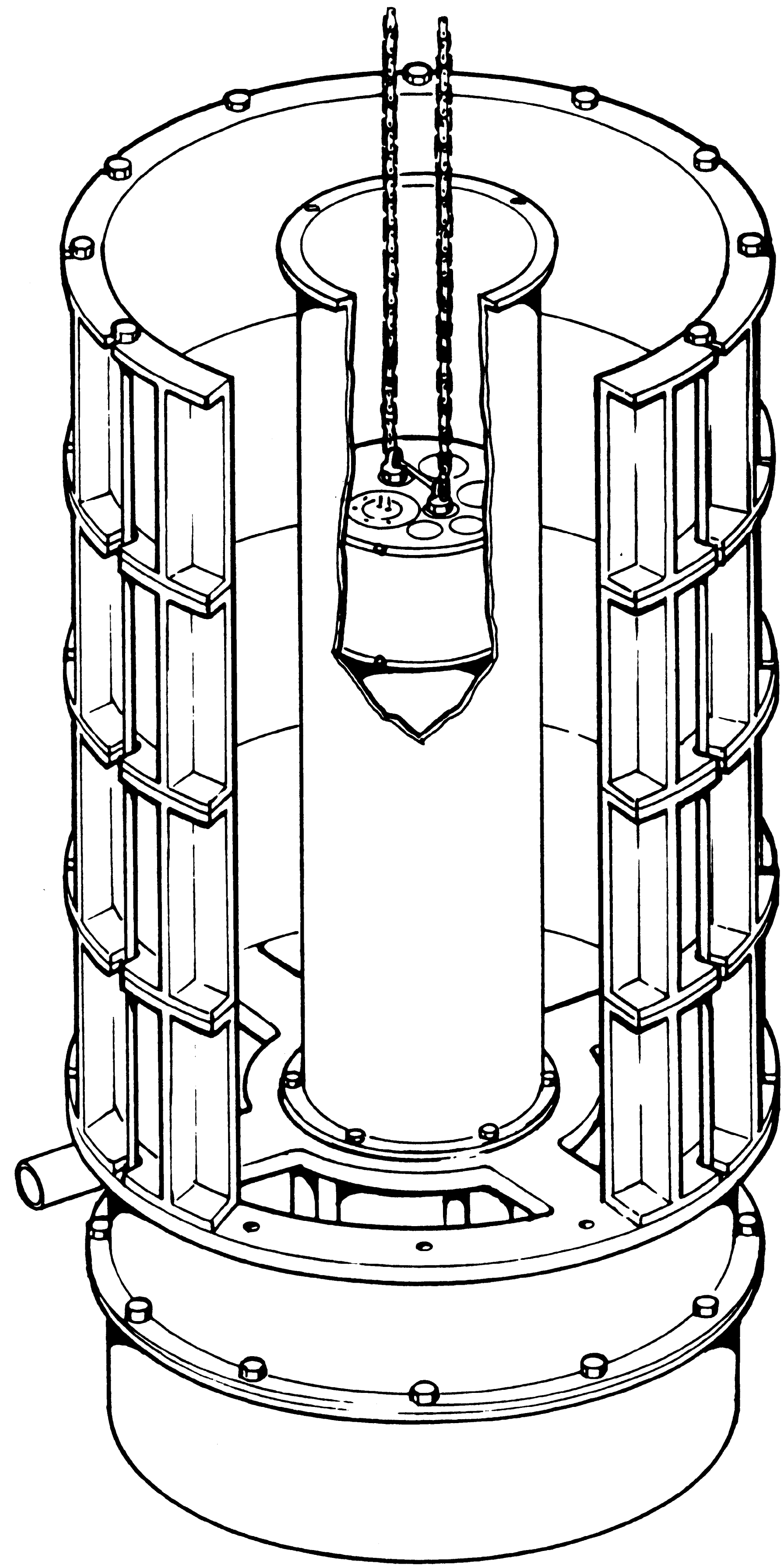


FIGURE 3 Core and reflector vessel assembly

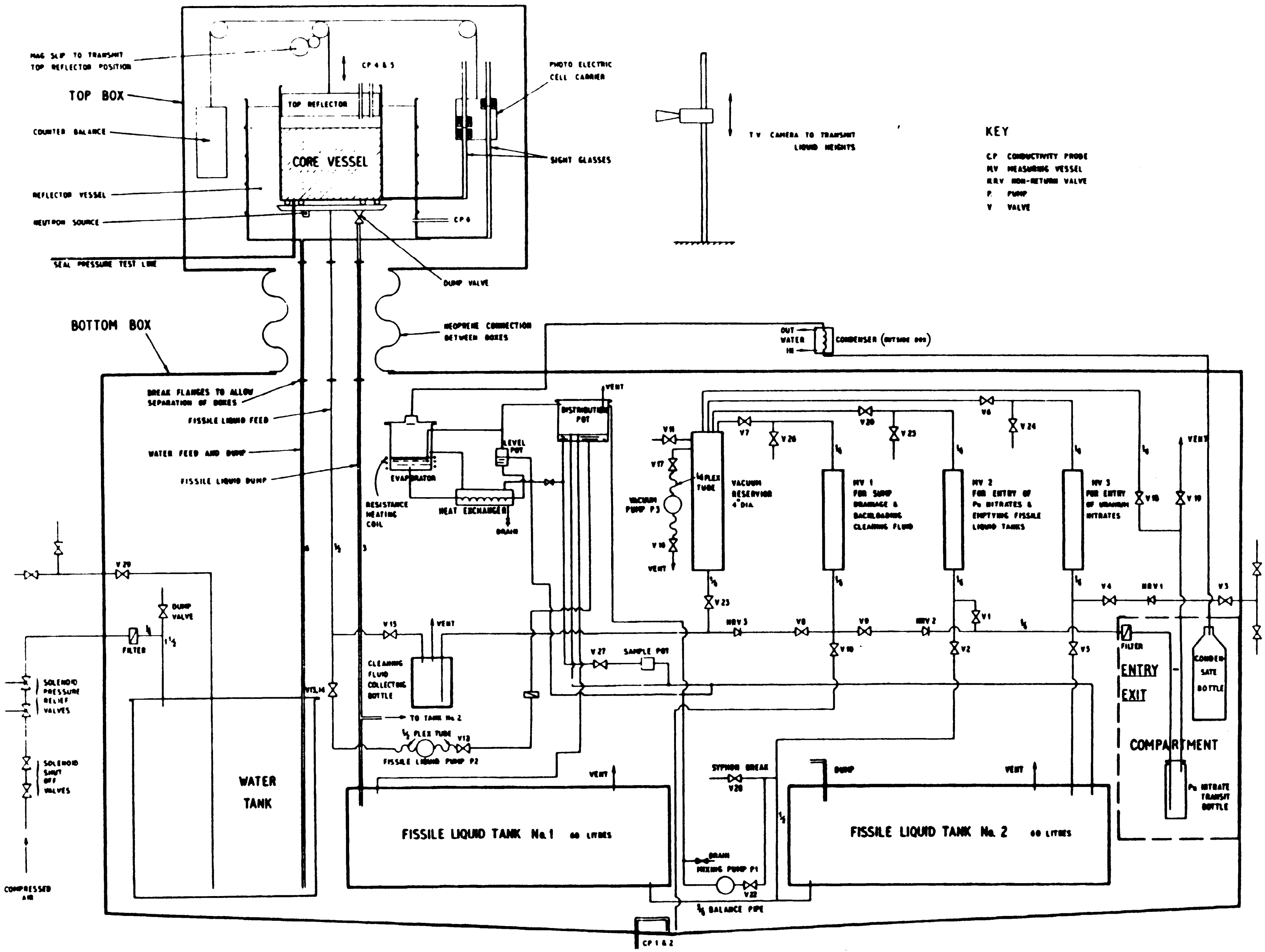


FIGURE 4 SCAMP — Flow diagram

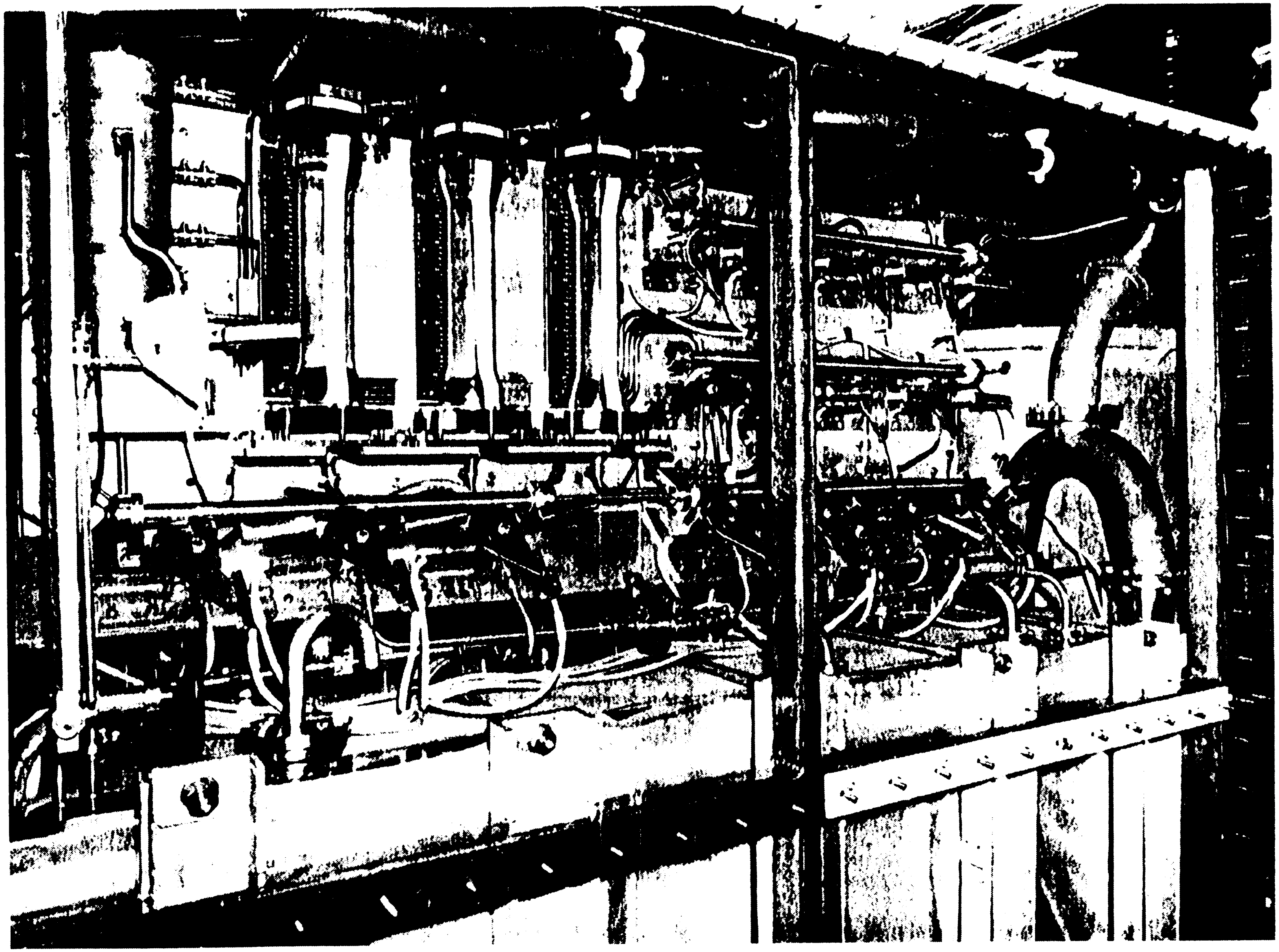


FIGURE 5. LOWER BOX SHOWING STORAGE TANKS AND SOLUTION HANDLING EQUIPMENT

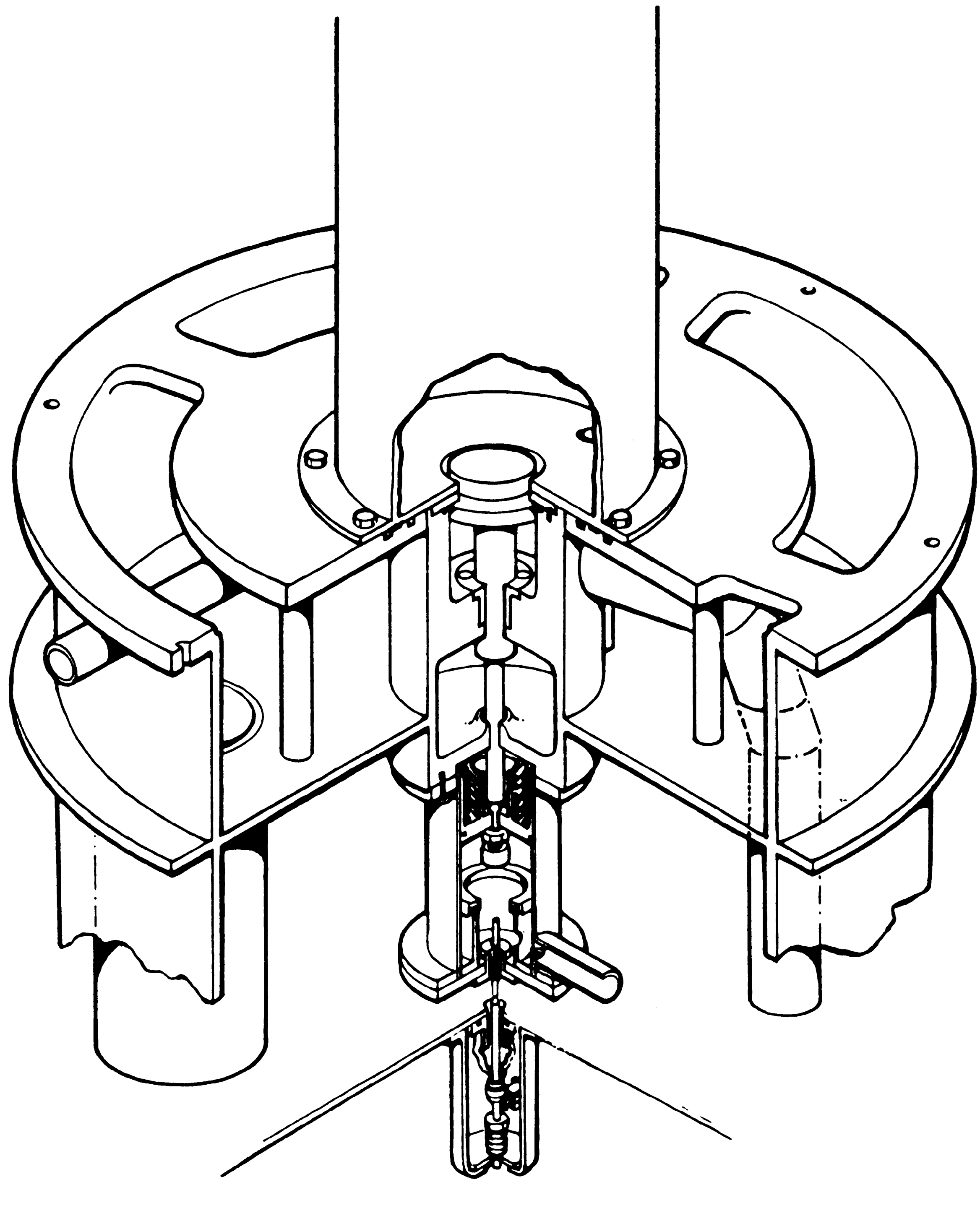


FIGURE 6 Fissile Solution Dump Valve

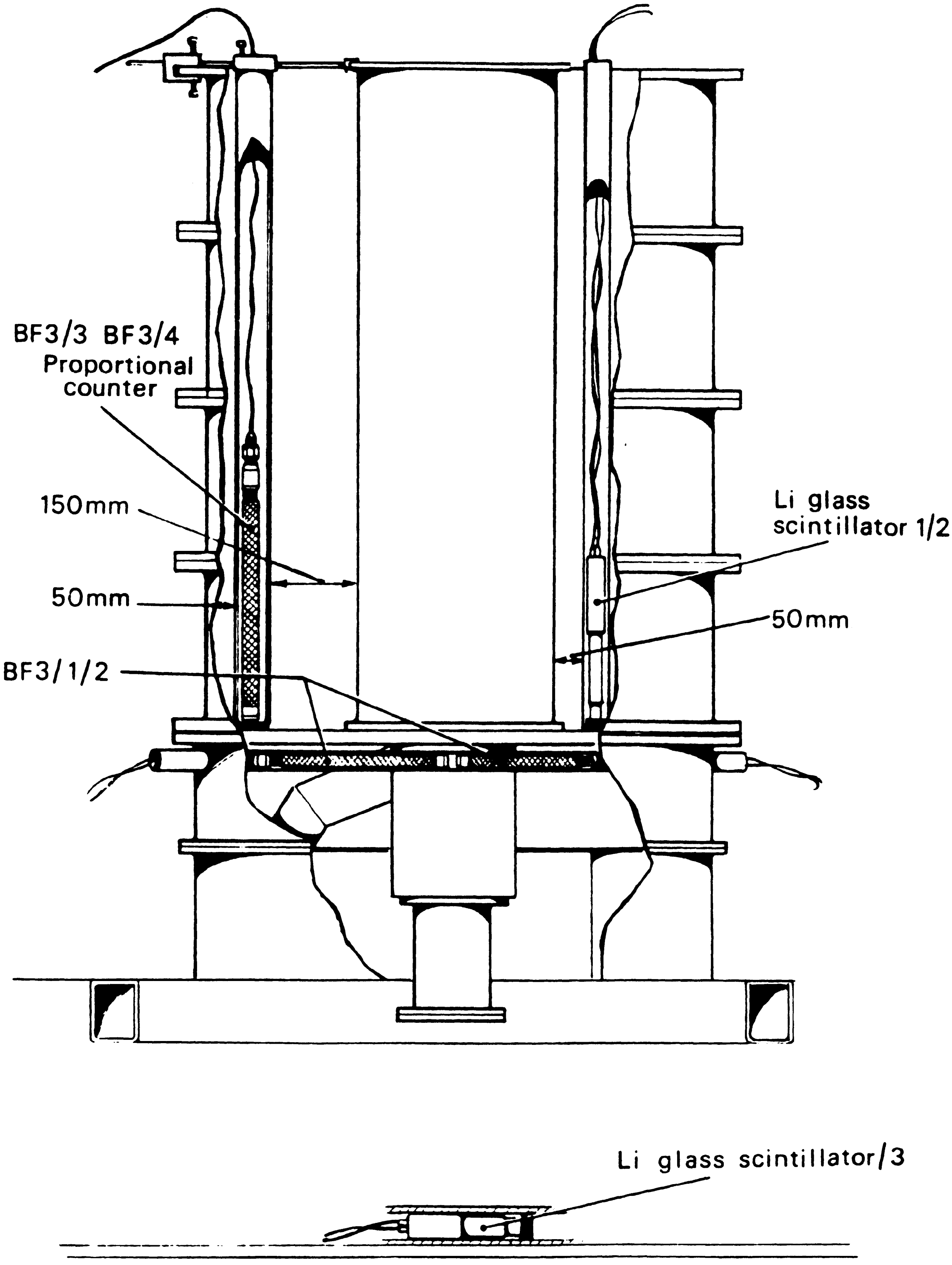


Figure 7
Neutron detector positions relative to the core

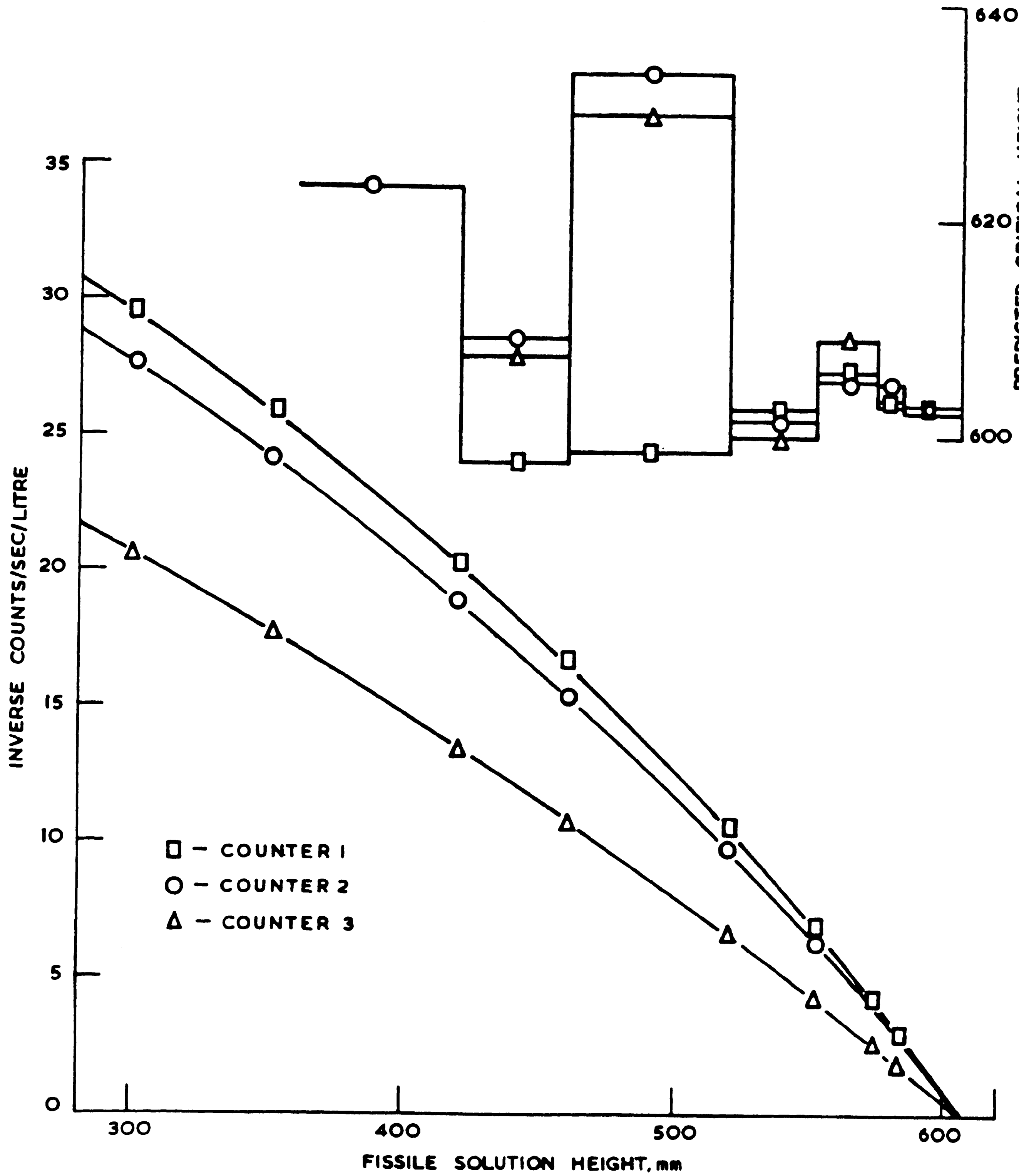
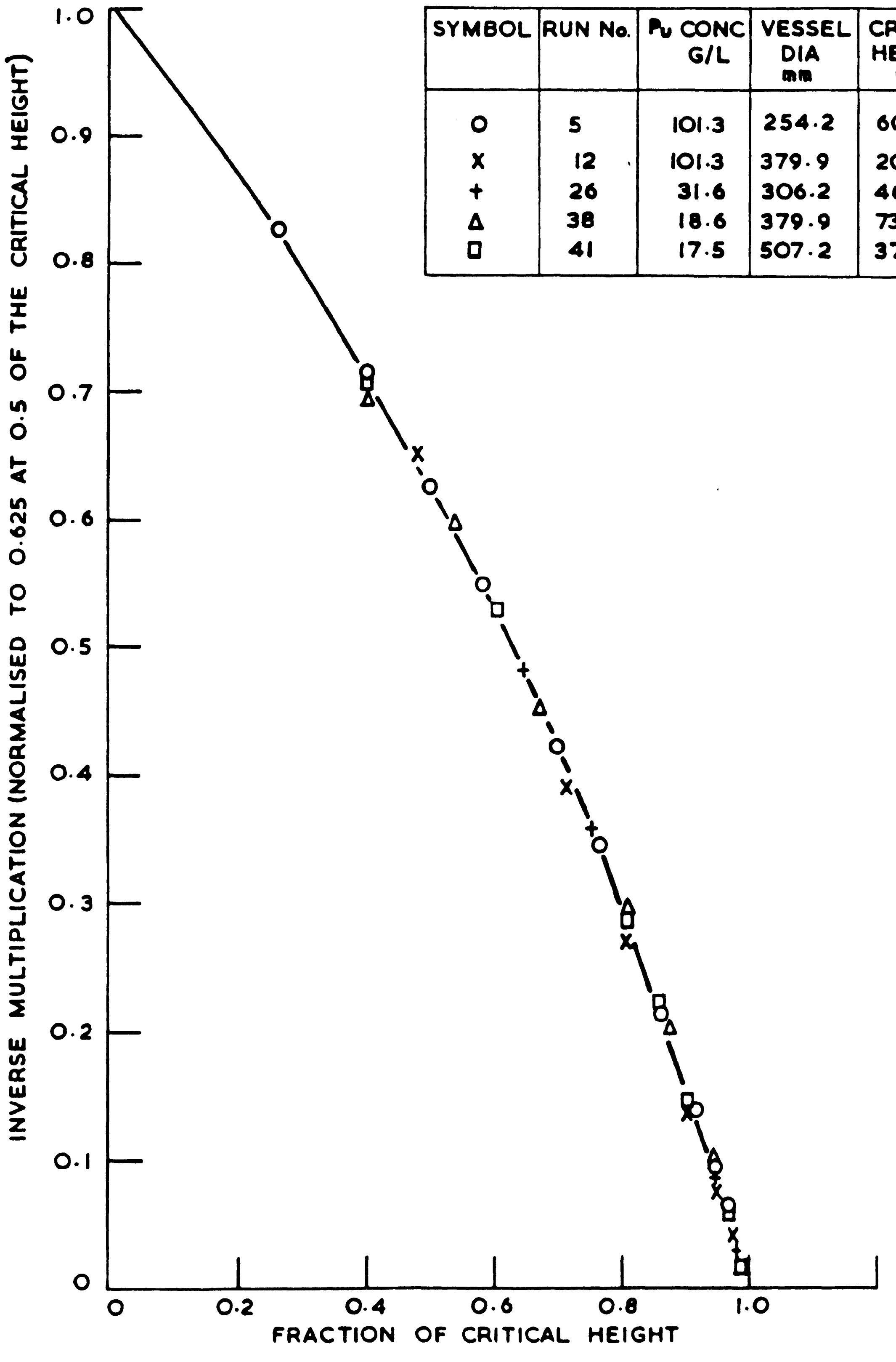


FIGURE 8. RECIPROCAL COUNT RATE PER UNIT HEIGHT AND EXTRAPOLATION TO CRITICAL - RUN 26



SYMBOL	RUN No.	Pu CONC G/L	VESSEL DIA mm	CRITICAL HEIGHT mm	RATIO HT/DIA
O	5	101.3	254.2	604.5	2.378
X	12	101.3	379.9	209.6	0.552
+	26	31.6	306.2	461.8	1.508
Δ	38	18.6	379.9	735.3	1.936
□	41	17.5	507.2	371.6	0.733

FIGURE 9. PLOT OF APPROACH CURVES FOR A WIDE VARIETY OF CORES

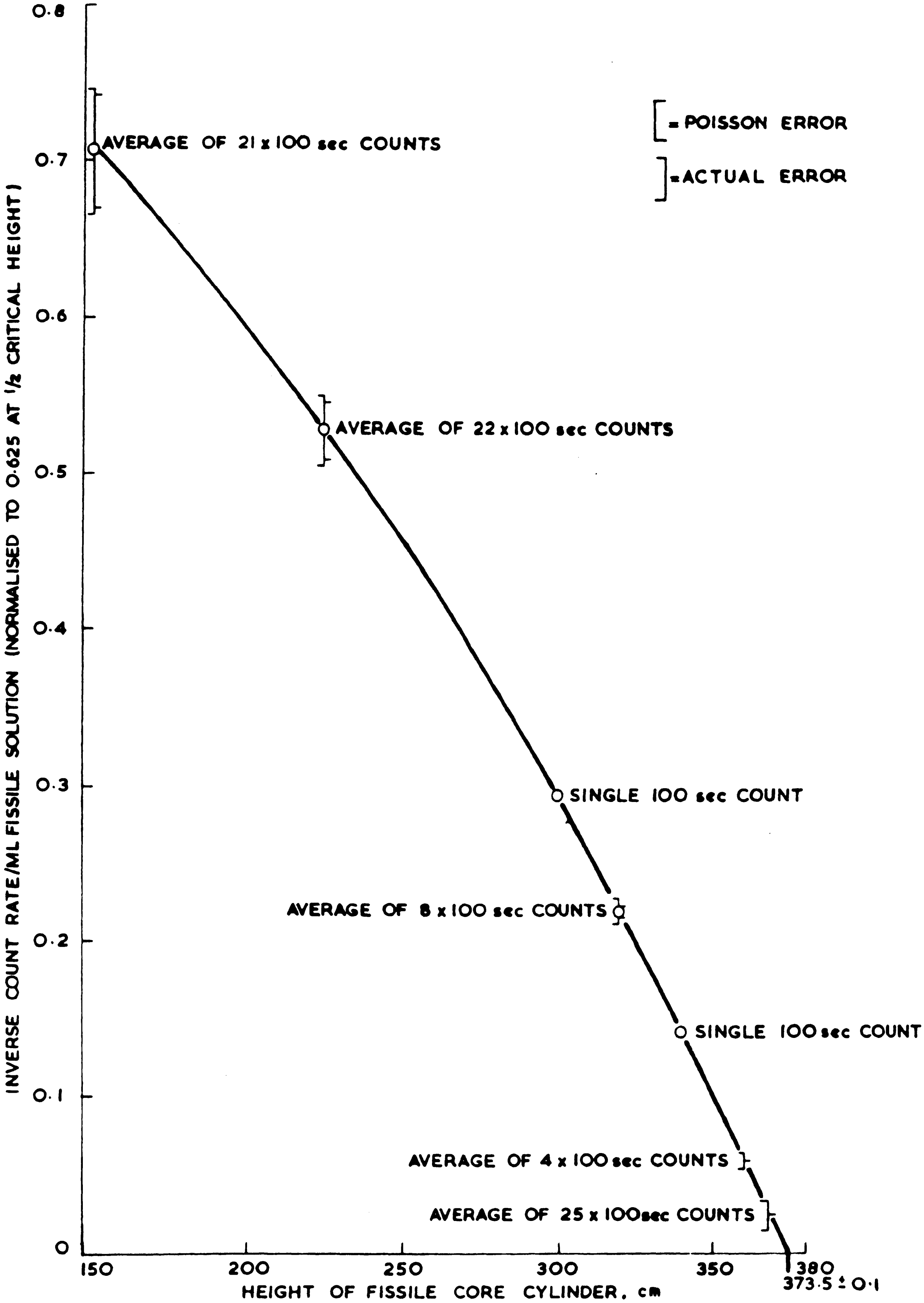


FIGURE 10. INVERSE COUNT RATE FOR RUN 41 TO SHOW OBSERVED AND EXPECTED ERRORS

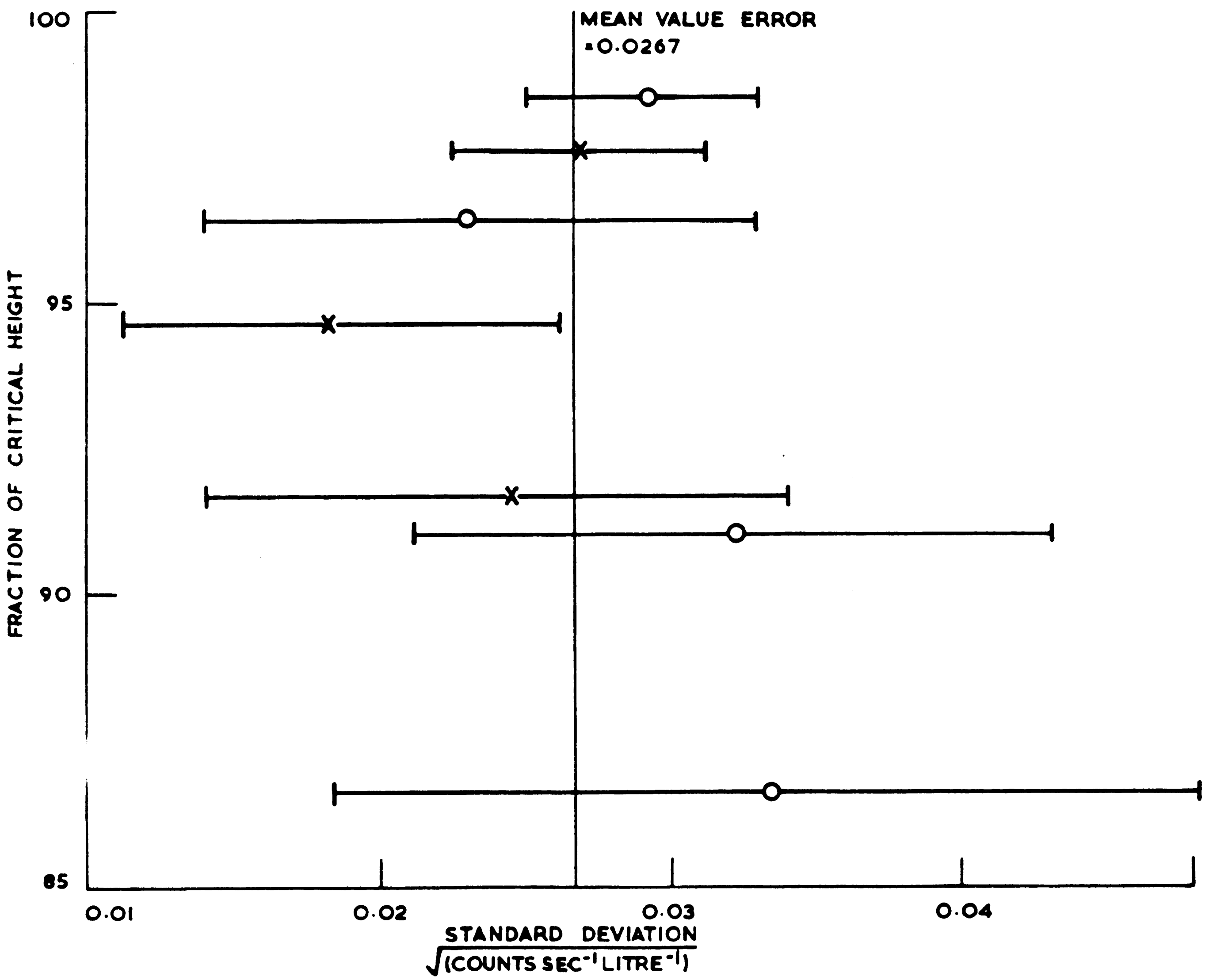


FIGURE 11. STANDARD DEVIATION OF NEUTRON COUNT RATE NOT DUE TO THE POISSON DISTRIBUTION OF NEUTRONS RECEIVED AT THE DETECTORS

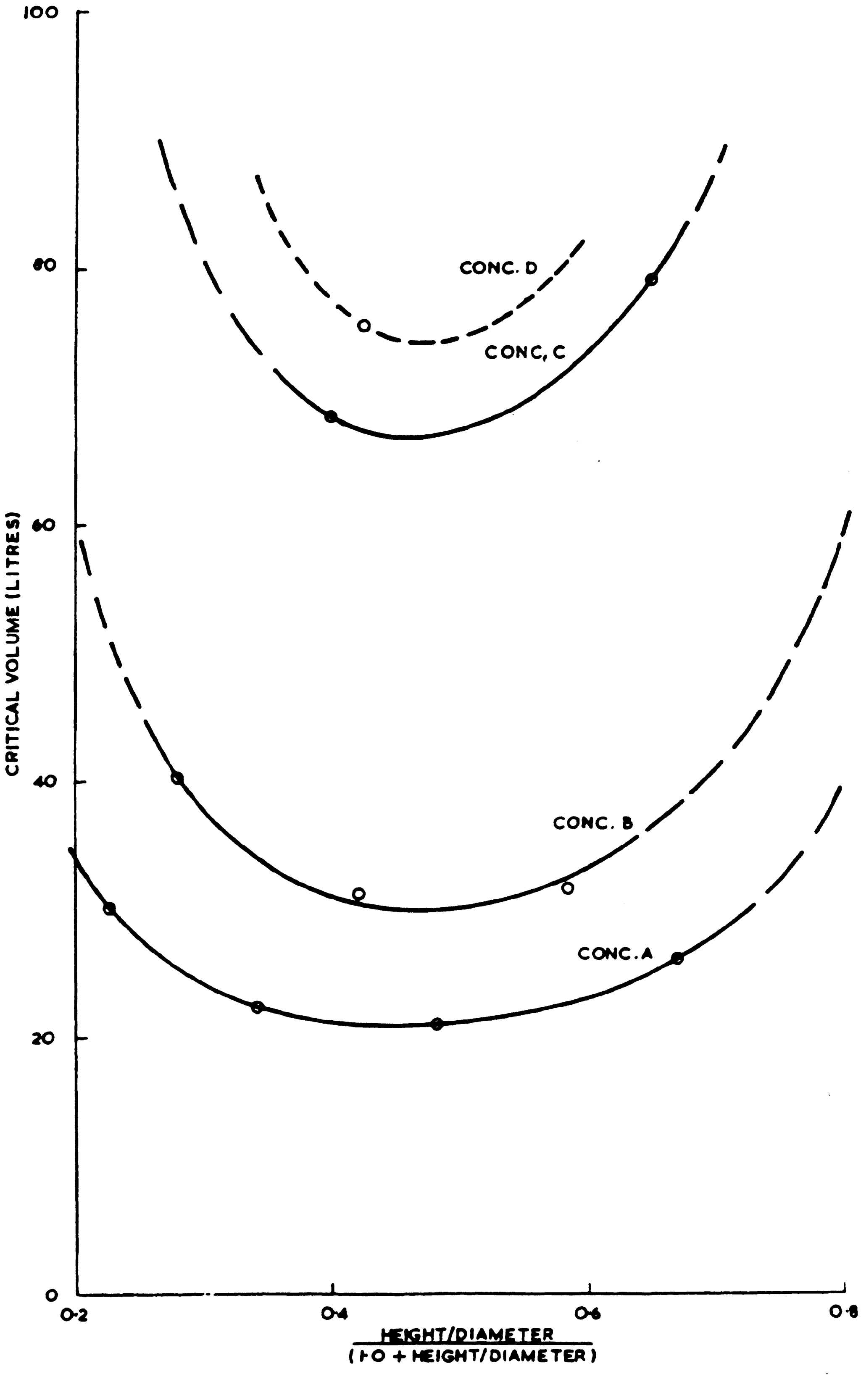


FIGURE 12. CRITICAL VOLUME OF SCAMP CORES (WITH EFFECTIVELY INFINITE WATER REFLECTOR) AS A FUNCTION OF CORE SHAPE.