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December 2, 1983

John H. Frye, III, Chairman
Administrative Judge
Atomic Safety and Licensing Board
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dr. Emmeth A. Luebke
Administrative Judge
Atomic Safety and Licensing Board
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Glenn O. Bright
Administrative Judge
Atomic Safety and Licensing Board
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Washington, D.C. 20555

In the Matter of
THE REGENTS OF THE UNIVERSITY OF CALIFORNIA
(UCLA Research Reactor)
Docket No. 50-142
(Proposed Renewal of Facility License)

Dear Administrative Judges:

I have enclosed the supplementation of the testimony on the shutdown mechanism which the Board has requested. The supplementation consists of a re-writing of the last section of the testimony which simplifies a number of unduly complicated matters and expands the physical description considerably. Several new figures have been added. University requests that the Board and parties replace the pages in the previously submitted testimony beginning with page 21. Also included is a photograph showing the void region around the outlet pipe channels referred to in the testimony. It is identified as UCLA Exhibit 23. We hope this new information is helpful to the Board and parties.

Also enclosed is "University's Response to CBG's Objections to Rebuttal Testimony."

Very truly yours,

William H. Cormier
Representing UCLA

Enclosures

cc w/enclosures: Service List

DS03

Q.32. Were the Borax and SPERT reactors open systems?

A.32. The Borax-I and SPERT A and B systems were closed in a certain sense. The vessle walls were sufficiently high that for 14 and 16 millisecond pulses, they could not eject enough water to prevent recriticality. After the first pulse they settled to a more or less stable boiling mode (Dietrich, Figure 11 and Schroeder et. al, Figure 8).

Q.33. How would you portray the UCLA Argonaut reactor in this regard?

A.33. In regard to inertial forces, the UCLA Argonaut reactor with a 10 inch water overburden, is less "closed" than either the SPERT-I or Borax-I reactors with overburdens of 2 to 4.5 feet. On the other hand, the larger void requirement demands a greater voiding rate if water eviction is to be achieved in a timely fashion.

Q.34. Explain the shutdown process.

The instantaneous (step) insertion of $3.00 excites a reactor period of approximately 14 msec in the UCLA Argonaut reactor. For the particular UCLA values of the void coefficient and reduced prompt neutron lifetime, the Forbes model of the shutdown or reactivity coefficient predicts a peak adiabatic temperature rise in the fuel plates of approximately 400°C. Comparison of predicted adiabatic peak temperature rises in the SPERT tests suggests that the actual peak temperature would be about 250°C for a 14 msec period. In this temperature region, under the

EXPERIMENTS ON WATER-MODERATED REACTORS

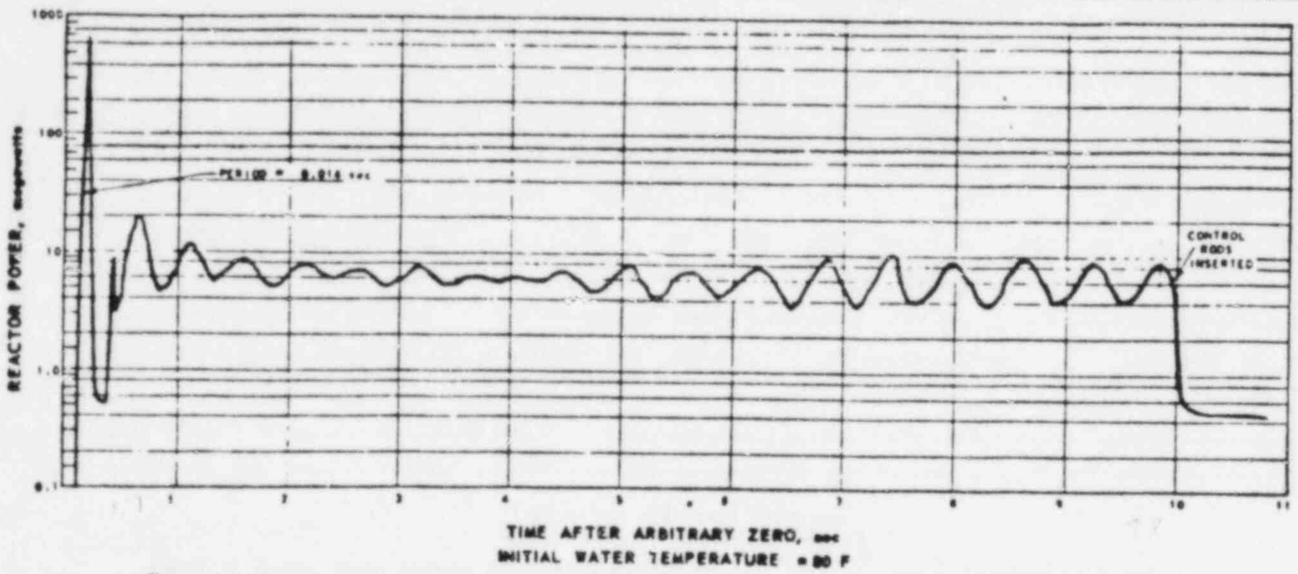


Figure 11. Reactor power variation during 10-second run following initial excursion of 14-millisecond period

BORAX - I

Reproduced from Dietrich, 1955 [1]. p.95

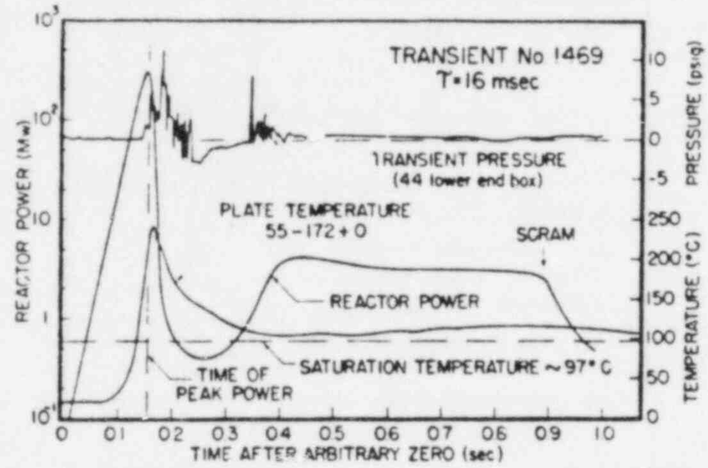


FIG. 8. Representative behavior following 1.0% reactivity addition ($\alpha = 62\ sec^{-1}$).

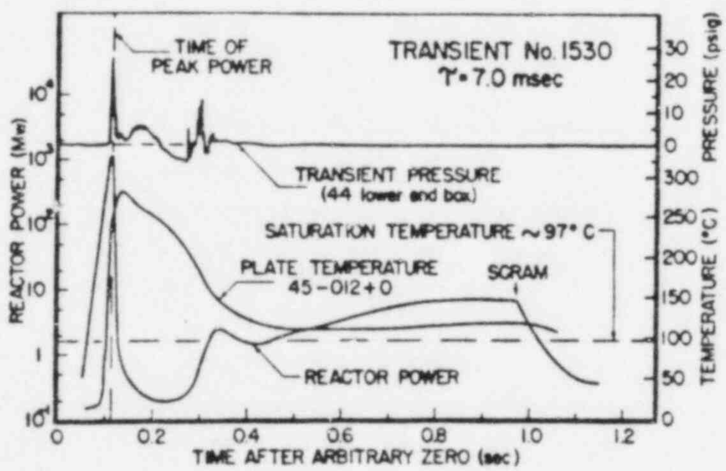


FIG. 9. Representative behavior following 1.4% reactivity addition ($\alpha = 143\ sec^{-1}$).

Reproduced from Schroeder, 1959 [4]. p.102, 103

conditions of a fast transient, the reactor enters the regime of subcooled nucleate boiling. Steam bubbles form and grow from the centermost or hottest fuel plates to the outermost plates in each of the two rows of fuel boxes. The steam formation creates a pressure pulse forcing water up to the top of the fuel boxes. The creation of the steam voids rapidly introduces negative reactivity which soon suffices to cancel the prompt excess reactivity and arrest the power growth. Steam generation and void growth continue to introduce negative reactivity until the displaced water occupies the readily available air volume above the normal water level of the UCLA reactor core.

In the UCLA reactor, the displaced water will rise as a slug in the air space above the fuel box outlet lines and will rupture the horizontal membrane across the bottom of the shield plug, continuing upward, it will fill the wedge shaped region defined by the deflector plate and the horizontal plane of the ruptured membrane. That volume, of approximately 29 square inches in horizontal cross section (per fuel box) with an average height of 3 inches, provides for a void region of 87 cubic inches (1.43 liters) per fuel box or 8.55 liters for the six fuel boxes. From the values given in A.17 and A.18, a void is worth about -209 inhours per liter or -0.75 dollars per liter. Thus the available space above the normal water level is capable of receiving displaced water equivalent to a void worth of about -6.40 dollars, and the net system reactivity at that time will be about -3.40 dollars. The reactor is shutting down exponentially on a period $\tau = (\ell/p) \div (\$ - 1) = -6.6$ milliseconds.

The upward expulsion of water is arrested when the free space is fully occupied. Recriticality is to be expected, and experimentally this occurs approximately 100 milliseconds after maximum power (at the power minima) as illustrated by Figures 8 and 9 of Schroeder et al (2). Water re-entry can only occur when the fuel plate temperatures have fallen to a level such that the re-entering water is not instantly vaporized. In the Argonaut situation, the steam generation will lead to a rapid pressure increase opposing water re-entry, the void is trapped and the deep minima illustrated by Schroeder et al Figures 8 and 9 cannot be expected. The power history will proceed more smoothly toward the asymptotic values of 4 to 8 megawatts (10 to 20 watts per square centimeter) of those Figures. The pressure will rise to a level which will accommodate the steam generation rate, even if this ultimately means rupturing the fuel boxes. The fuel plate temperatures will also asymptotically approach about 10 deg C superheat necessary to sustain nucleate boiling.

An analysis of where the water goes requires investigation of the existing piping, alternate leakage paths, and some description of the void spaces in the central core region exterior to the fuel boxes.

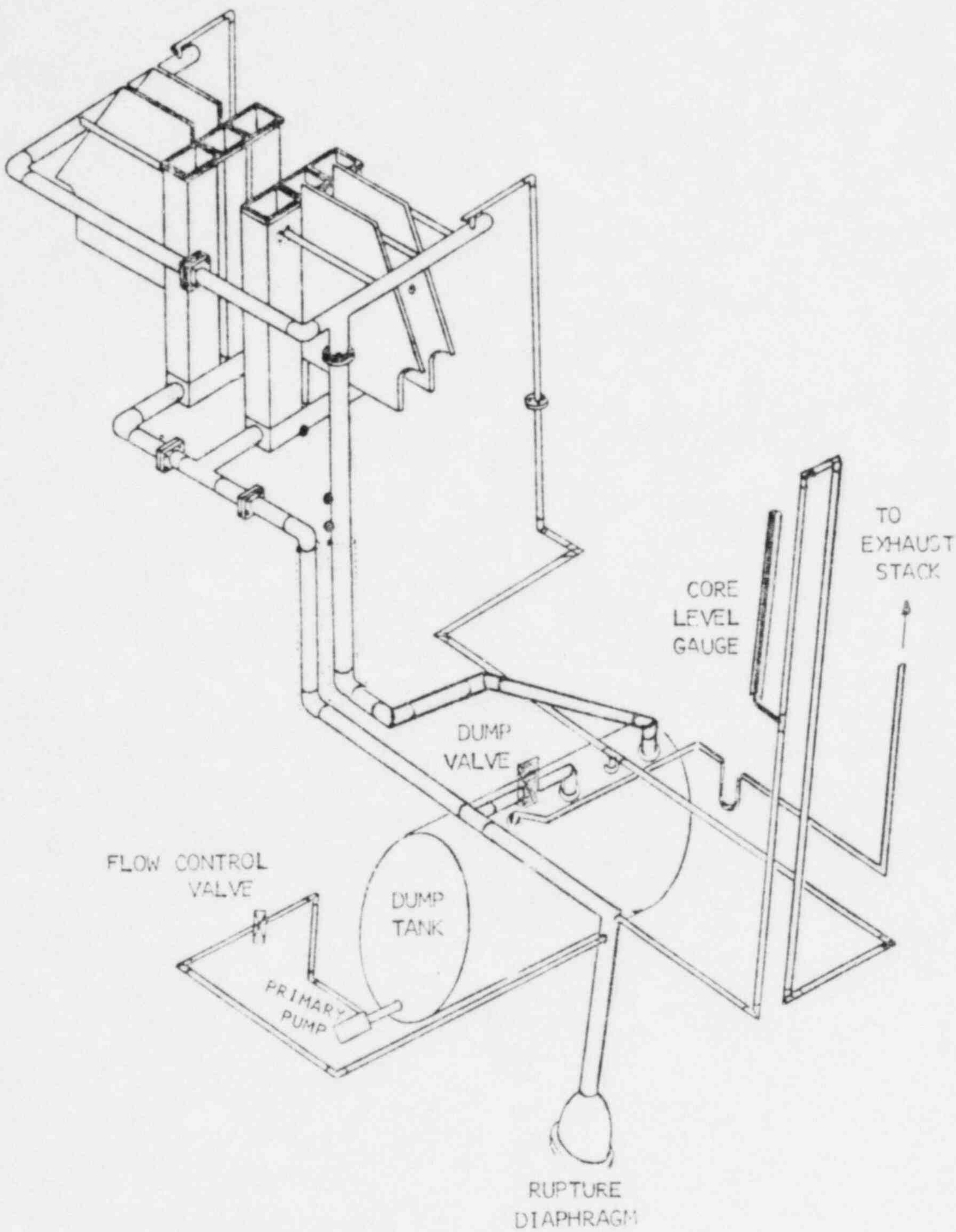
Q.35. Describe the voiding spaces in the UCLA Argonaut?

A.35. The two-slab, three-fuel-box-per-slab reactor core and coolant system is depicted in the following figures:

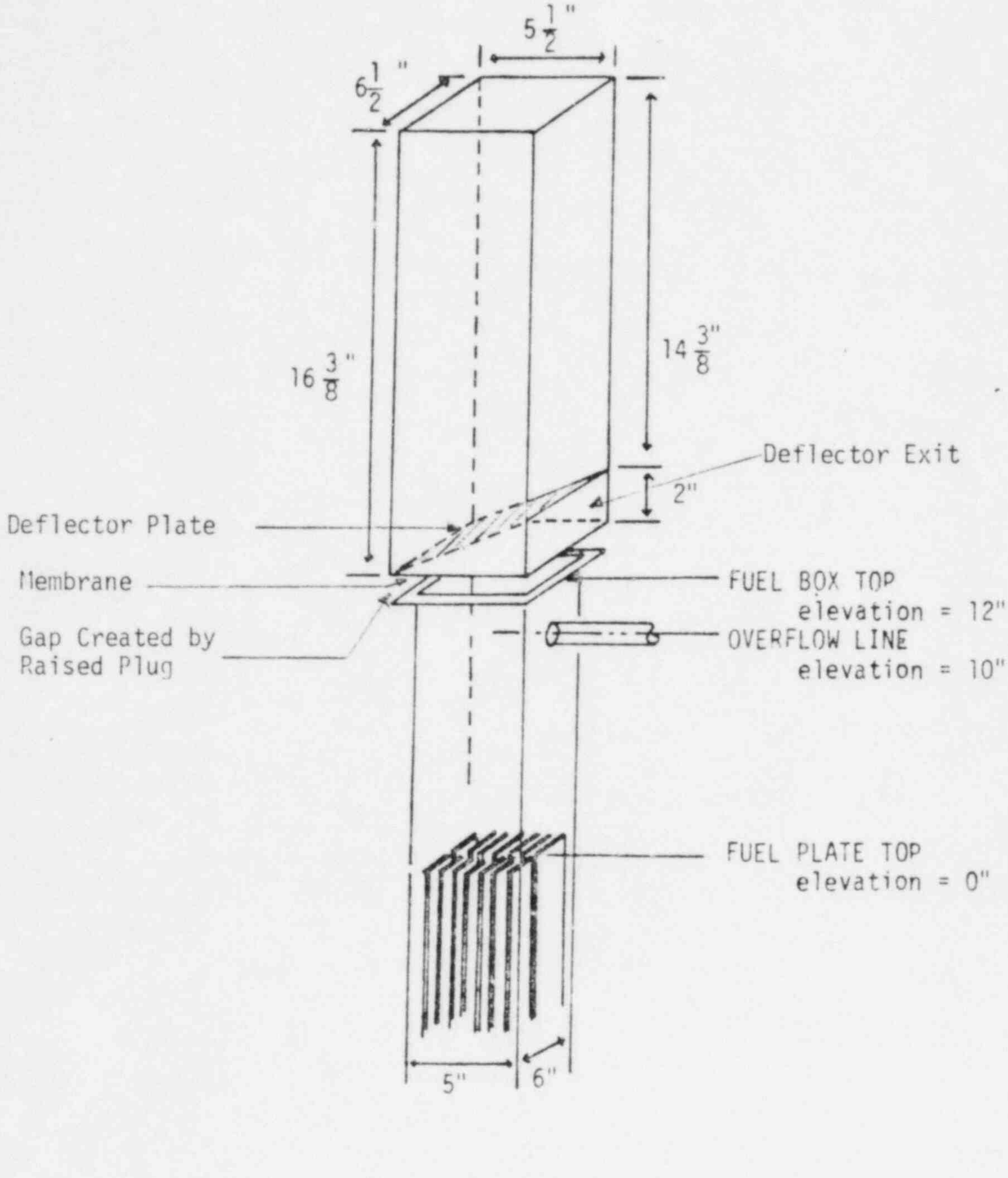
Figure (a) is a schematic of the coolant system which shows the six outlet pipes exiting from the top of each fuel box and the position of the rupture disk which is located at the end of the inlet line.

Figure (b) is a dimensional diagram of a fuel box and fuel box plug. During normal operation water flows into the fuel boxes at a rate of about 16 gallons per minute rising to a level about the midpoint of the overflow line which is approximately 10" above the top of the fuel plates. The overflow or outlet line is 2" below the top of the fuel box flange.

The fuel box plug is shown in Figure (d), with the dimensions given in Figure (b). The plug rests on top of the fuel box, the outside dimensions of the plug approximately equal with the outside dimensions of the fuel box lip. The top 10 inches of the plug consists of graphite, the next 4 inches below that is a lead section. Below the lead there is a rectangular void space partitioned into two wedges by a sloping deflector plate. The deflector region opens to the outside face (overflow line side) of the fuel boxes creating an aperture of approximately 6 1/2 inches by 2 inches. Mounted near the bottom of the deflector region, there is a thin aluminum membrane which during normal operation seals the top of the fuel box to prevent water vapor from reaching the graphite reflector, an effect which reduces reactivity. The membrane is mounted approximately 1/3 inch above the bottom of the fuel plug (top of the fuel



Cooling Water System
Figure (a)



Fuel Box and Shield Plug Geometry

Figure (b)

ISOMETRIC VIEW

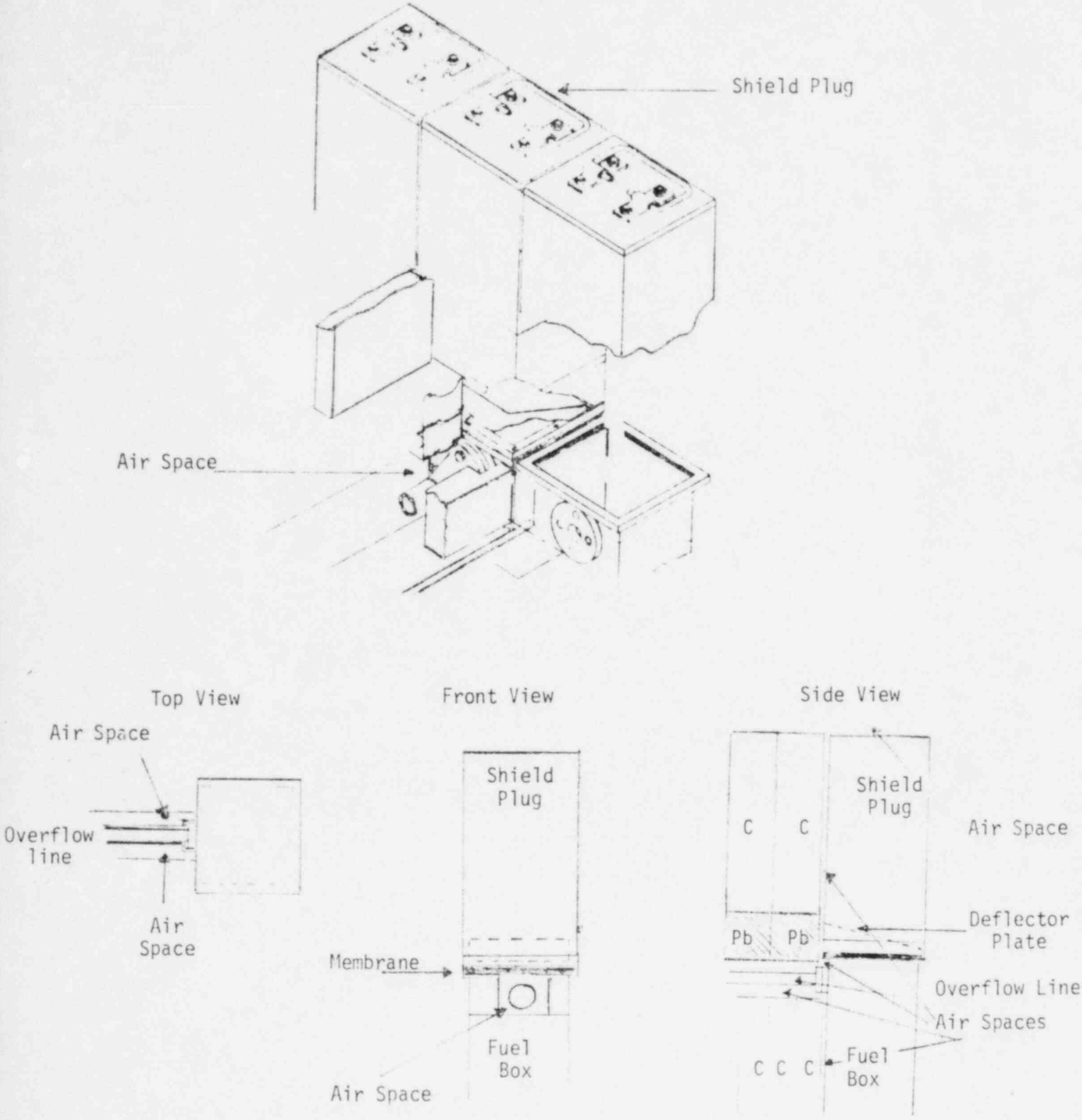
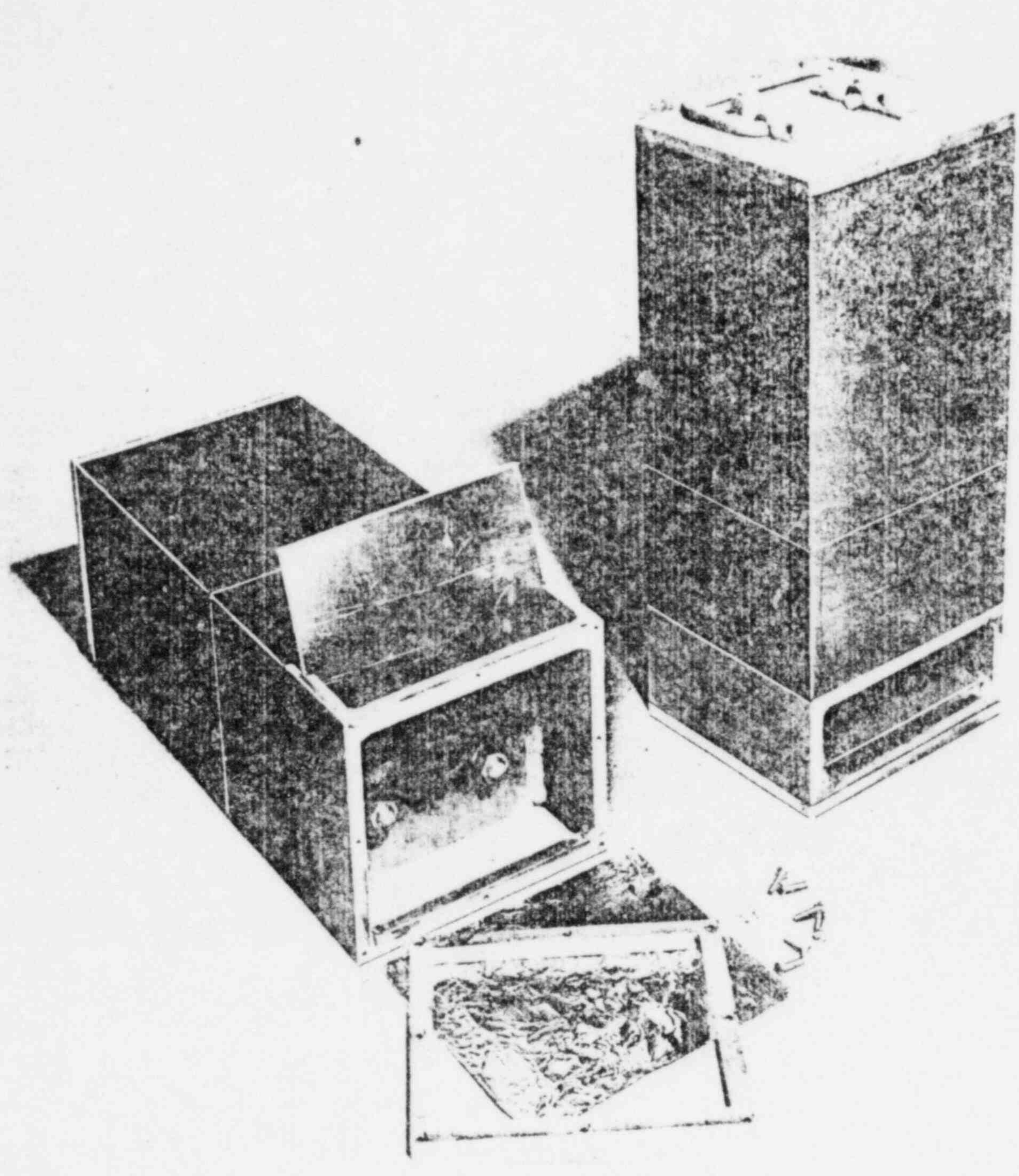


Figure (c)
(not to scale)



LEAD GRAPHITE SHIELDING PLUG

Figure (d)

box) by a flange.

Figure (d) shows the membrane, flange and deflector plate, which has been partially withdrawn to show two of the four bolts which clamp the fuel plug assembly together.

The principal spaces which are easily defined are the overflow pipes, their manifolds, and the square pipeways which contain the circular pipes. The interior volume of the pipe is not more than fifty percent occupied at the initiation of the transient and provide free volume of 0.64 liters and 8.1 liters in 90 inches and 140 inches of overflow and manifolding respectively. The pipeways through the reflector (Exhibit 23 and Figure (c)) provide at least 0.55 liters adjacent to the overflow lines and 6.0 liters adjacent to the manifolding.

Less well-defined spaces exist because of the difficulty of fitting rectangular blocks (lead bricks and graphite) to circular flanges, curved elbows, and tees.

Finally, there are clearances around the shield plugs, above the control blade shrouds, around the control blade drive shafts and couplings as well as other imperfections in the stacking of lead bricks and graphite.

The total volume of all such interstitial spaces is unknown. These spaces should not be viewed entirely as reserviors, but rather as

passages through which water can be forced to leak with transitory occupancy prior to draining to the vented dump tank or the process pit sump.

It can also be noted that the five to six feet of concrete above the core weighs no more than seven to 10 pounds per square inch and pressures of this magnitude distributed over a substantial portion of the core would lift the concrete to form new and larger void spaces.

Q.36. Where does the water go upon exiting the deflector region?

A.36. I misspoke earlier when I said the deflector plates face a graphite wall. The deflector plate aperture actually faces the first layer of lead bricks which are stacked on top of the graphite. But the situation is the same. The shield plugs weigh about 100 pounds each and are manually removed and reinserted during fuel changes. To accomplish this, a clearance is required which I and others estimate to be about 1/8 inch. That is the lead bricks which surround the deflector region of the fuel box plug are separated from the plug by a 1/8 inch gap. The first layer of lead bricks around the top of the fuel boxes rest on top of the graphite blocks. The graphite blocks outside the fuel box on the side of the deflector aperture are cut out by means of square cuts to accommodate the round outflow line and flange leading horizontally from each of the fuel boxes to the edge of the core region. (The void spaces that

exist around the outflow lines and control blade shrouds are best seen in the photographs intorduced as UCLA's Exhibits 6, 7, and 8; Exhibit 12 is a photograph of the first layer of lead bricks stacked on top of the graphite). There is thus at least one passage way from an origin near the deflector plate exit toward the larger volume region around the manifold.

Q.37. What is the role of the rupture disk in influencing the course of the event?

A.37. At a pressure of 47 psig, the thirty feet of water in that line will accelerate at about 3500 cm/sec^2 or 162 $liters/sec^2$. The time required to expel 35 liters through this line will be about 0.66 seconds. The 35 liters is that quantity which will preclude criticallity (all of the water overburden and 15 percent of the water in the fuel plate region). The time taken for the pressure pulse to reach and break the rupture disk (< 10 ms) will be negligible relative to the expulsion time via this route.

Q.38. How much water can be expelled through the one inch overflow lines?

A.38. These lines have a cross-sectional area of 5.07 cm^2. At a pressure difference of 47 psi absorbed by entrance and exit losses of one velocity head ($1/2\ \rho v^2$) each, the velocity of 18 meters/sec would provide a combined flow rate through the six lines of about 55 liters per second.

If these lines and the rupture disk line are considered jointly, the expulsion of 35 liters with a pressure differential of 47 psi

will require about 0.40 seconds. The flow rate at t = 0.40 seconds is about 81 liters per second.

Q.39. The SPERT experimental data indicate that pressures fall below one atomosphere during the recritically stage. This does not appear to be consistent with the high pressures assumed in the proceeding answer. Please explain.

A.39. In the experiments, the adiabatic expansion of the void leads to condensation and sub-atmospheric pressure. Although something like this may happen with the trapped void in the UCLA reactor the trapping occurs fairly early, and sub-atmospheric pressures may not arise at all. Boiling continues in regions peripheral to the void (at the center of the core), which in reality can occupy no more than 23 percent of the core volume due to the space limitation. This tends to maintain an elevated pressure.

The time scale for recriticality is dictated by fuel plate cooling, which experimental data indicates is on the order of 100 milliseconds. This is, as the fuel plates cool, water tends to reenter the core with two effects. It moves the system towards criticality and it moves the system into a normal (saturated nucleate boiling mode). In the saturated nucleate boiling mode fuel plate surface temperatures are rarely more than 20^{0} C above the saturation temperature.

Q.40. What factors suggest the 47 psi pressure?

A.40. The first factor is the steam generation rate. The SPERT-IA data of Schroeder's Figures 8 and 9 indicate that semi stable power levels of 4 to 8 megawatts were attained following recriticality. The heat transfer area of that core was approximately 4×10^5 cm^2 and the corresponding average heat flux is 10 to 20 watts/cm^2. A value of 12 watts per square centimeter was selected to represent the UCLA reactor. This is a conservatively high number because it leads to expulsion times which are comparable to or shorter than the time required for the SPERT-IA reactor to settle to their asymptotic heat fluxes.

The steam generation rate at 12 watts/cm^2 is approximately 0.056 grams/cm^2-sec for a total of 920 gms/sec over the 1.6×10^5 cm^2 of heat transfer surface in the Argonaut core.

The second factor is the estimated flow area through which water can be expelled. The most important areas are leakage paths rather than the existing plumbing. In this model, the rupture disk line responds too slowly and the overflow lines are too small to handle the requisite flow rates at any reasonable pressure. A consequence of this model, using steam generation at 12 watts/cm^2, is that leakage will be forced.

The assumed leakage paths are comprised of (1) a gap or clearance of 1/8 inch between the deflector exit and the adjacent lead bricks and (2) a gap of 0.2 inches created at the top of the fuel box by lifting the fuel box shielding plug. The flow area of the six overflow lines ($5.07 \times 6 = 30.4\ cm^2$) is also added.

Assuming a clearance of 1/8 of an inch at the deflector area exists around the entire perimeter (17 inches) of each of the six deflector exits (2" x 6.5"), a total flow area of 82.3 cm^2 is provided. Assuming a uniform 0.2 inch clearance between the fuel box lip and the bottom of the lifted plug which is useful around the perimeter of each of the two fuel box triads (50 inches of perimeter per triad), an additional flow area of 129 cm^2 results. The sum of the three flow areas is $30.4 + 82.3 + 129 = 242\ cm^2$.

Assuming that a pressure drop of 47 psi is absorbed by two velocity heads across this gap, the flow velocity will be 18 meters/sec and the volume rate about 440 liters/sec.

The actual steam volume rate of 920 grams per second at 47 psig is about 405 liters/sec and according to this model, the expulsion of 35 liters at a rate of 405 liters/sec will be accomplished in less than 0.10 seconds. The 47 psig is a result of seeking that pressure at which the steam generation rate (405 liters/sec) approximately balances the water expulsion rate (440 liters/sec) through a specified area (242 cm^2).

Q.41. Why do the shield plugs lift?

A.41. The shield plugs weigh about 100 pounds each and have a cross sectional area of about 29 square inches. The shield plugs rest on top of the fuel boxes and are not secured in any way. A gap exists between the top of the plugs and the shield blocks on top. The plugs will lift at a pressure of 3.45 pounds per square inch (3.45 psi).

Q.42. There is a horizontal thin aluminum membrane near the bottom of the fuel box shield plug. How does it influence the water expulsion?

A.42. The membrane is an aluminum rectangle 5 inches by 6 inches and a thickness of 0.020 inches.

Using "Marks" Standard Handbook for Mechanical Engineers, seventh edition (Baumuster, ed, McGraw-Hill), section 5, pages 68, 69, and 70, case 16 leads to a uniform loading of about 1.5 psi to rupture aluminum of 24000 psi ultimate tensile strength. That tensile strength is the upper limit cited in the same reference, same section, page 5.

In all likelihood, the membrane will be ruptured by the air as it is compressed above the rising water. The air, with a density one thousandth that of water, can easily escape through the 1/8 inch gap at the deflector exit.

Q.43. At A.35, a number of void spaces within the core are described, some in only qualitative terms. The description does not sum to 35 liters and the question of where the water goes is unanswered. Will you explain?

A.43. A full response to that question certainly involves consideration of the several related questions concerning the quantity of water, the disposition versus time, and the connectivity of the interstital spaces described in A.35. No detailed information of that kind exists.

However, and for example, there is a clearance of at least 1/2 inch between the top layer of graphite and the bottom of the upper shield blocks. With an areal extent of 25 square feet, that volume alone is about 30 liters. If the pressure near the fuel box tops rises to 10 psi or so, graphite and concrete can be lifted and totally change the connectivity of the interstitial spaces.

In brief, the water pressure will rise to whatever level is necessary to occupy existing voids or to create new voids of temporary residence. The likelihood of squeezing any of that water back into the core is extremely remote, there are too many optional leakage paths.

On a much longer time scale, the bulk of the water will go to the process pit and sump via the reactor floor drain under the influence of gravity.

Q.44. What are the fuel plate temperatures during the return to criticality?

A.44. The temperatures decline toward a level about 10 deg C above the saturation temperature (boiling point). At 47 psig, the asymptotic fuel plate temperature is about 156 deg. C.

Q.45. Will there be oscillations or "chugging?"

A.45. Not of the kind exemplified by BORAX-I (Figure 10 of Dietrich, second curve). The volume expansions and contractions associated with chugging are strongly limited by the fuel box shield plug and the time scale for water expulsion is too short to permit extended "power chugging" which Dietrich (1) describes as having a repetition rate of about one per second. He further states that the amplitude of the pulse following the first burst is smaller than that of the first peak. The temperatures must necessarily follow that same pattern; that is, they will be less than those arising in the first peak.

The experimental evidence does not preclude the occurrence of the short period oscillations in the UCLA reactor that are manifested by closely spaced positive and negative pressure pulses. These are fast, self-cancelling, and do not sensibly alter the longer term average behavior of the system. Figure 11 of Dietrich illustrates a sequence with a frequency of about 2 per second, and the amplitudes are very small relative to the first power maximum.

Q.46. If the circulating pump continues to operate, how will that alter the course of events?

A.46. Assuming that the power approaches 12 watts/cm^2, the steam generation rate is approximately 920 grams per second which at a pressure of 47 psig is a volume displacement rate of 405 liters per second. The normal circulation rate of 16 gallons per minute or 1 liter per second is negligible relative to the expulsion rate of 405 liters per second.

Q.47. Please summarize your conslusions regarding the self-limiting shutdown of the UCLA Argonaut reactor?

A.47. There is more than an adequate margin of safety to preclude fuel melting in the first burst initiated by a 14 millisecond transient. Following the first burst, the rate of water return is limited by evolving steam, and can represent only a ramp insertion of reactivity. The subsequent rise of power will be similar to that of a boiling water reactor with water leaks which remove moderator and in which the energy generation is dissipated by producing steam. Although I have ignored the rupture disk line in the analysis, it could become a useful release route if the boiling stage is at lower pressure and hence more prolonged than I have estimated. I find no phenomena here that can induce melting and fission product release, and hence there is no potential for endangering the public health and safety in such an event.

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