CRITICALITY ACCIDENTS

WHEN, WHERE, CONSEQUENCES
LESSONS LEARNED

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ANS Trinity Section

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LA-13638

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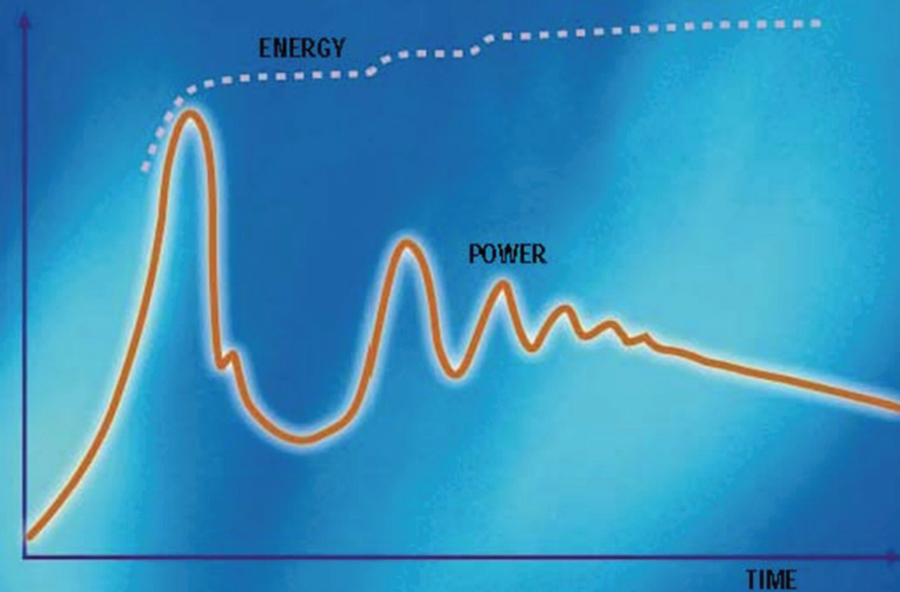
A Review of Criticality Accidents

2000 Revision



Los Alamos
NATIONAL LABORATORY

Los Alamos, New Mexico 87545

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36.

LA-13638 - CONTENTS

- Process Accidents
  - Accident Descriptions
  - Physical and Neutronic Characteristics
  - Observations and Lessons Learned
- Reactor and Critical Experiment Accidents
  - Fissile Solution Systems
  - Bare and Reflected Metal Assemblies
  - Moderated Metal or Oxide Systems
  - Miscellaneous Systems
- Power Excursions and Quenching Mechanisms

CATEGORIES OF CRITICALITY ACCIDENTS

Critical Assemblies/
Reactor Experiments

~ 50,000 Experiments

38 Accidents

12 Fatalities

Process Operations

22 Accidents

21 Solution; 1 Metal

9 Fatalities

Process Criticality Accidents

Total Reported = 22	21 Solutions; 1 Metal
Worker Fatalities = 9	
Public Exposures:	Not health threatening; Measured levels in only One accident
Environmental Contamination:	Negligible
Equipment Damage:	Negligible

CHRONOLOGY OF PROCESS ACCIDENTS

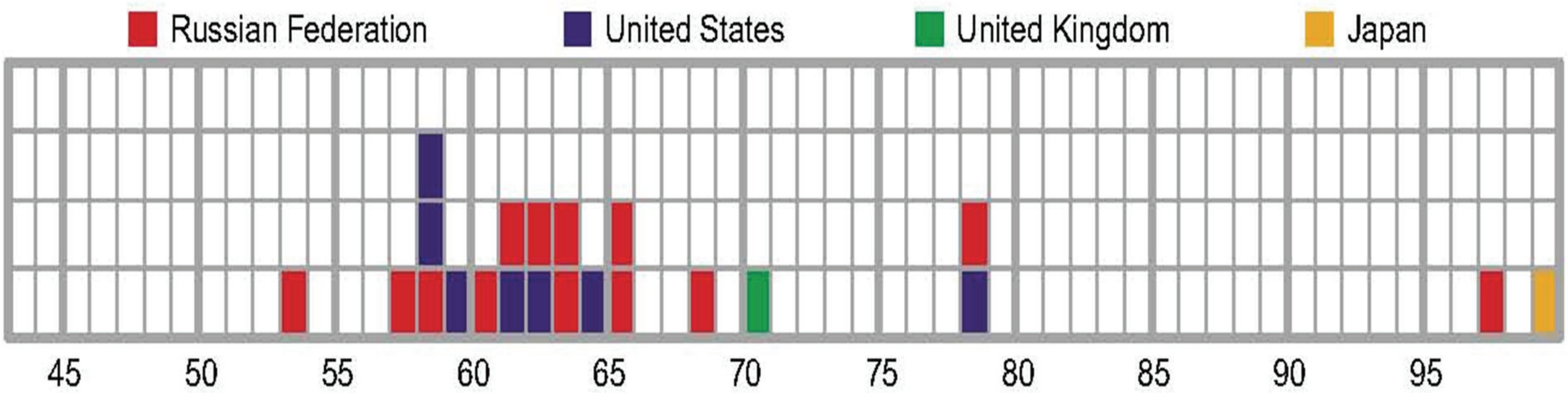


Figure 1. Chronology of process criticality accidents.

RUSSIAN FEDERATION ACCIDENTS

Figure 2. Map of the Russian Federation showing the sites of the process criticality accidents, the capital, Moscow, and Obinisk, the location of the regulating authority, IPPE.

UNITED STATES ACCIDENTS

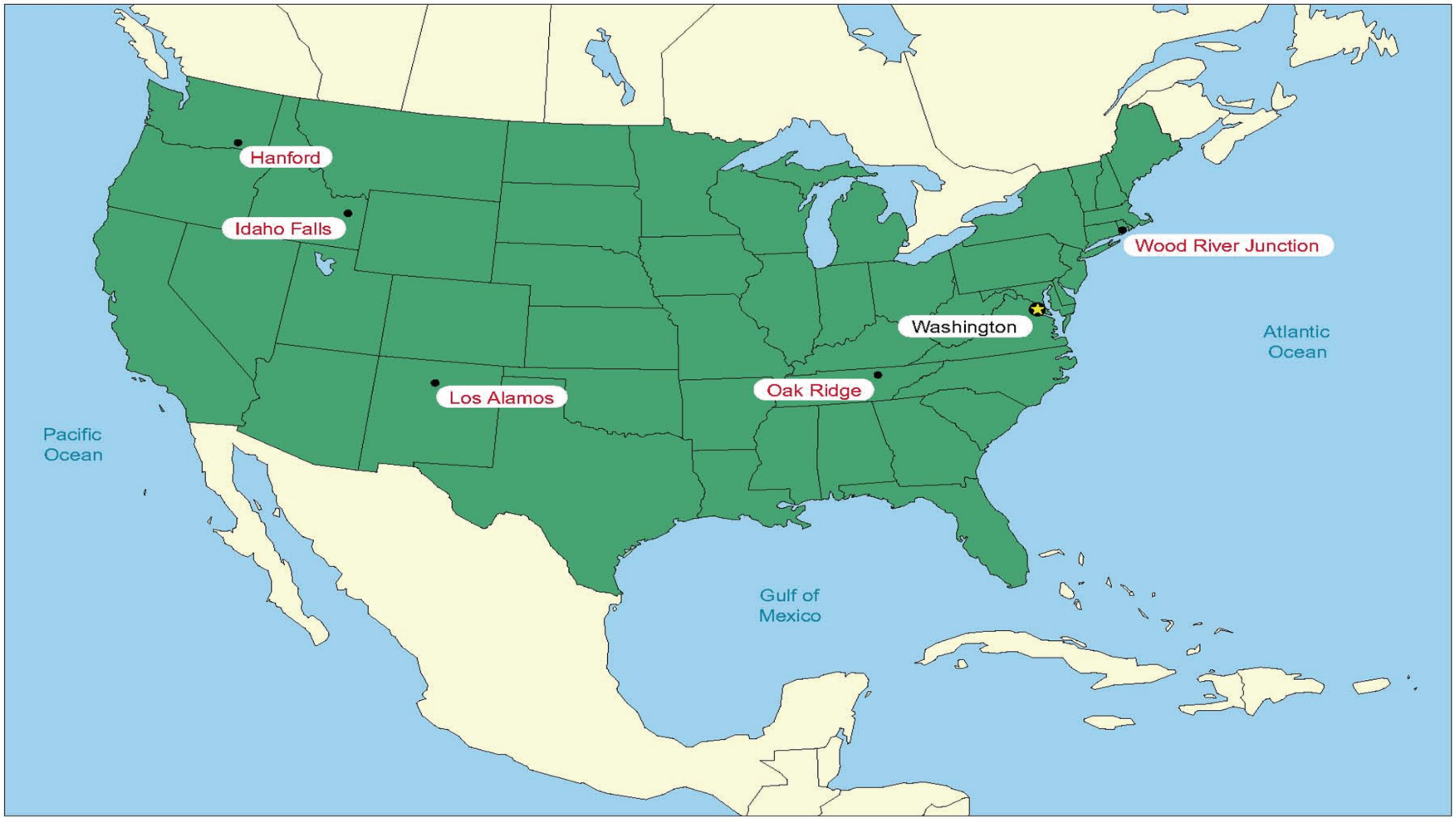


Figure 3. Map of the United States showing the sites of the process criticality accidents, and the capital, Washington.

BRITISH ACCIDENT

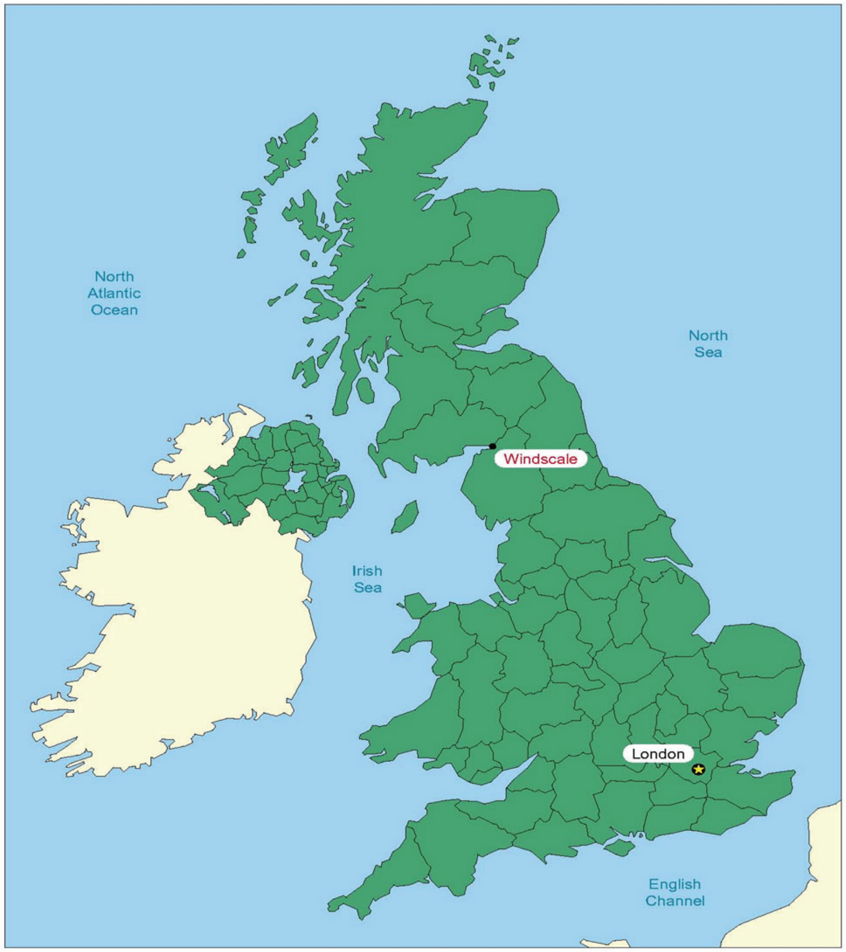


Figure 4. Map of the United Kingdom showing the site of the process criticality accident and the capital, London.

JAPANESE ACCIDENT

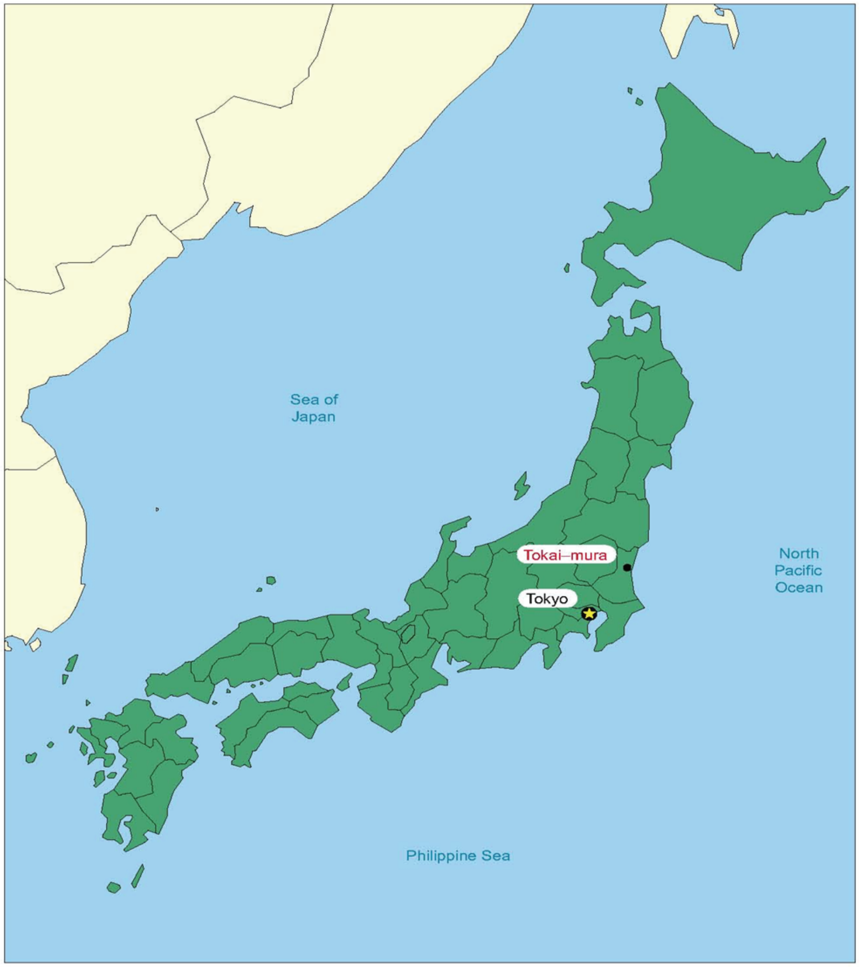


Figure 5. Map of Japan showing the site of the process criticality accident and the capital, Tokyo.

OBSERVATIONS

- Accident Frequency: zero; 1/yr; 1/10 yrs; ???
- Storage Operations: none
- Transportation Operations: none
- Significant Exposures: Only Immediate Vicinity
- Shielded Operations: Negligible Exposures
- None Attributed Solely to Equipment Failure

OBSERVATIONS

- None Attributed to Faulty Calculations
- Many Occurred During Non-Routine Operations
- Administrative Considerations Determined Facility Down-time
- No New Physical Phenomena

LESSONS LEARNED - OPERATIONAL

- Avoid unfavorable geometry vessels in areas with high-concentration solutions.

- Put important instructions, information, and procedural changes in writing.

- Understand processes thoroughly so that credible abnormal conditions are recognized and analyzed.

LESSONS LEARNED - OPERATIONAL

- Fissile material accountability (MC&A) is integral to a good NCS program.
- Operator understanding of NCS implications of proper response to process upsets is important.
- Operations involving both organic and aqueous solutions require extra diligence.

LESSONS LEARNED - OPERATIONAL

- Remote readouts of radiation levels where accidents may occur should be considered.
- Operations personnel should be made aware of criticality hazards and stop work policies.
- Operations personnel should be trained to understand the basis for why they must always follow procedures.

LESSONS LEARNED - OPERATIONAL

- Hardware that is important to criticality control and whose failure or malfunction would not necessarily be apparent to operators should be used with caution.

- Criticality alarms and adherence to emergency procedures have saved lives and reduced exposures.

LESSONS LEARNED – SUPERVISORY, MANAGERIAL AND REGULATORY

- Process supervisors should ensure that operators are knowledgeable and capable.
- Equipment should be designed with ease of operation as a key goal.
- Policies and procedures should encourage self-reporting of upsets and err on the side of learning more, not punishing more.

LESSONS LEARNED – SUPERVISORY, MANAGERIAL AND REGULATORY

- Senior management should be aware of the hazard of accidental criticality and its consequences.
- Senior management and regulators should be aware of operations with criticality hazards.
- Regulators should ensure that those they regulate are knowledgeable and capable.
- Regulations should promote safe and efficient operations.

CONCLUSIONS

- Likelihoods of criticality accidents are extremely low, but will never be zero.
- Diligence is required to maintain a proper, acceptably low, accident risk while balancing the need for process ease and efficiency.

MAYAK 1953

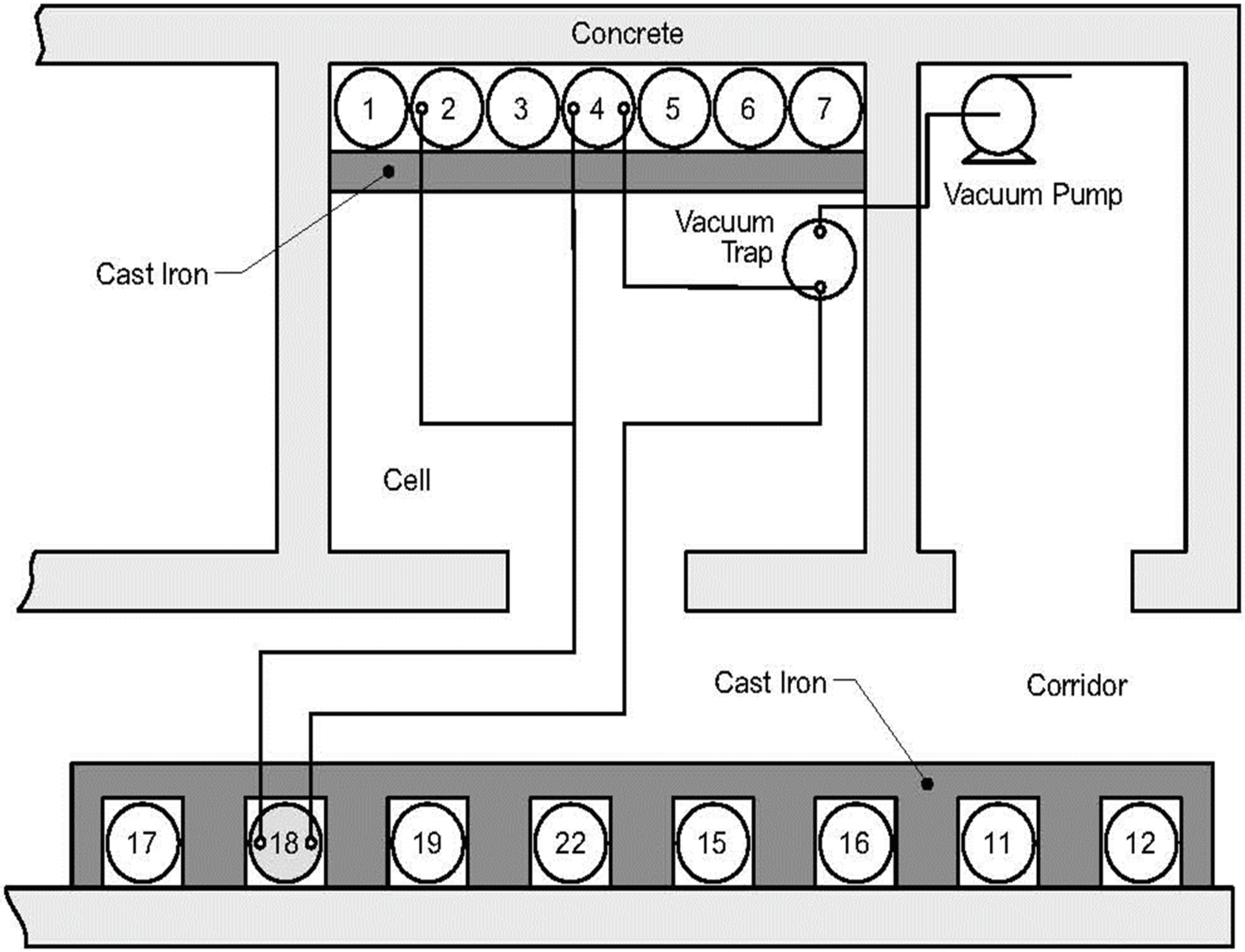


Figure 6. Layout of vessels and equipment in the staging area.

MAYAK 1957

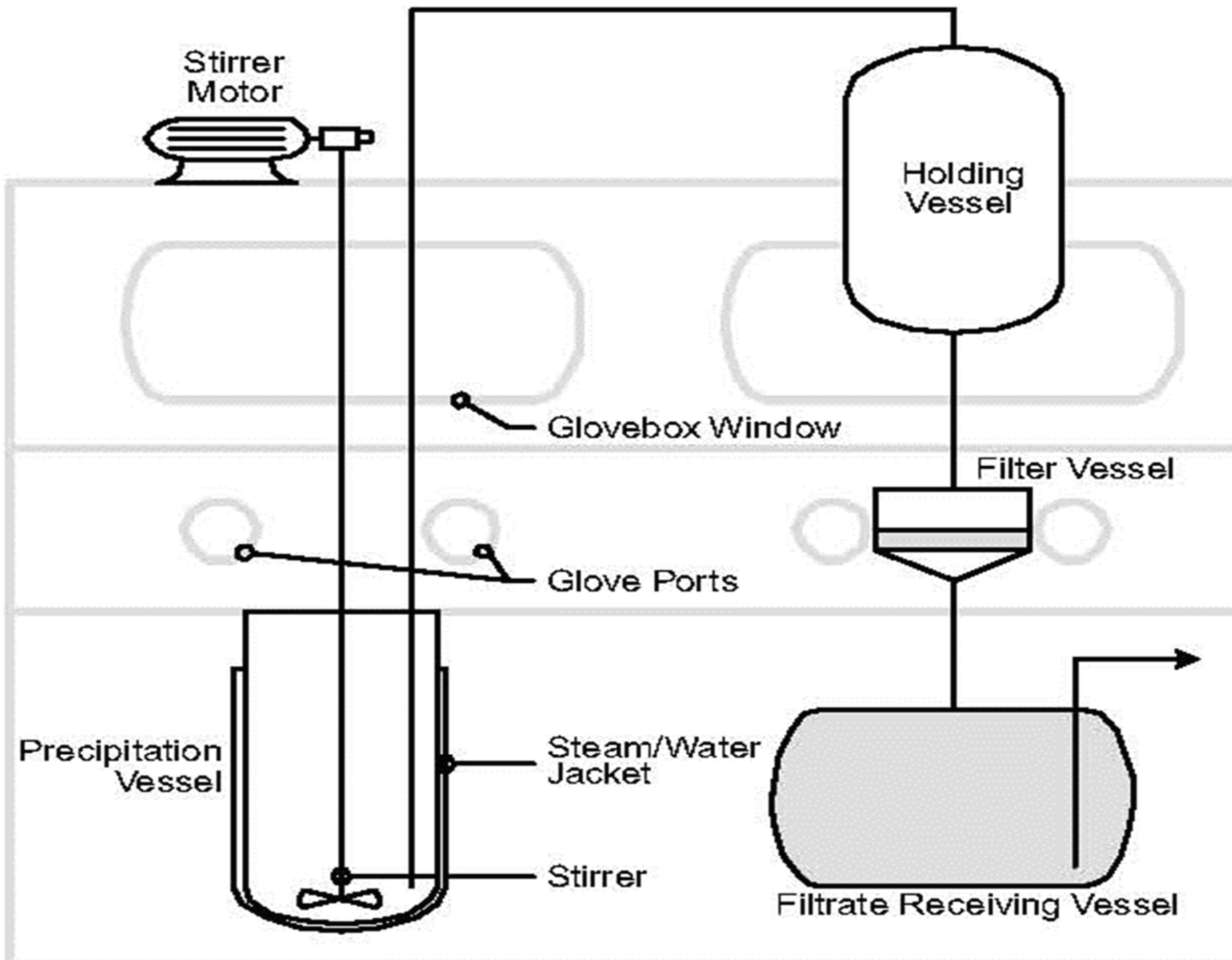


Figure 7. Equipment layout for the oxalate precipitation and filtration process.

MAYAK 1958

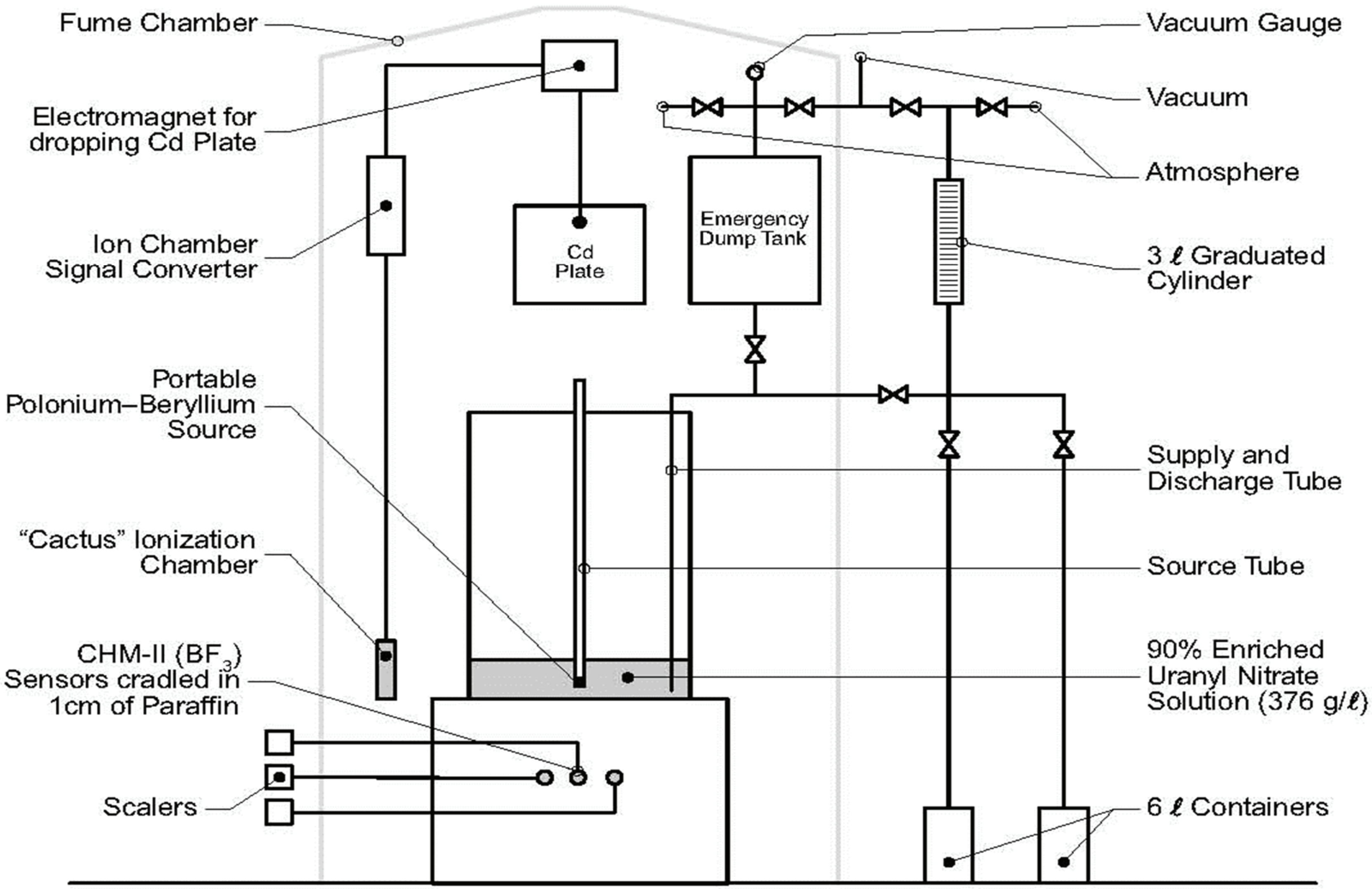


Figure 8 Layout of the experimental equipment

OAK RIDGE, Y-12   1958

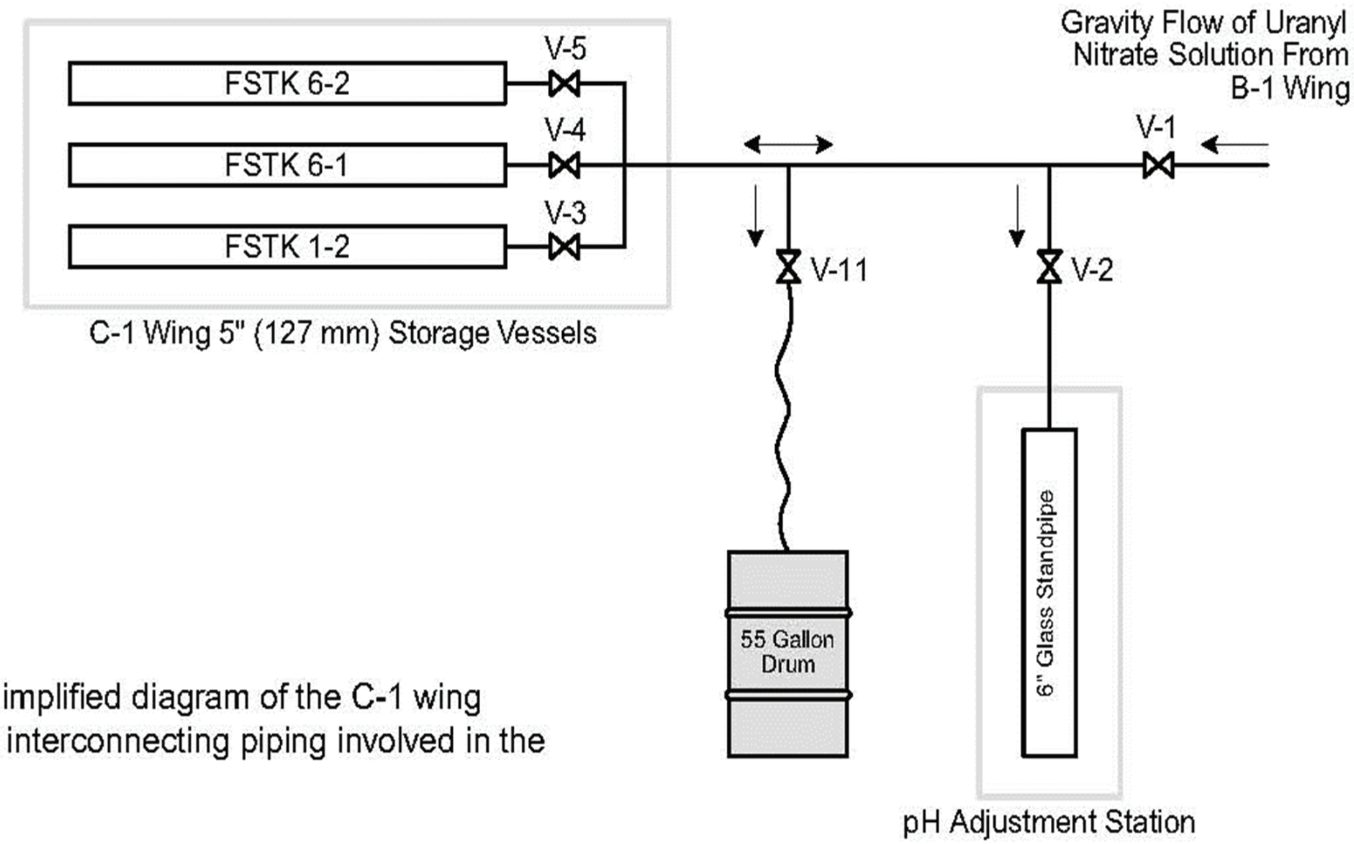


Figure 9. Simplified diagram of the C-1 wing vessels and interconnecting piping involved in the accident.

LOS ALAMOS 1958

Figure 12. Vessel in which the 1958 Los Alamos process criticality accident occurred.

LOS ALAMOS 1958

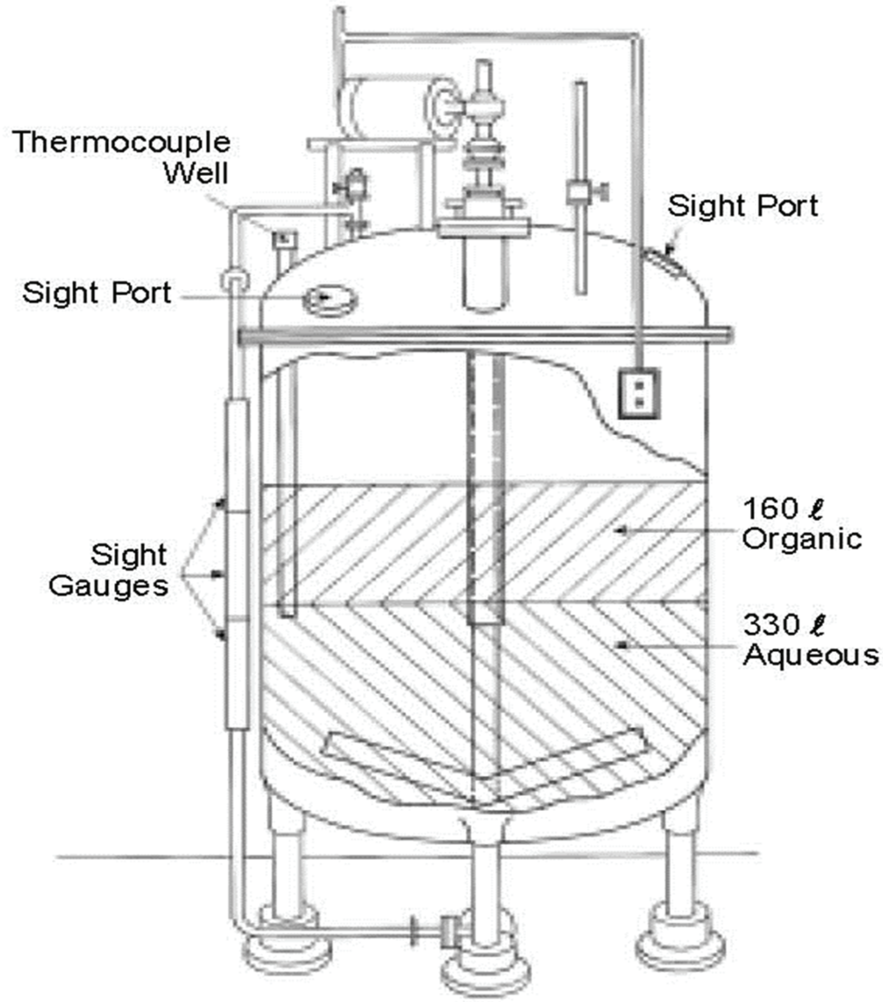


Figure 11. Configuration of solutions (aqueous and organic) in the vessel before the accident.

MAYAK 1960

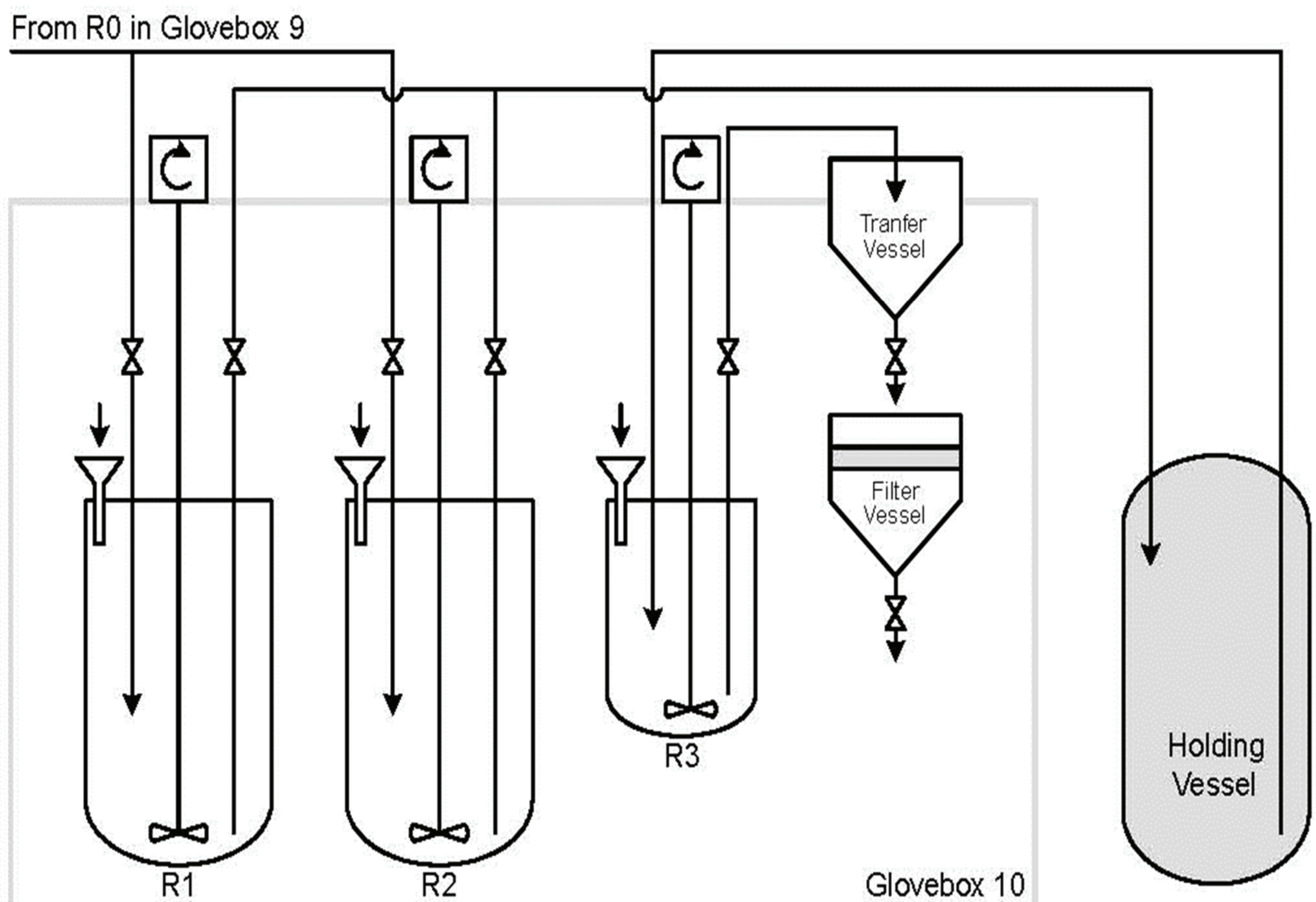


Figure 13. Layout of vessels in Glovebox 10 and the holding vessel external to the glovebox.

TOMSK, SCC 1961

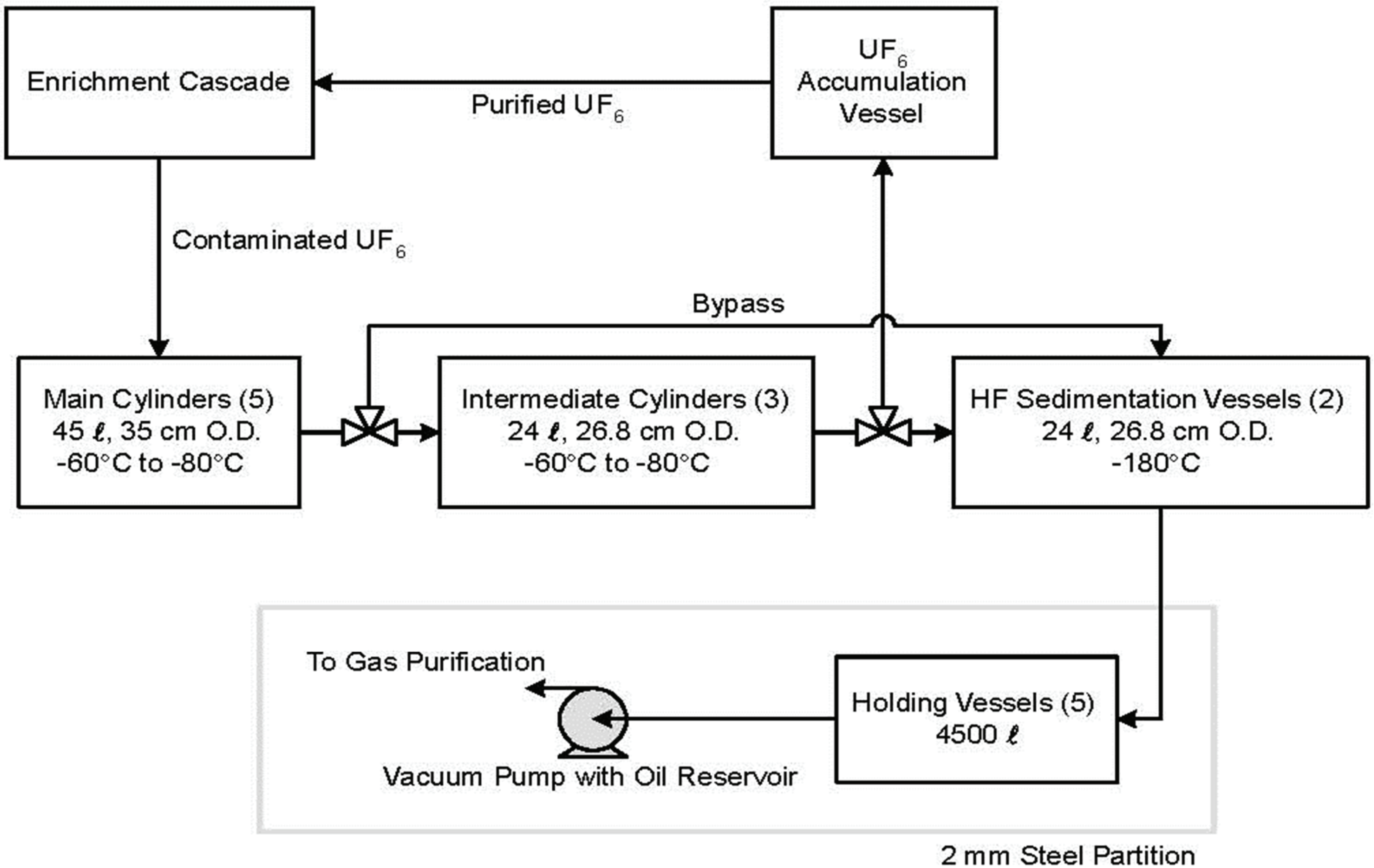


Figure 14. Layout of DSS–6.

TOMSK, SCC   1961

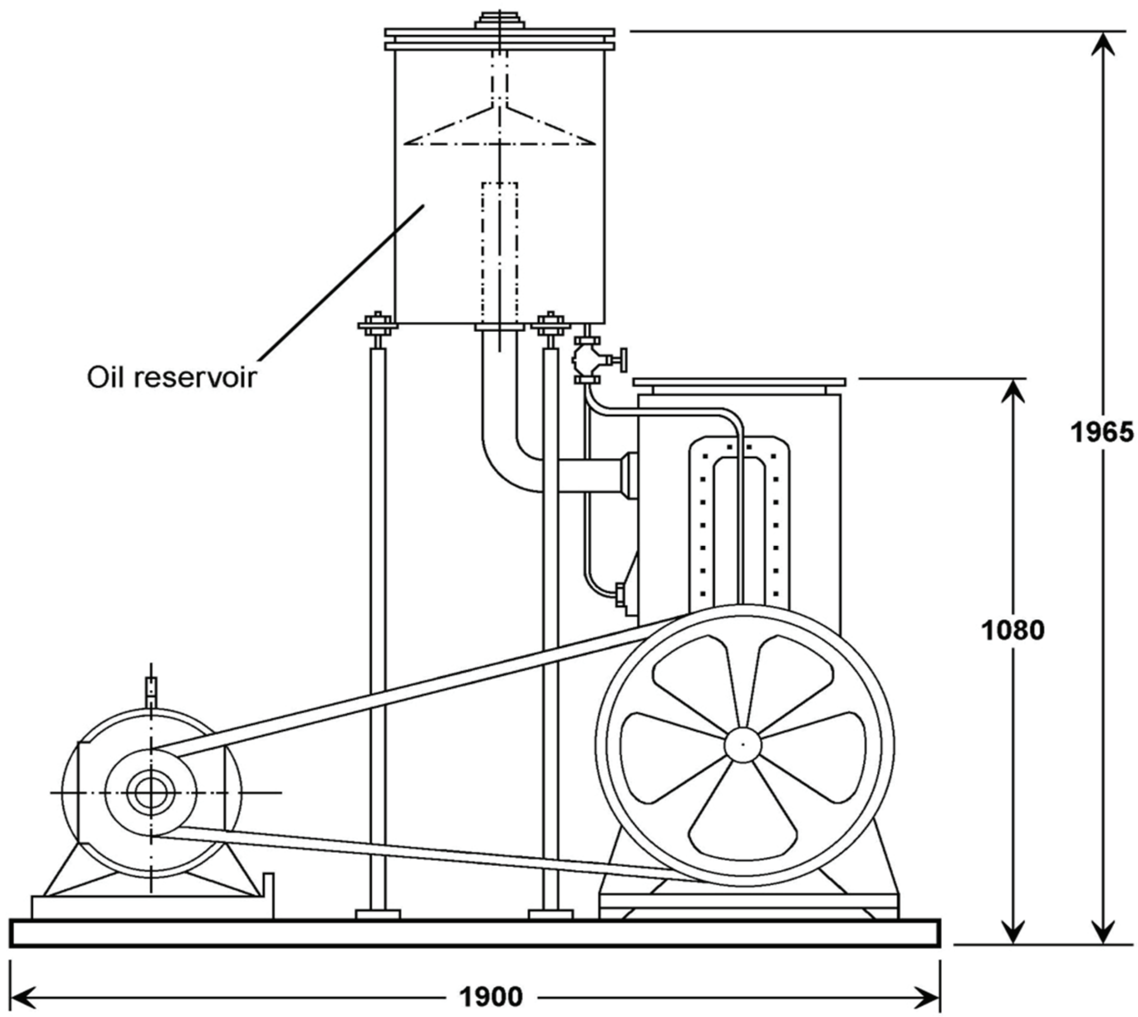


Figure 15. Vacuum pump diagram showing oil reservoir (Dimensions are in mm).

TOMSK, SCC 1961

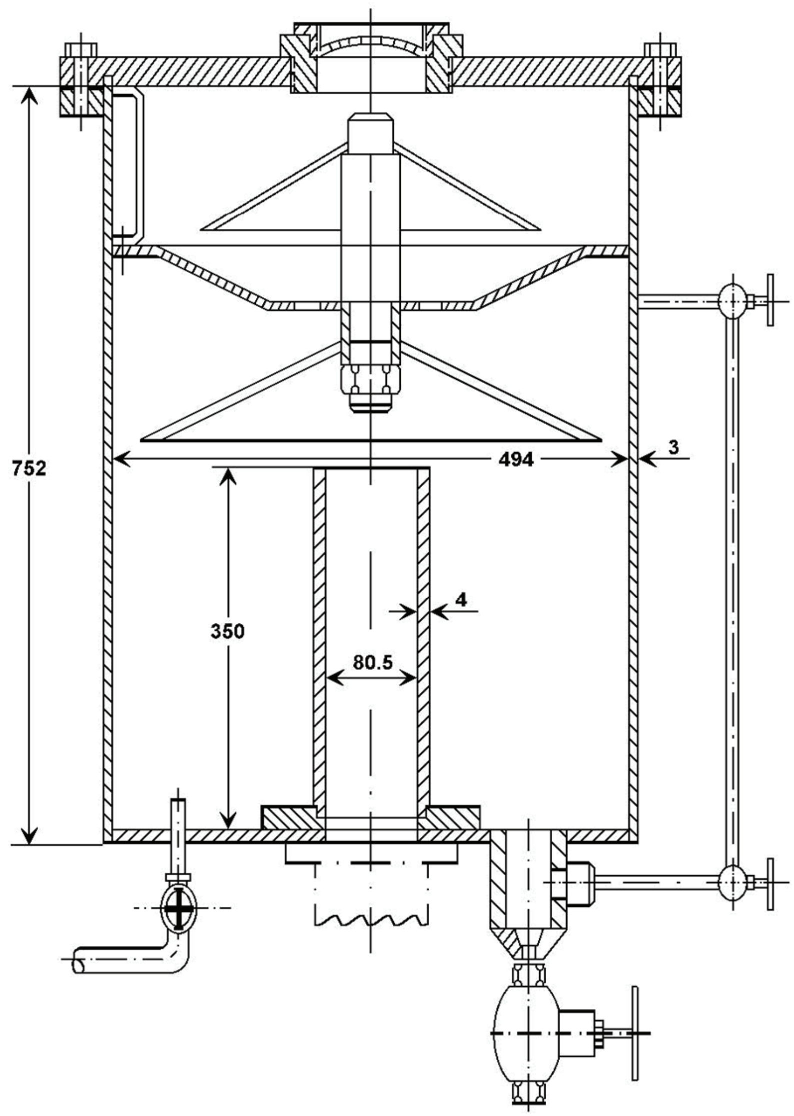


Figure 16. Oil reservoir (Dimensions are in mm).

MAYAK 1962

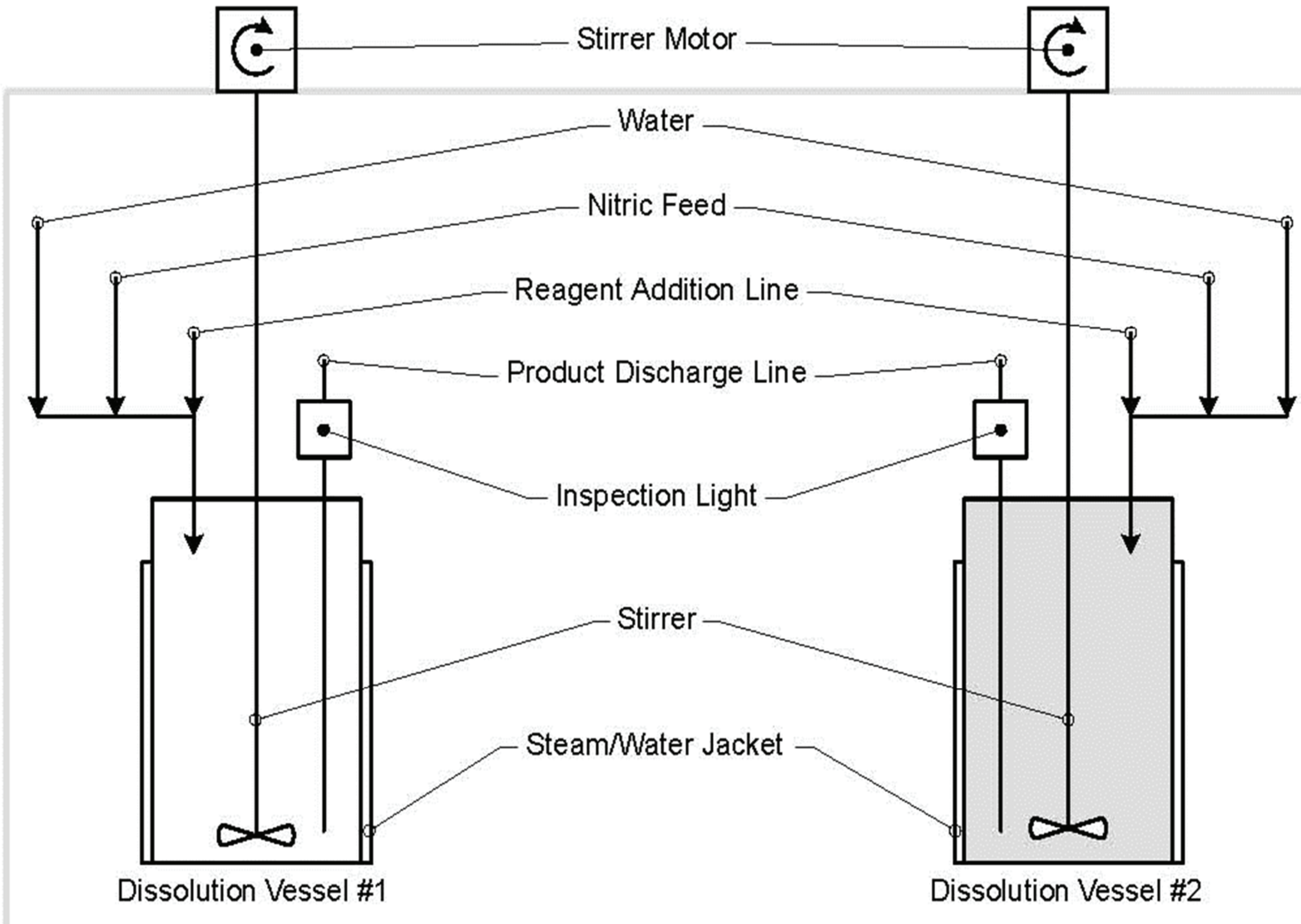


Figure 17. Layout of glovebox equipment.

TOMSK, SCC Jan. 1963

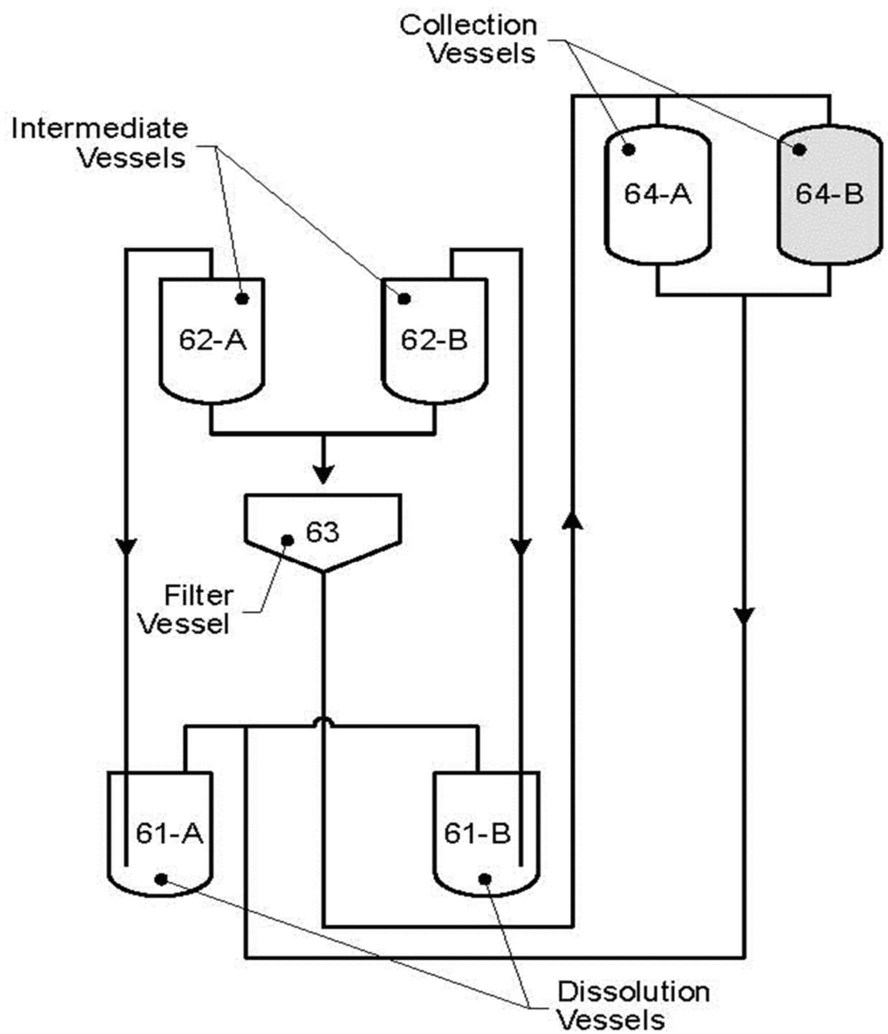


Figure 18. Process vessels and material flow diagram.

TOMSK, SCC   Dec. 1963

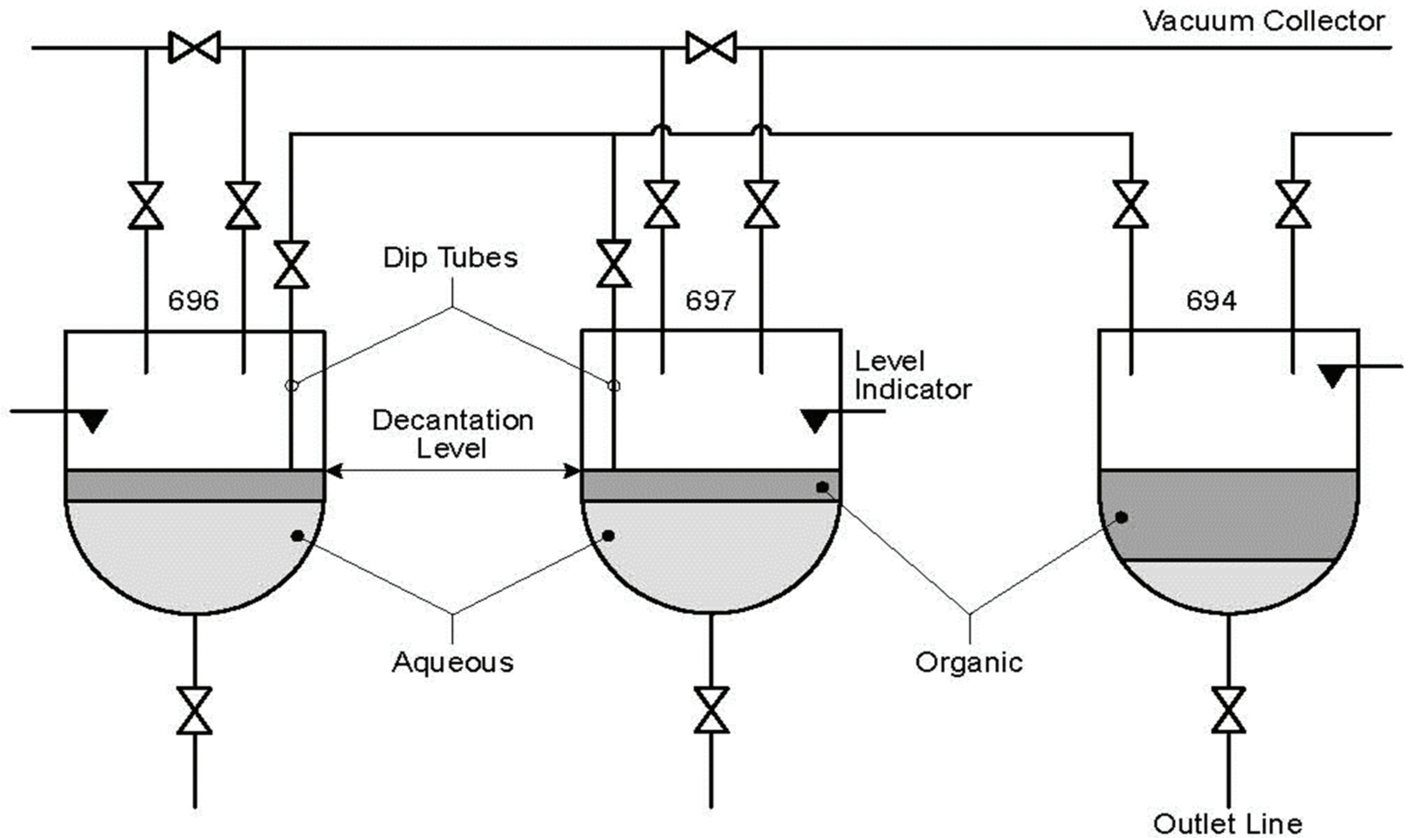


Figure 19. Schematic of vessels showing organic and aqueous solutions (not intended to imply the exact conditions at the time of the accident).

ELECTROSTAL 1965

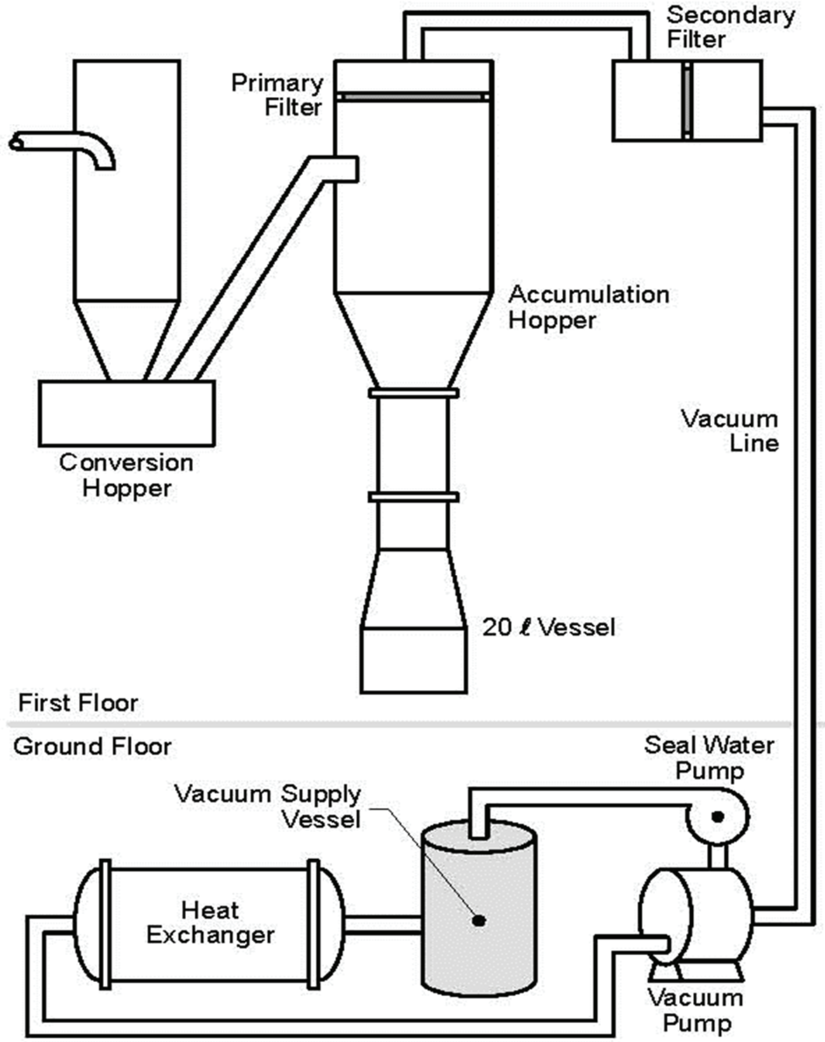


Figure 20. Layout of UF_6 to uranium oxide conversion equipment and associated vacuum system.

MAYAK 1965

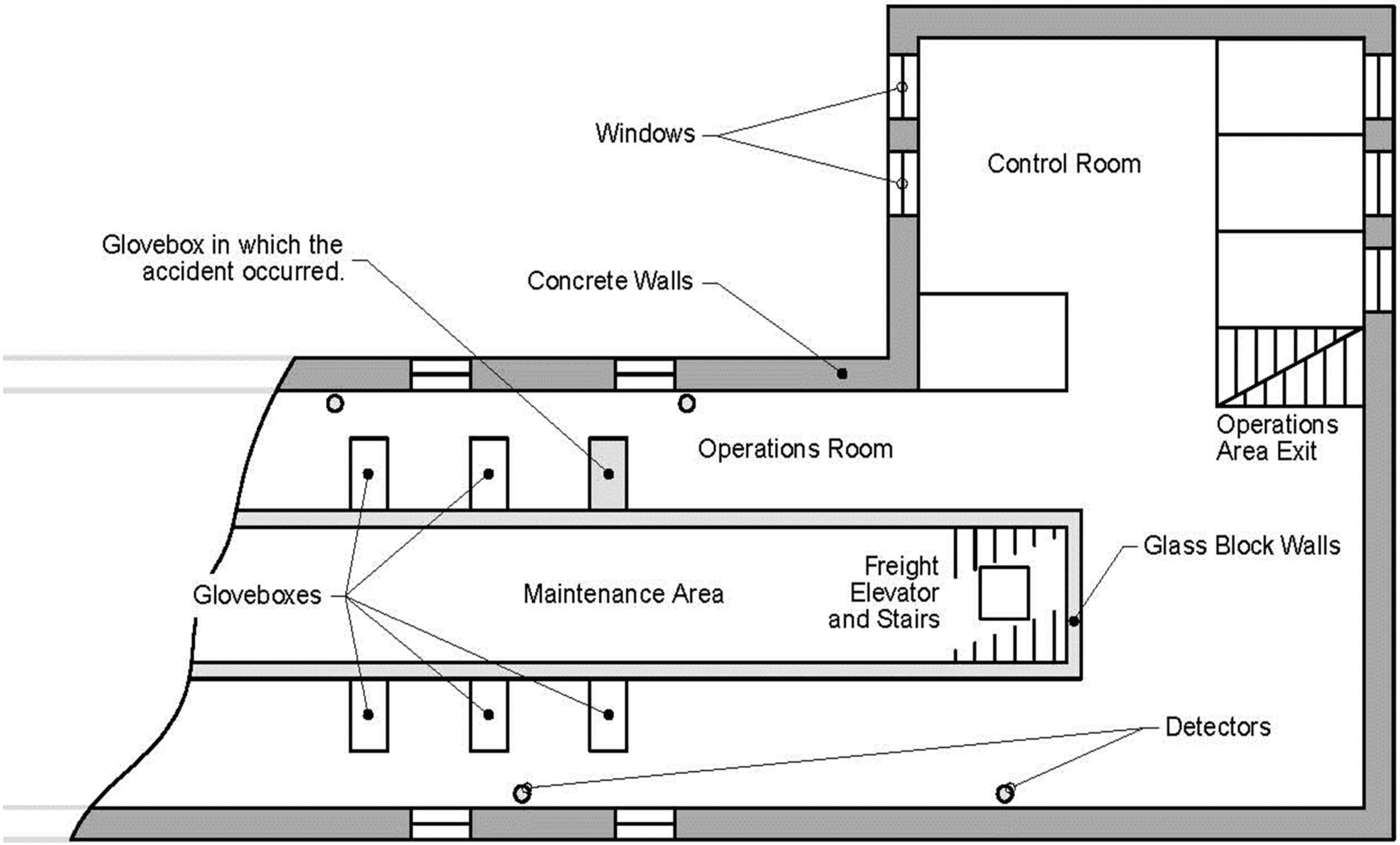


Figure 21. Residue recovery area layout.

MAYAK 1965

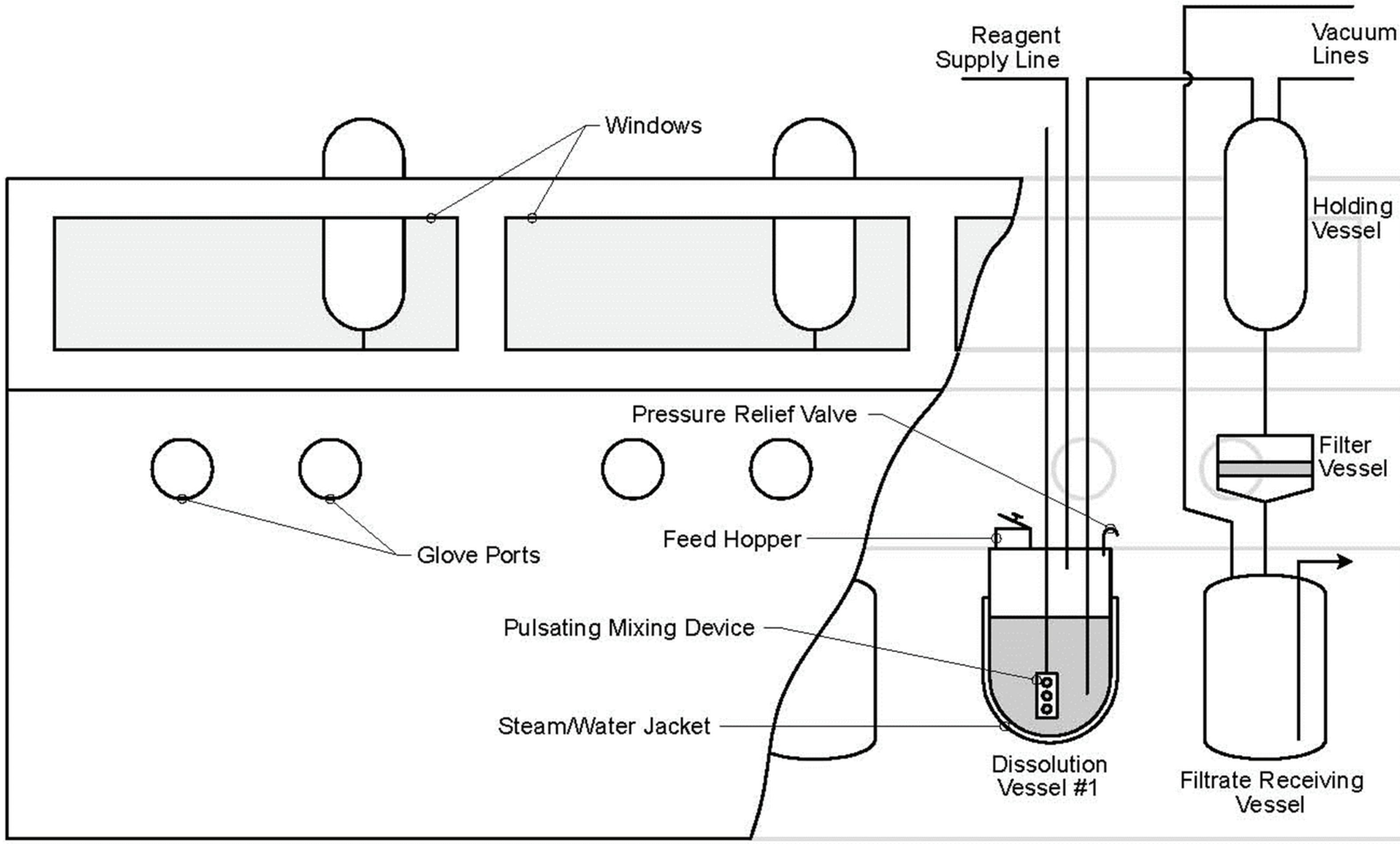


Figure 22. Layout of dissolution glovebox.

MAYAK 1968

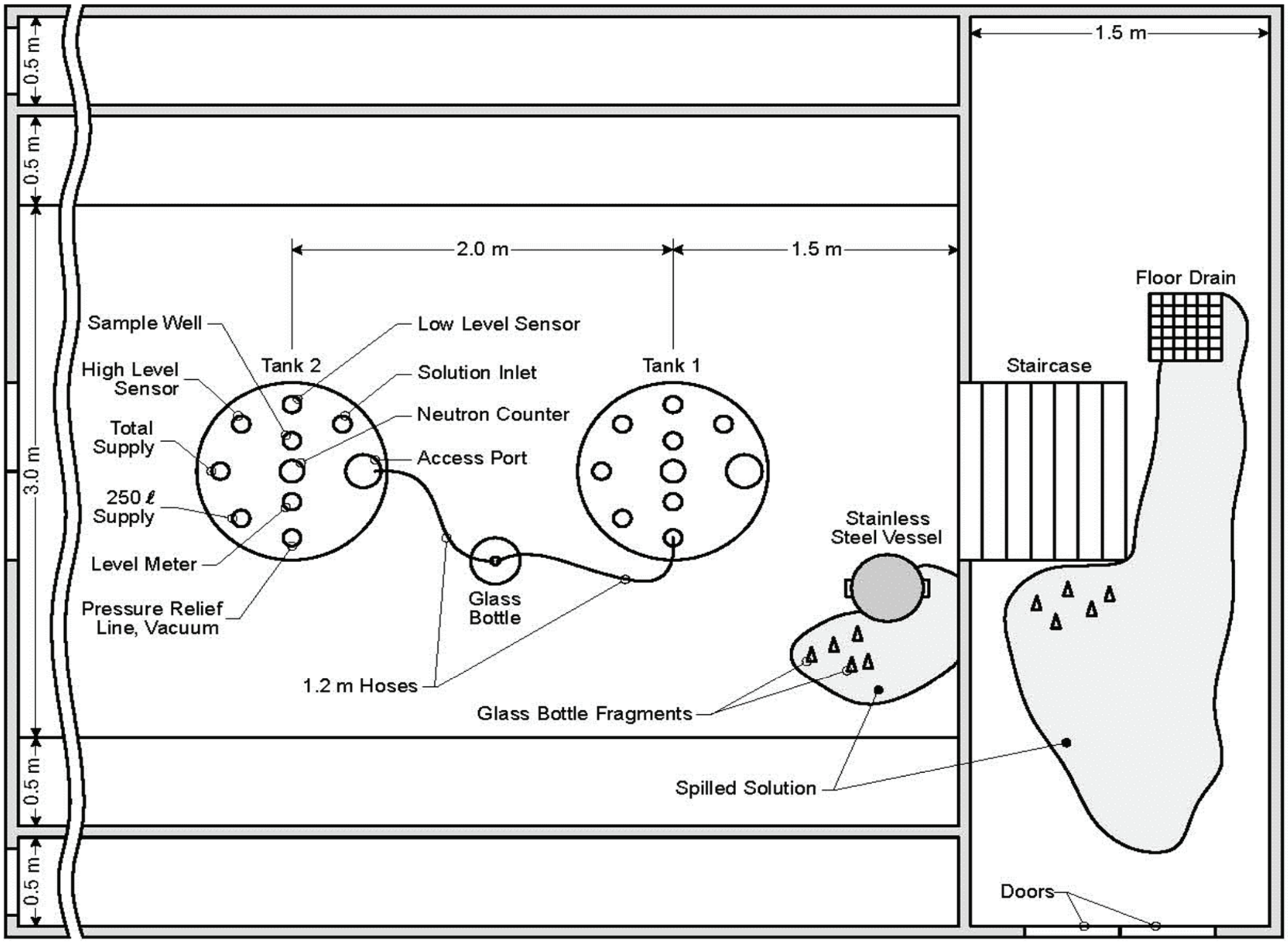


Figure 23. Plan view of the tanks involved in the accident.

MAYAK 1968

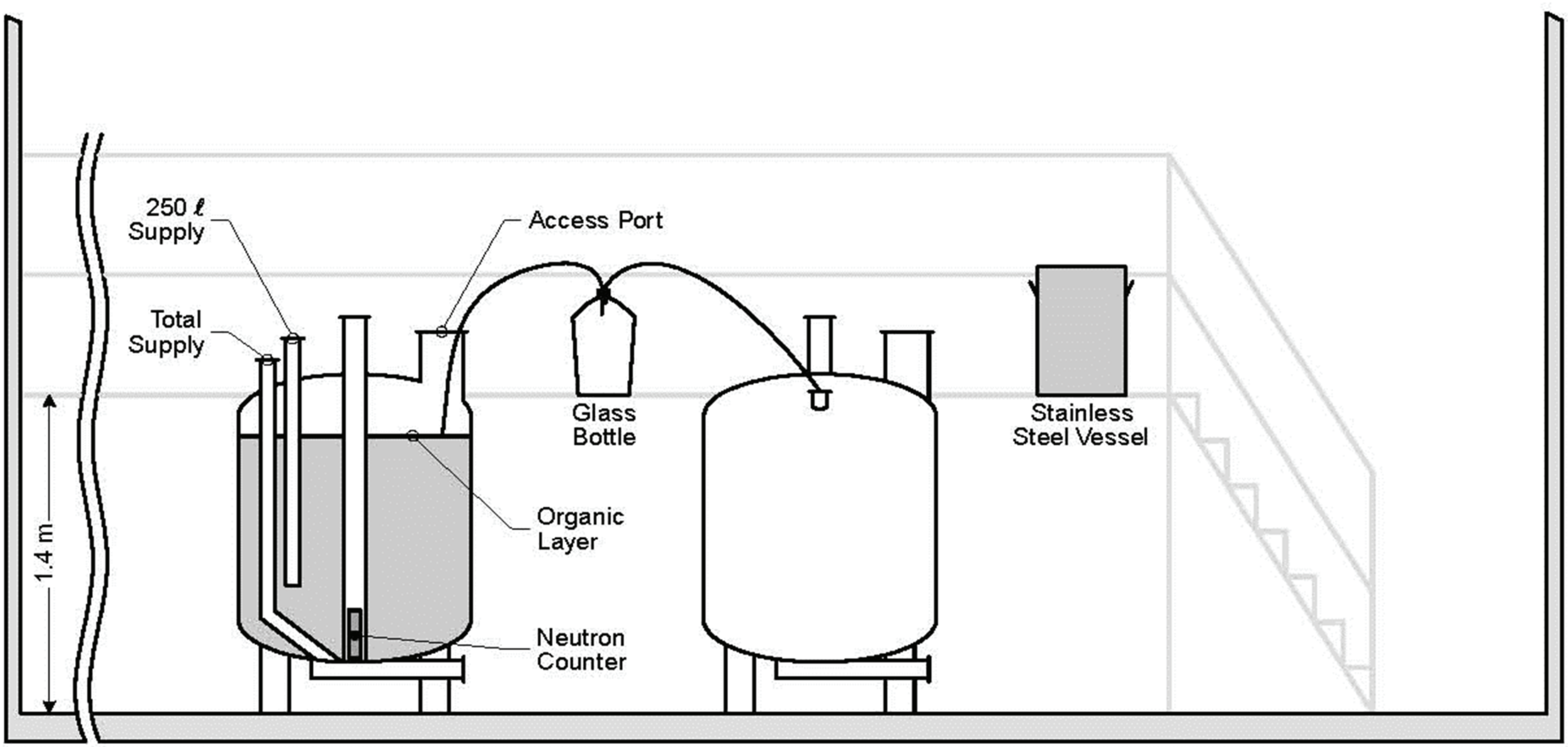


Figure 24. Elevation view of the tanks involved in the accident.

WINDSCALE WORKS, UK 1970

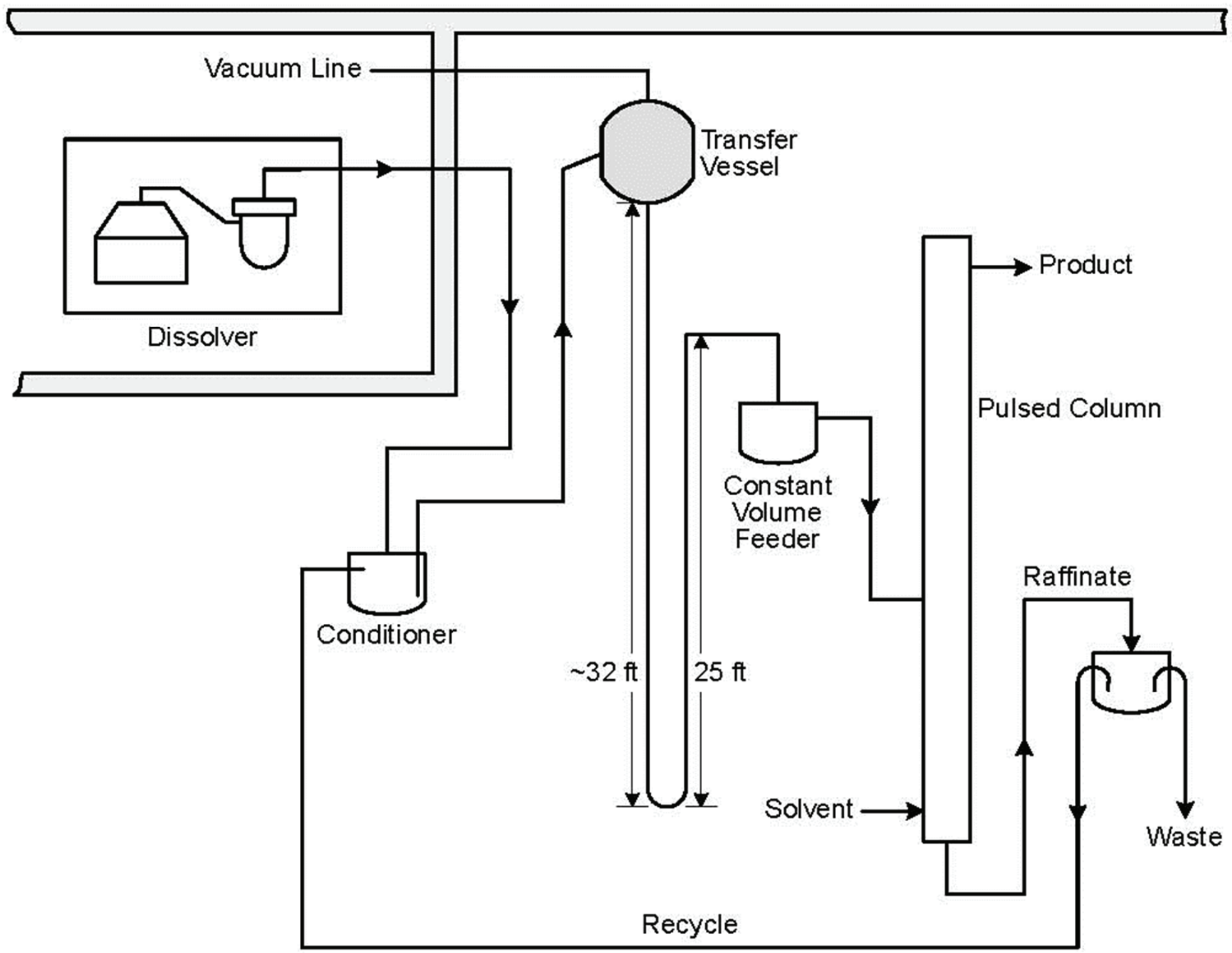


Figure 25. Process equipment related to the criticality accident.

WINDSCALE WORKS, UK   1970

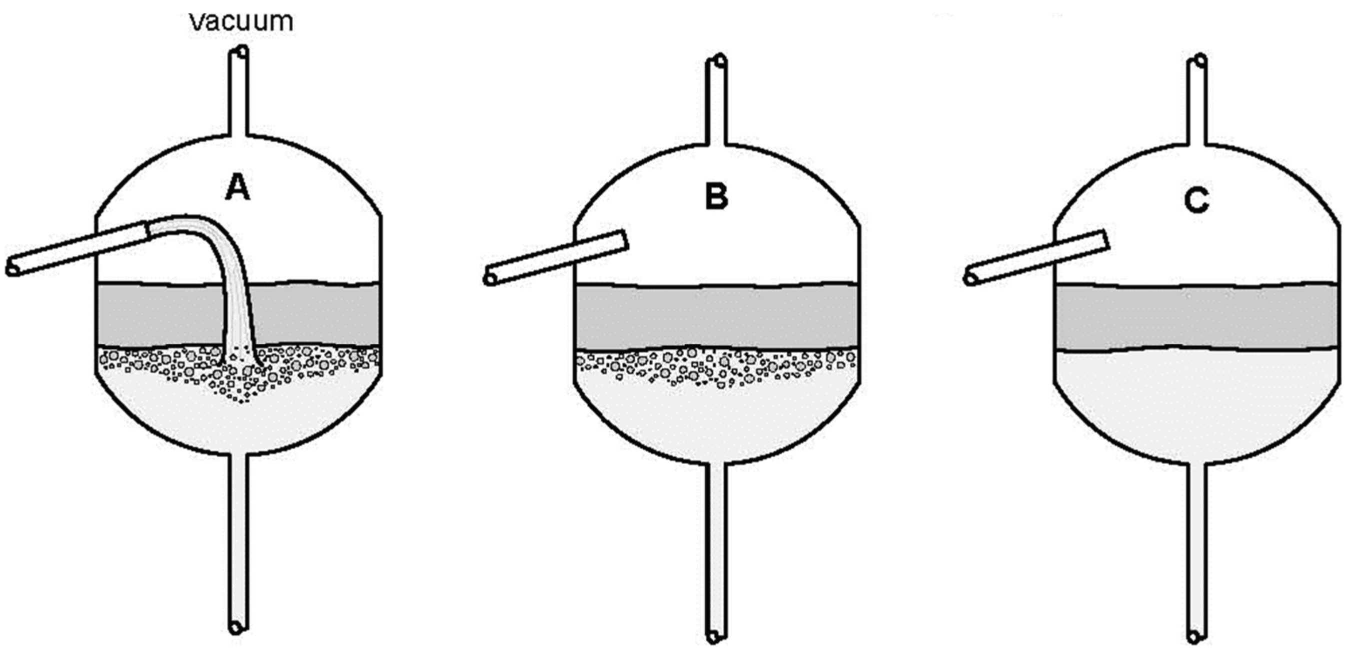


Figure 26. Solution transfer as re-constructed from the transparent plastic mockup of the transfer vessel. Configuration (B) is the postulated state at the time of the accident.

IDAHO, ICPP 1970

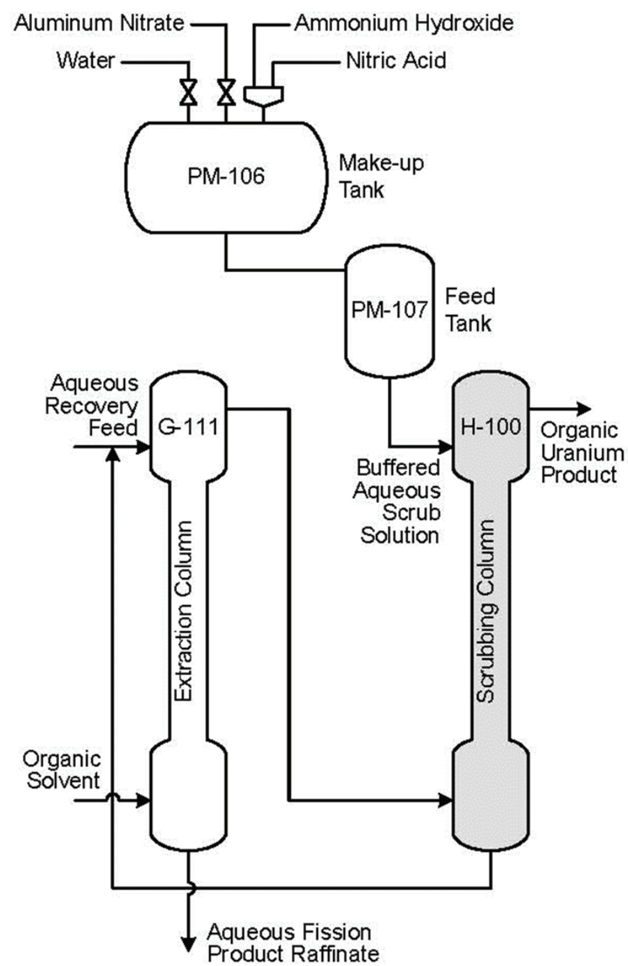


Figure 27. First cycle extraction line equipment. The accident occurred in the lower disengagement section of the H-100 column.

TOMSK, SCC 1978

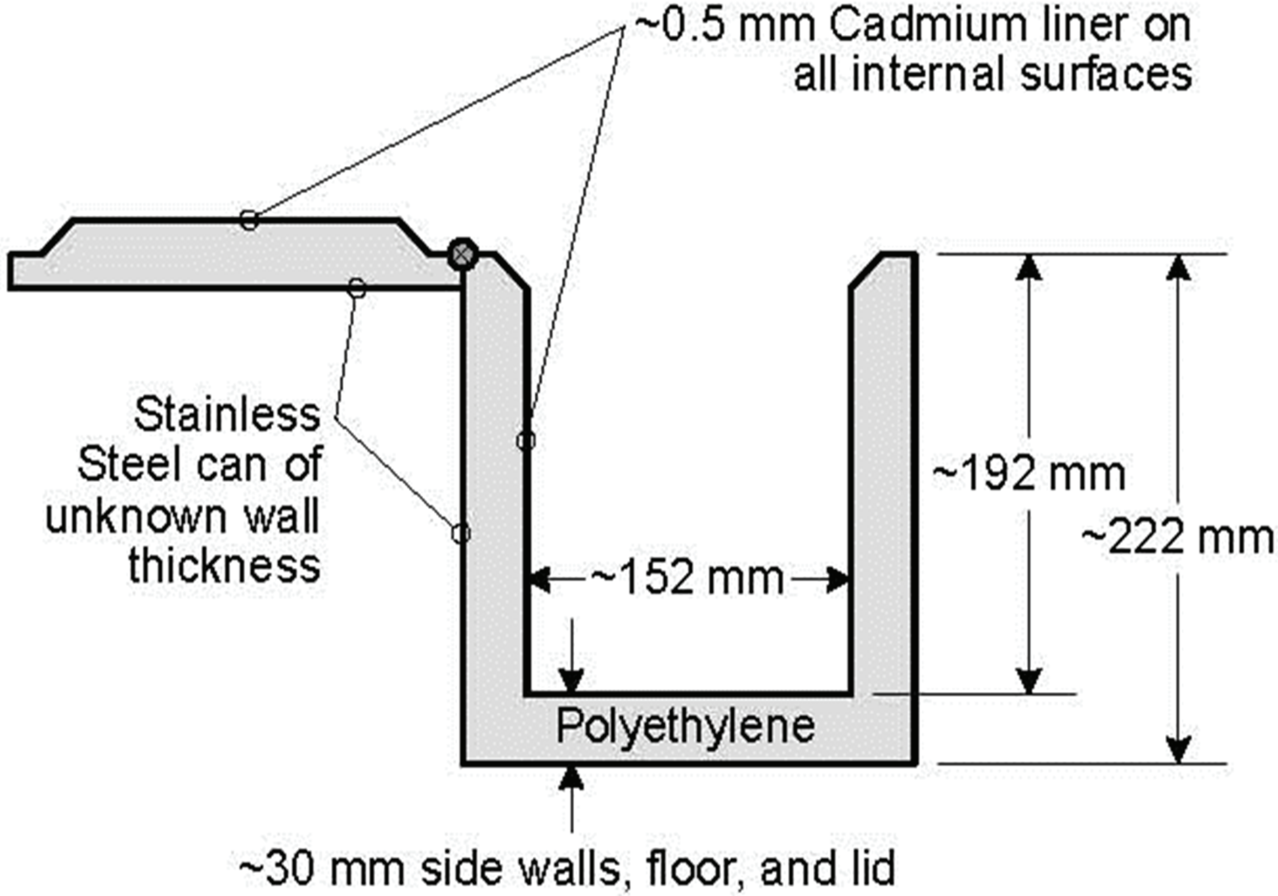


Figure 28. Storage container.

TOMSK 1978

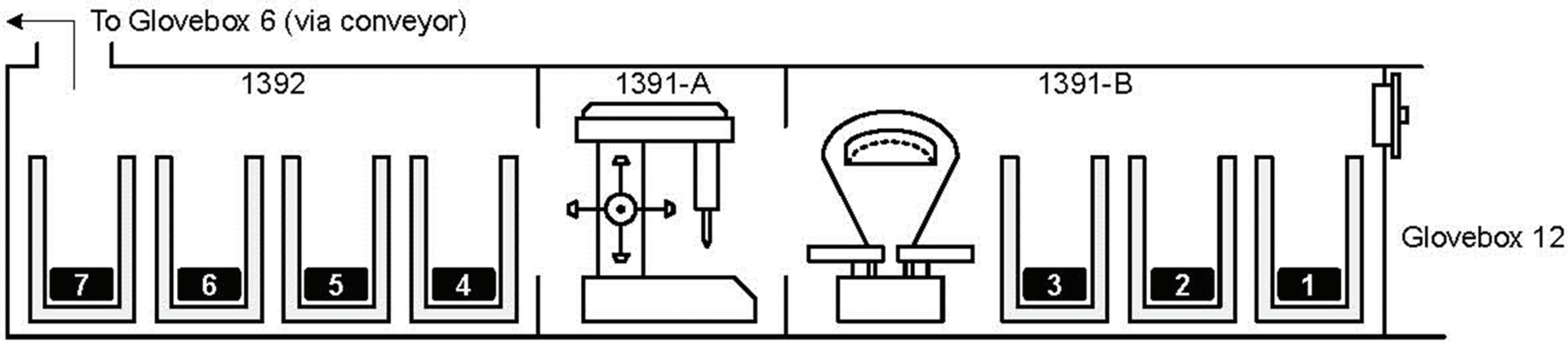


Figure 29. A simplified layout of Glovebox 13.

TOMSK 1978

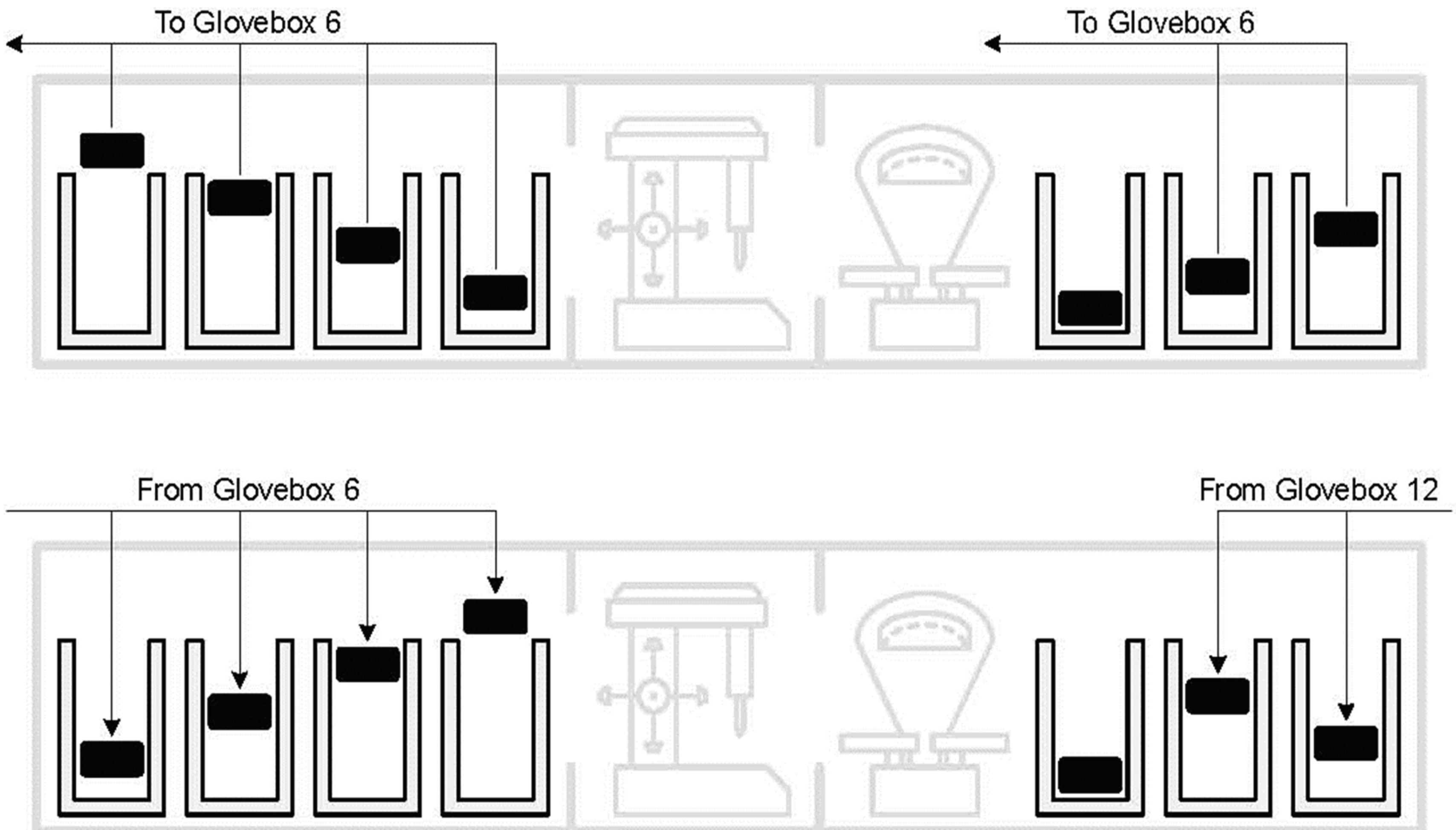


Figure 30. Intended sequence for the transfer of ingots from and to Glovebox 13.

TOMSK 1978

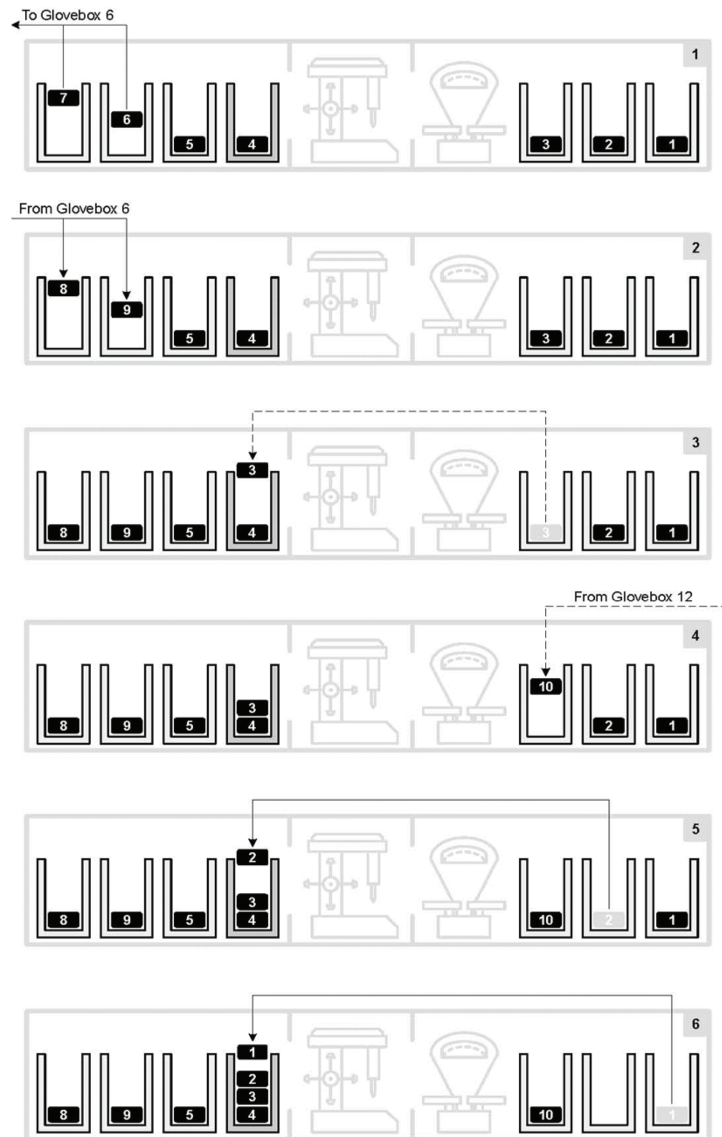


Figure 31. Actual order of ingot transfers from and to Glovebox 13. The solid lines represent the actions of operator A and the dotted lines the actions of operator B.

NOVOSIBIRSK 1999

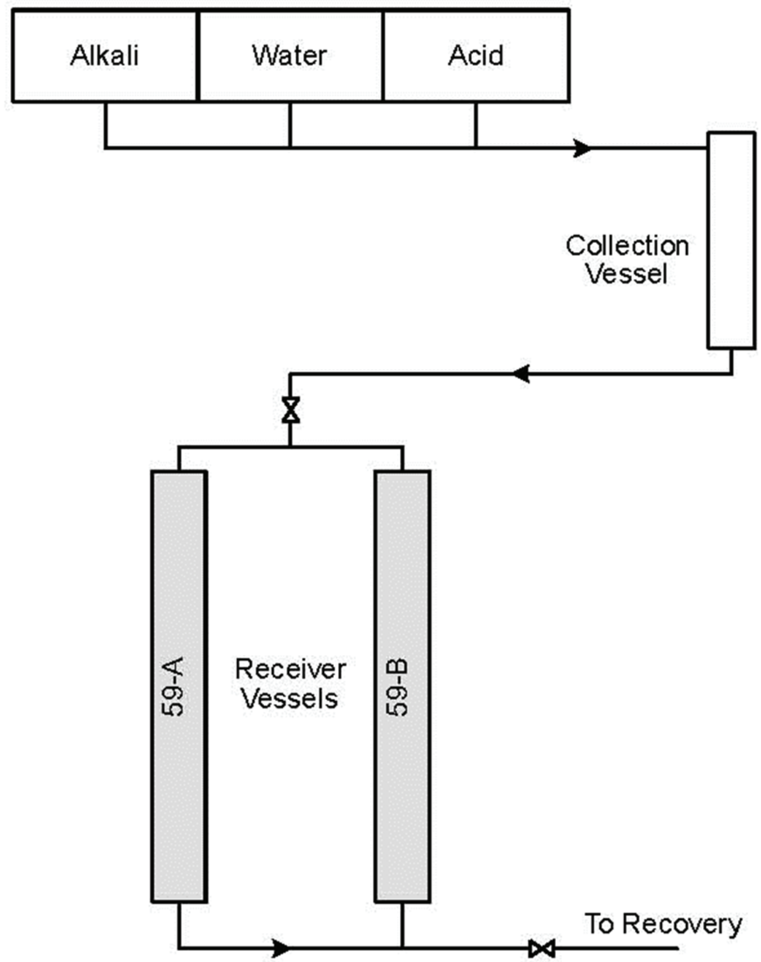


Figure 32. Major components of the chemical-etching process.

NOVOSIBIRSK 1999

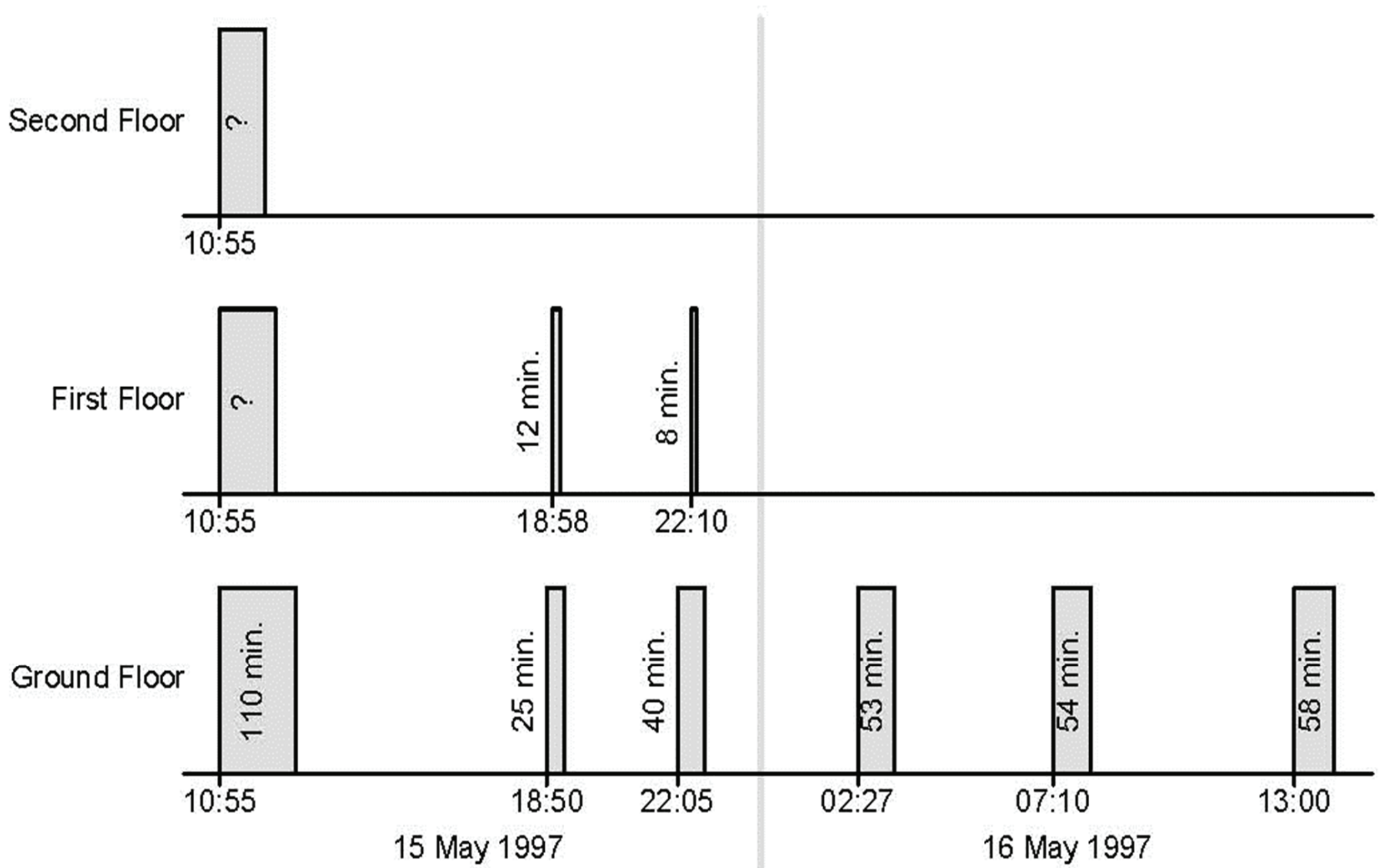


Figure 33. Sequence of alarms and duration that the radiation levels exceeded the alarm level (36 mR/h).

TOKI-MURA, JCO, JAPAN 1999

Figure 35. The precipitation vessel in which the process criticality accident occurred.

TOKI-MURA, JCO, JAPAN 1999

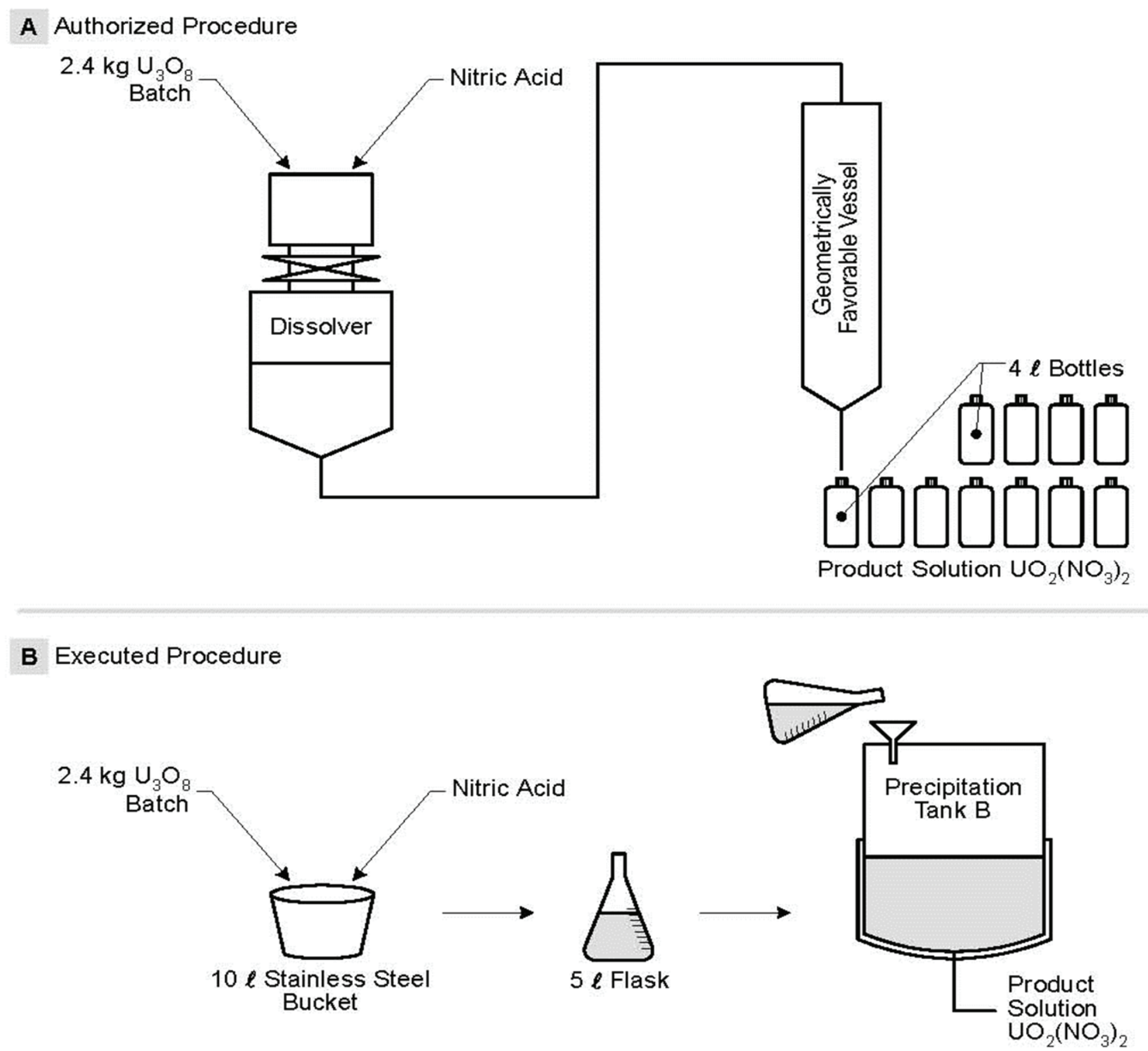


Figure 34. Authorized and executed procedures.

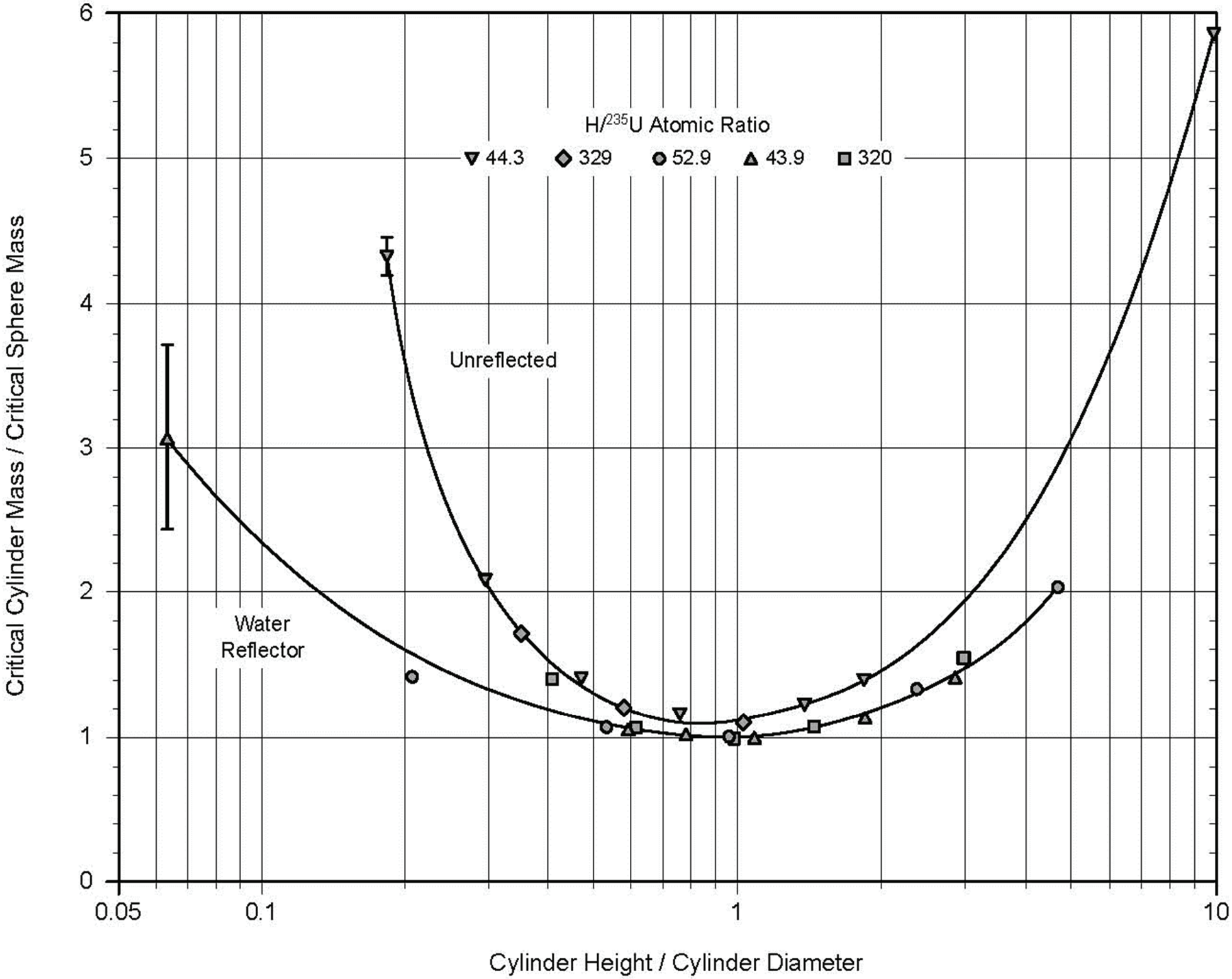


Figure 36. The ratio of cylindrical to spherical critical masses of $U(93)O_2F_2$ solutions, unreflected and with water reflector, as a function of cylinder height to cylinder diameter ratio.

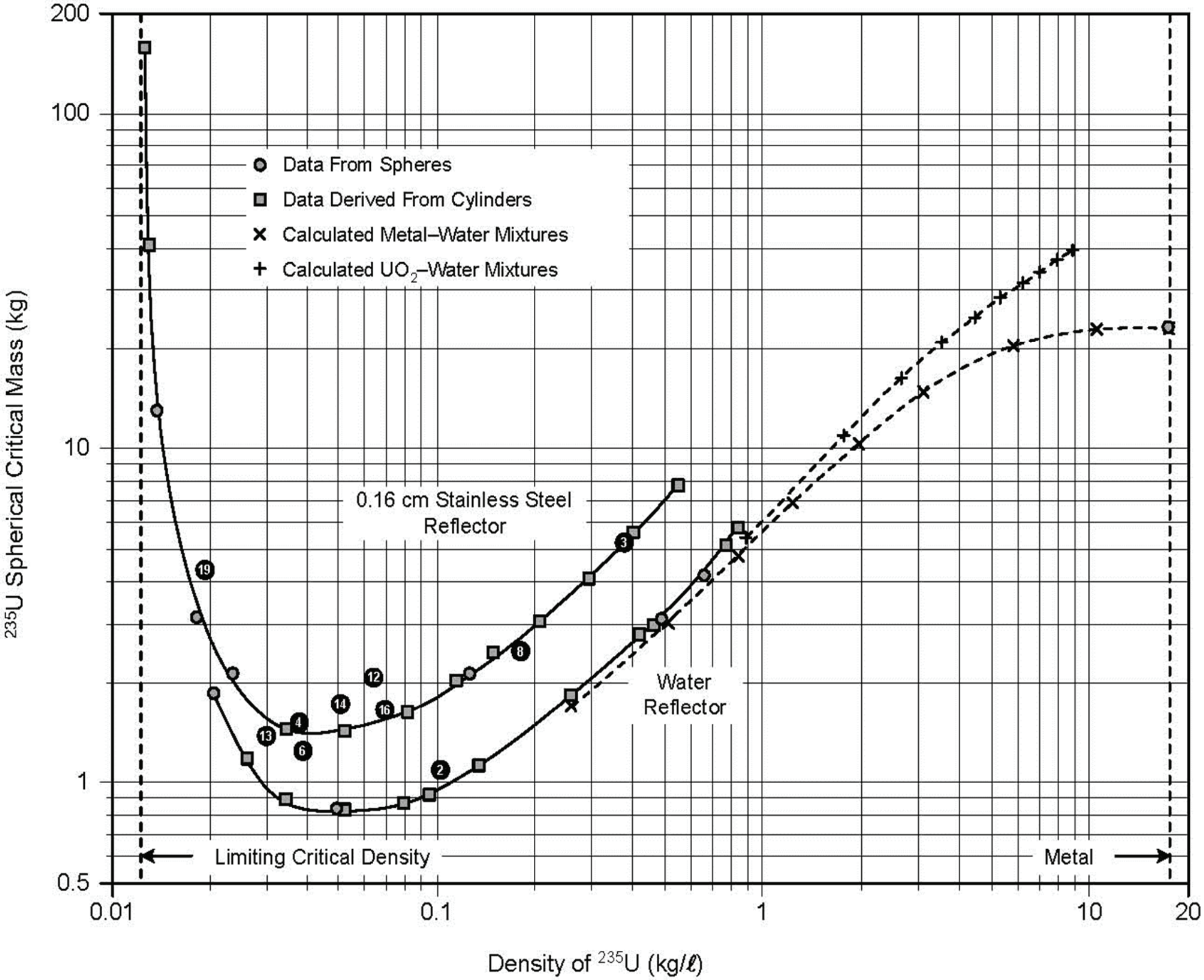


Figure 37. Critical masses of homogeneous water moderated U(93.2) spheres. Solution data appear unless indicated otherwise. The accidents are shown by numbered circles.

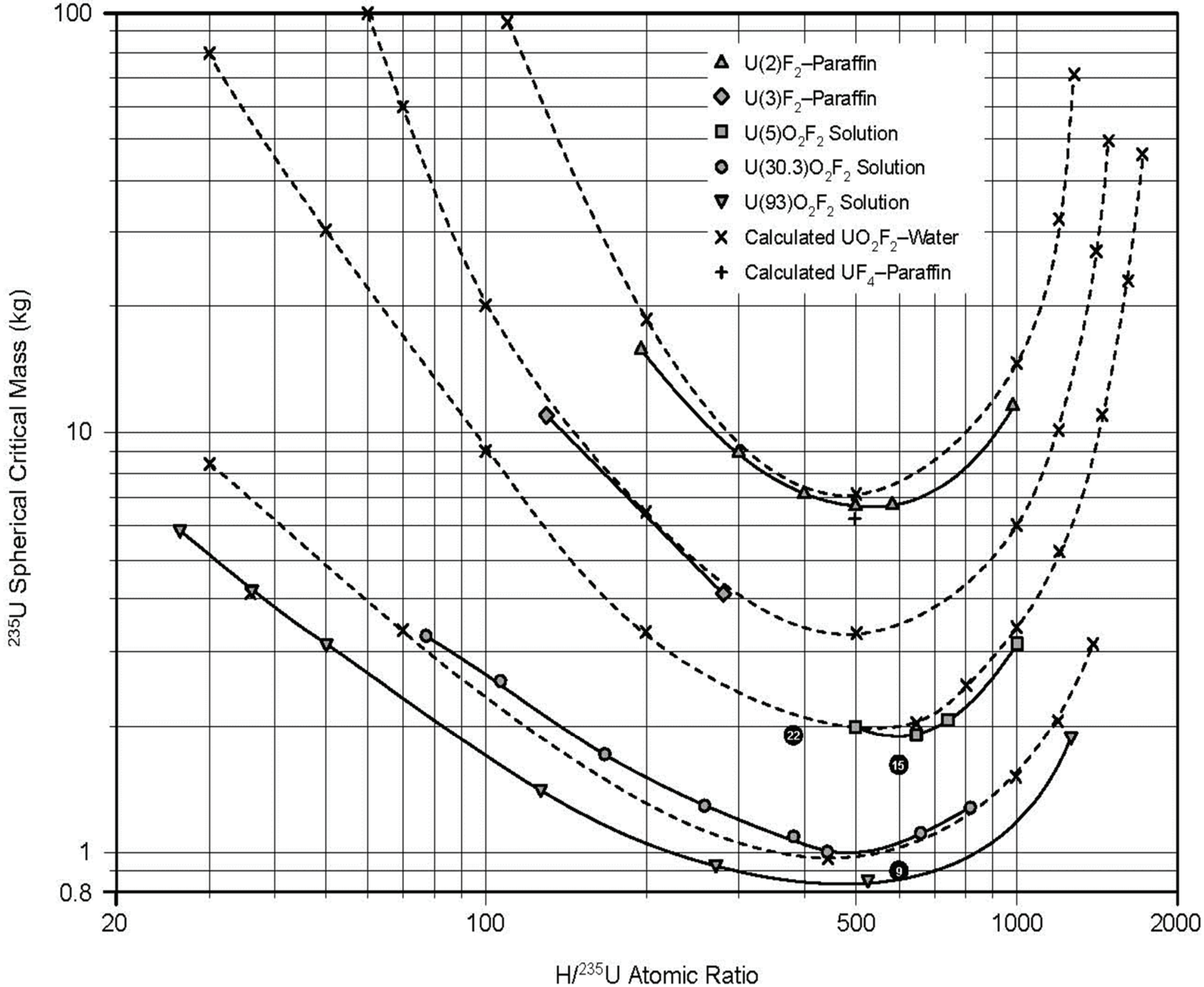


Figure 38. Critical masses of water-reflected spheres of hydrogen-moderated U(93), U(30.3), U(5.00), U(3.00), and U(2.00). The accidents are shown by numbered circles.

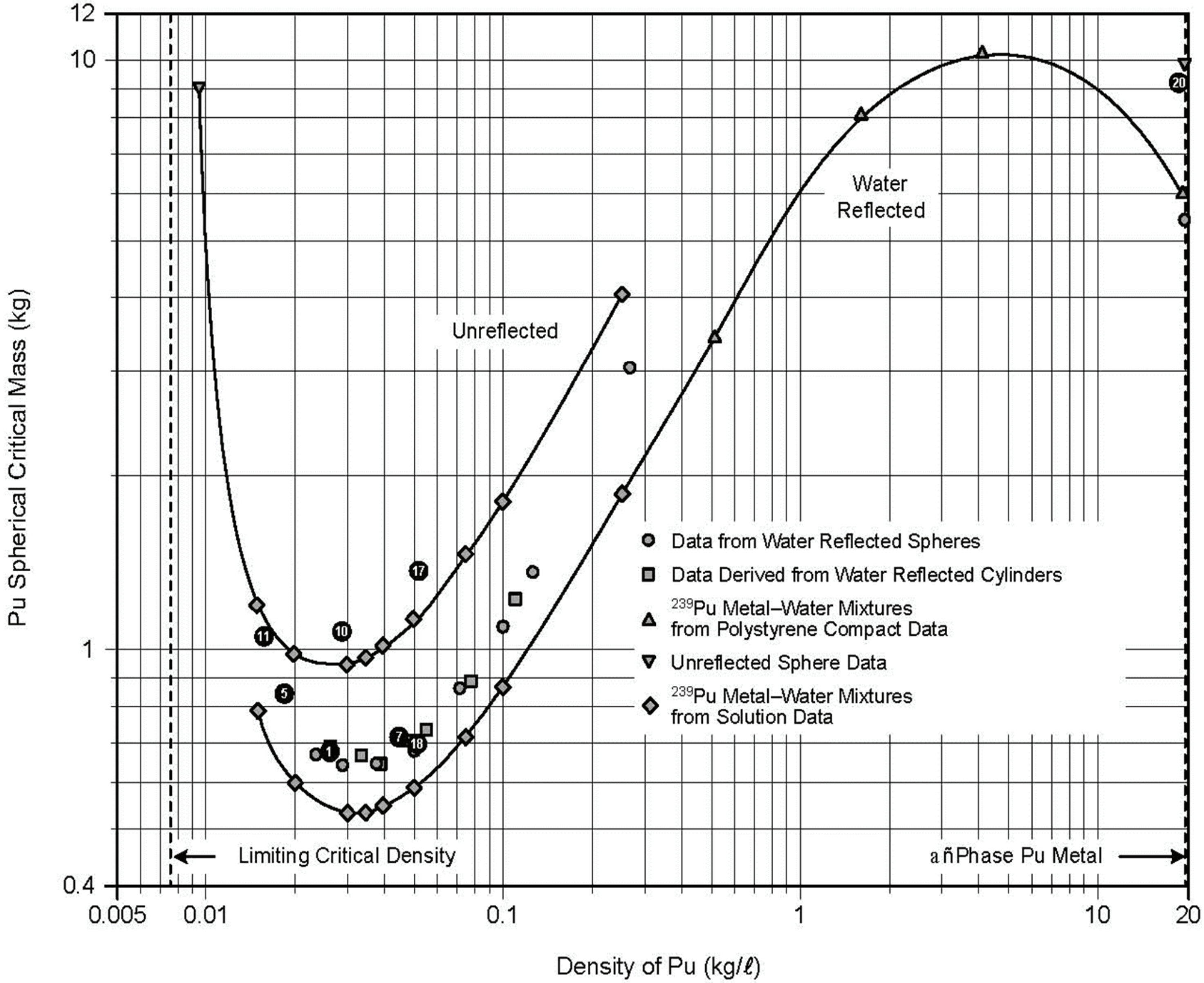


Figure 39. Critcial masses of homogeneous water moderated plutonium spheres. The points suggesting an intermediate curve apply to water reflected $Pu(No_3)_4$ solution with 1 N HNO_3 and 3.1% ^{240}Pu content. The accidents are shown by numbered circles.

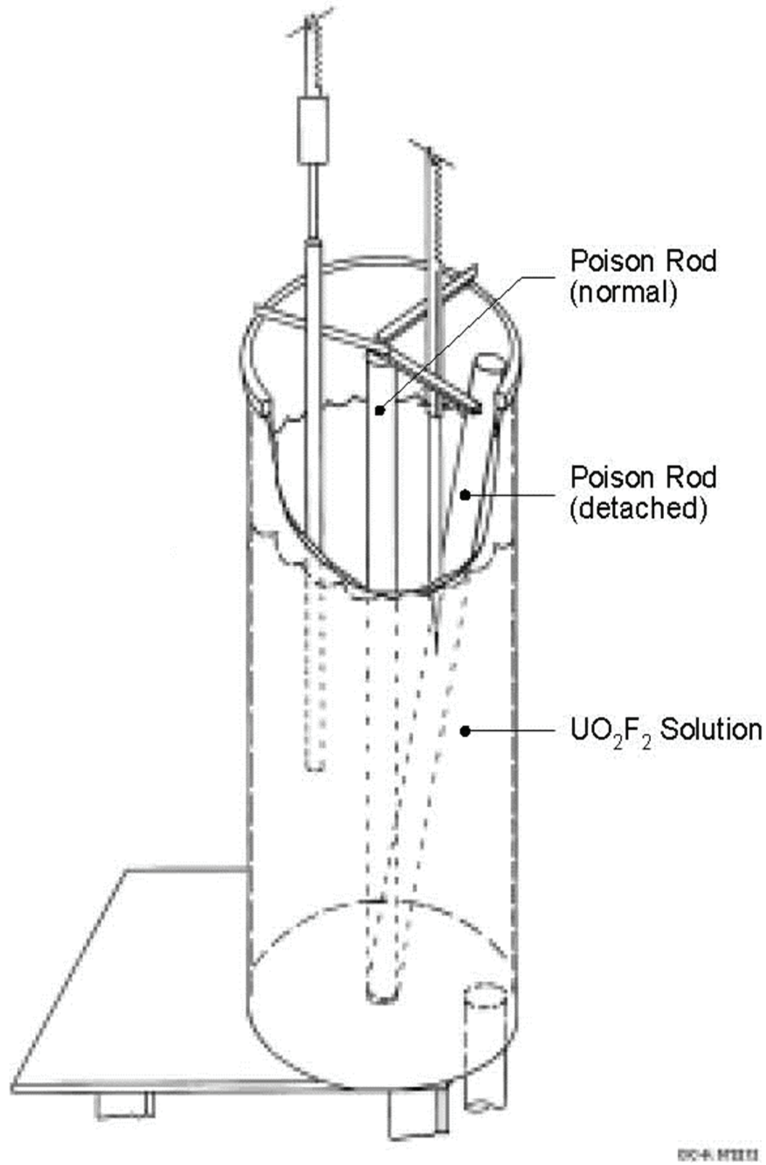


Figure 40. The Oak Ridge National Laboratory uranium solution assembly showing the normal and detached positions of the central poison rod.

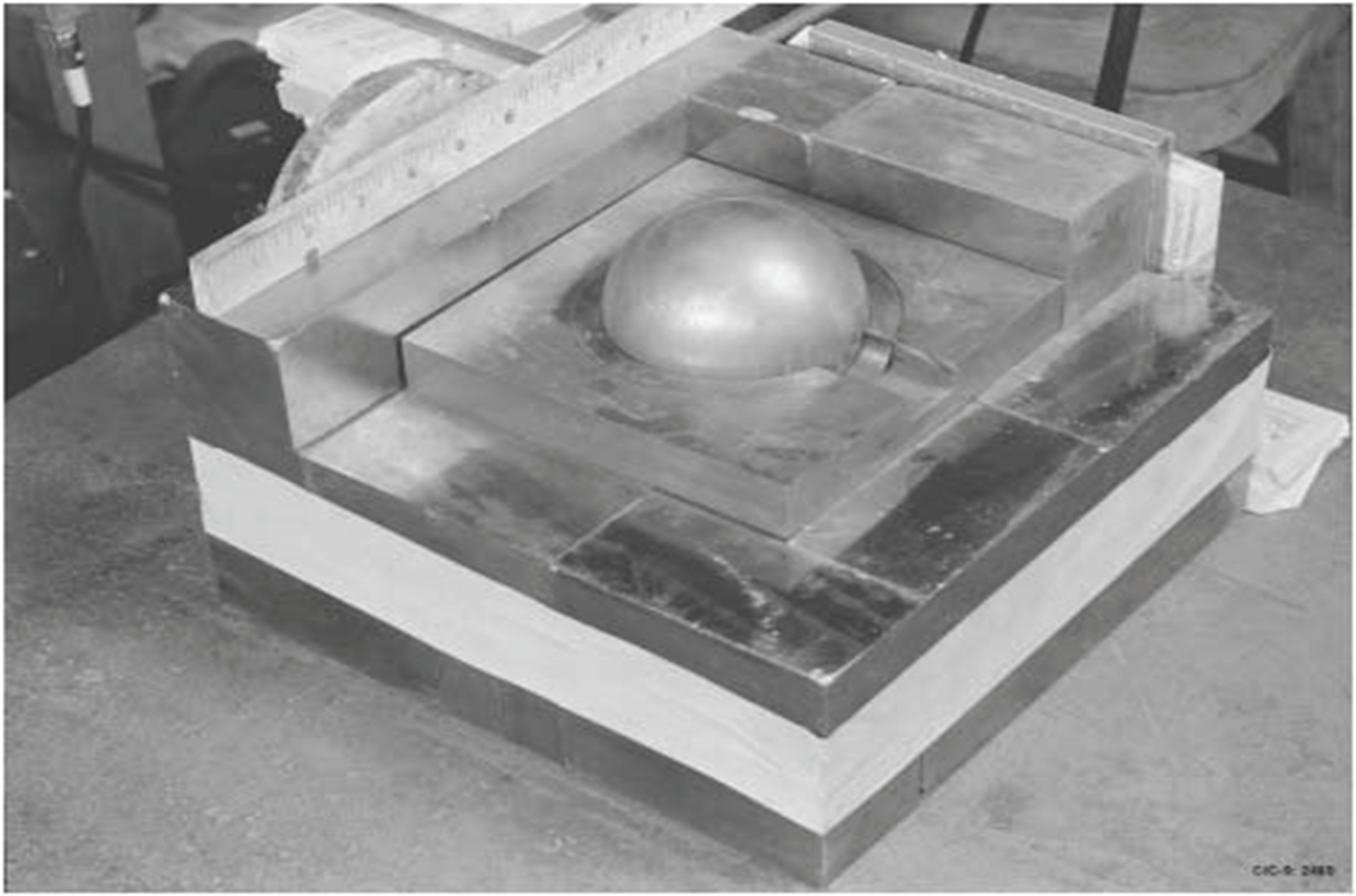


Figure 41. Plutonium sphere partially reflected by tungsten-carbide blocks.

Figure 42. Configuration of beryllium reflector shells prior to the accident 21 May 1946.

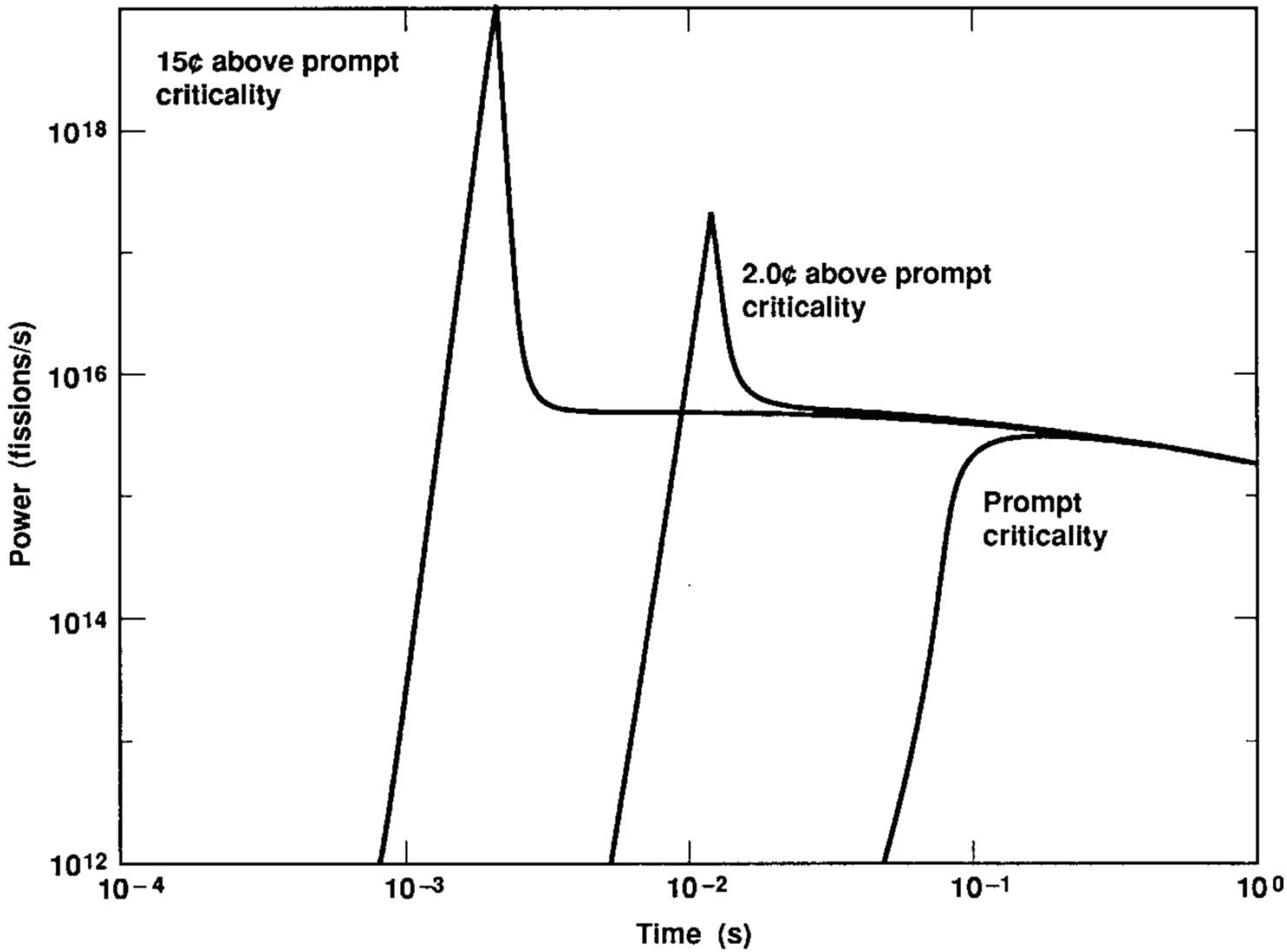


Figure 43. Calculated fission rate for the 6.2-kg plutonium sphere.

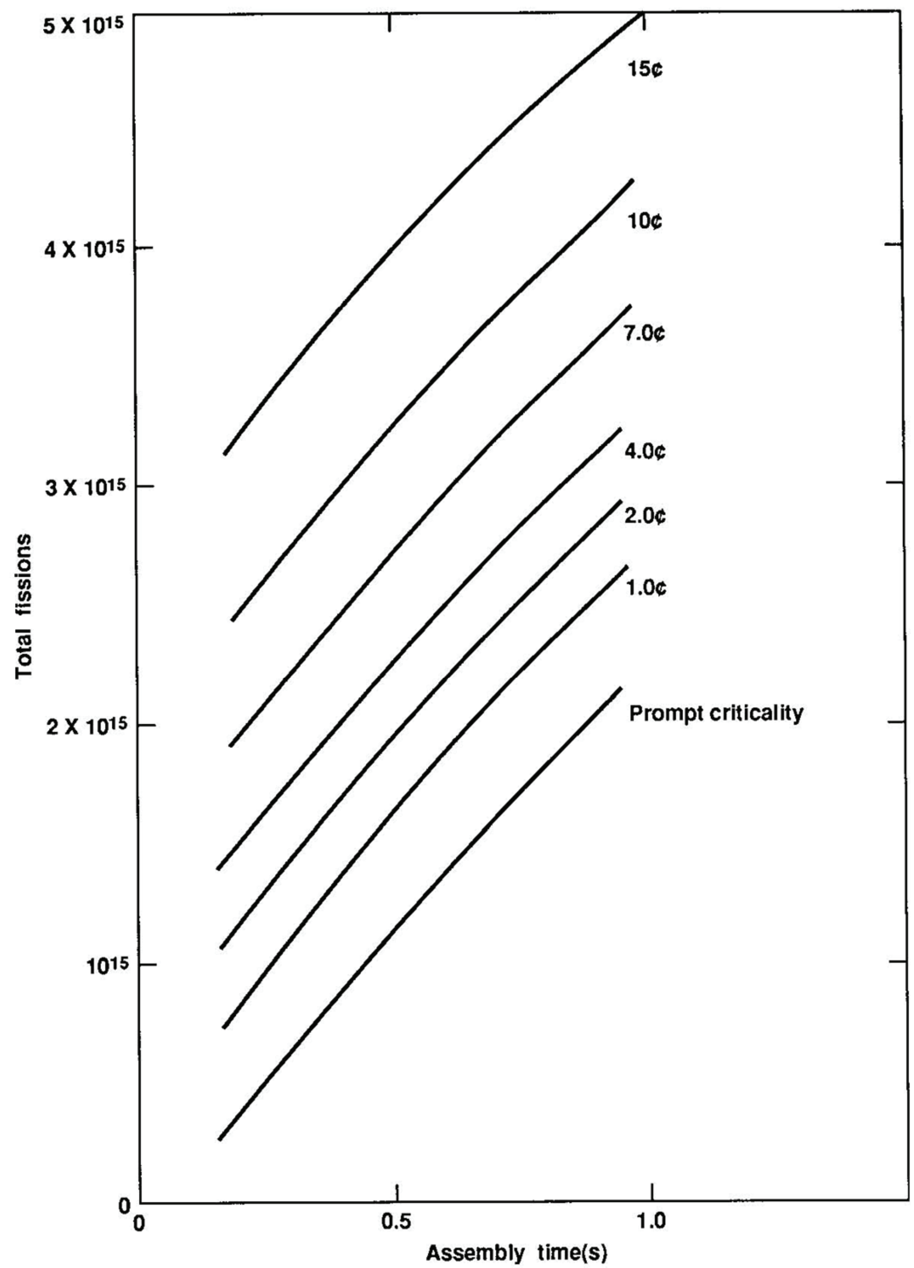


Figure 44. Calculated total fissions vs. time for the 6.2-kg plutonium sphere.

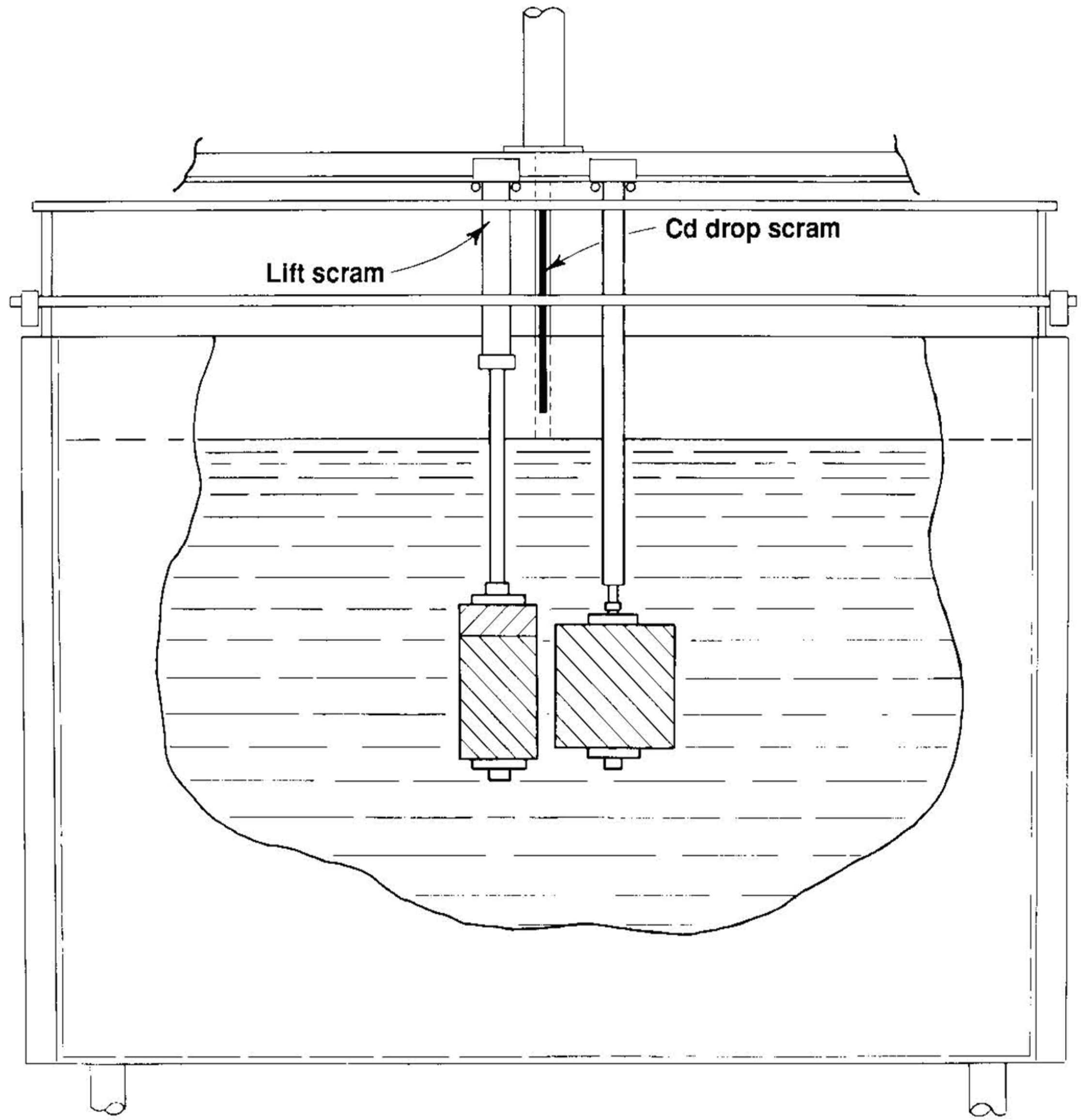


Figure 45. The Los Alamos Scientific Laboratory assembly machine employed for measurements of critical separation distances.

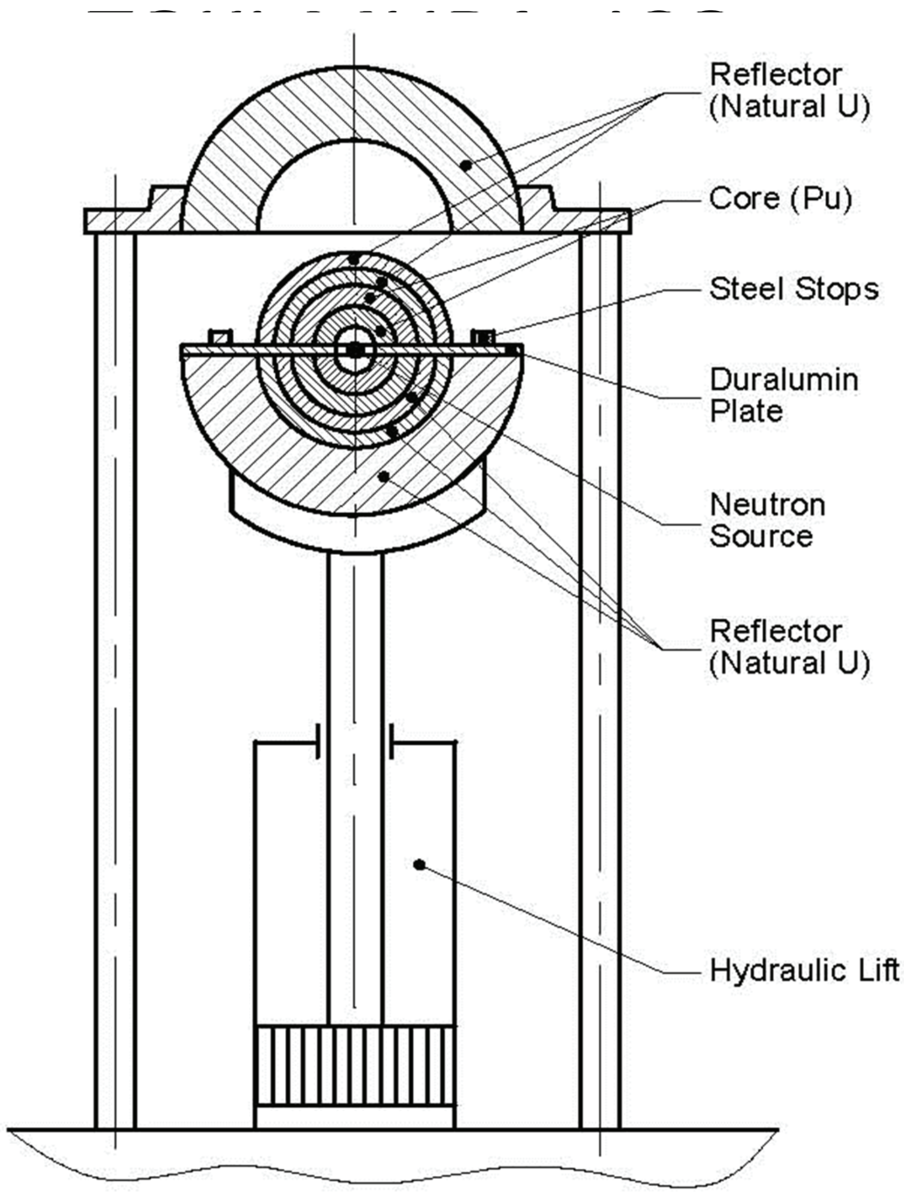


Figure 46. FKBN and assembly involved in the
9 April 1953 accident.

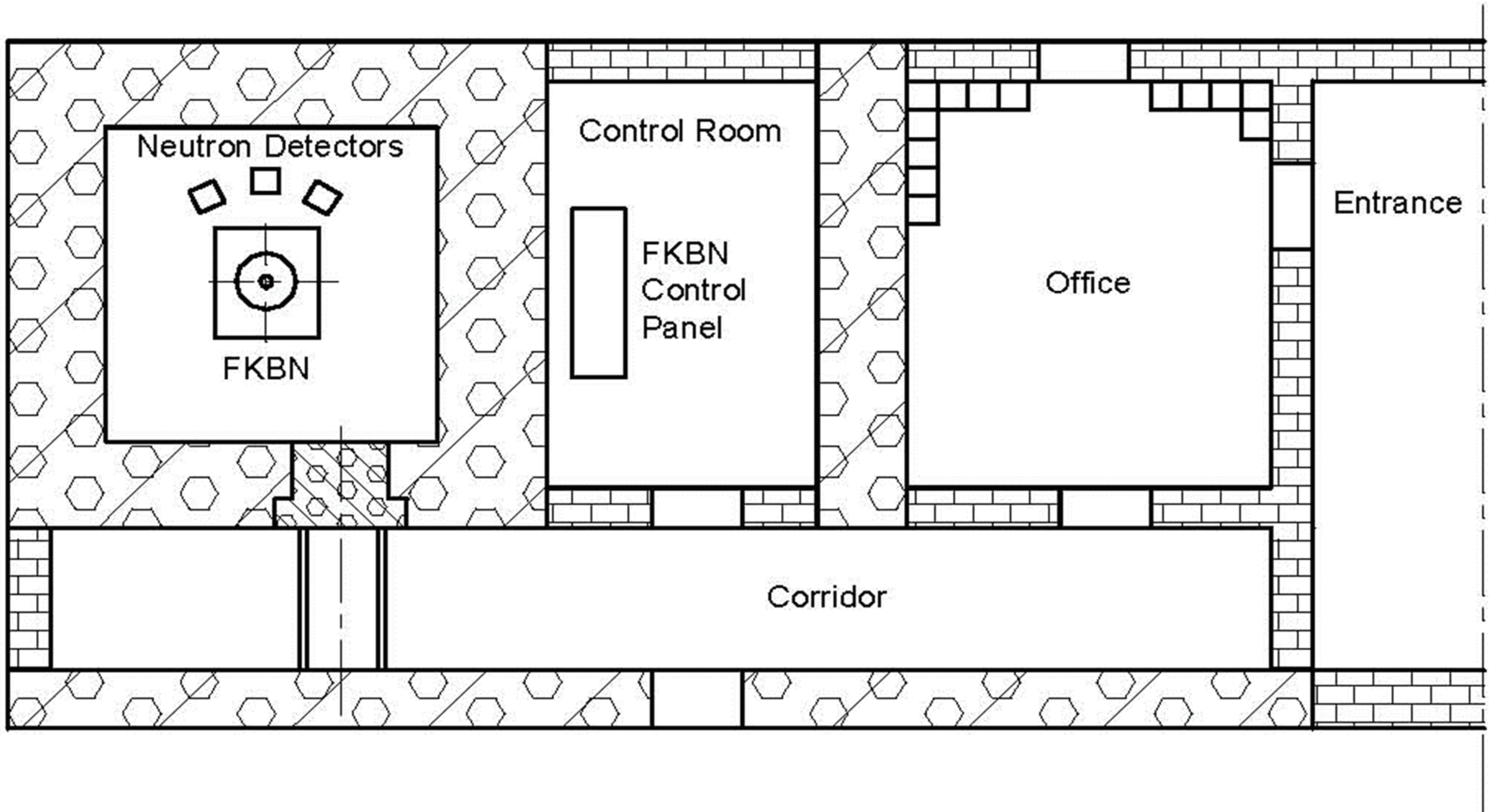


Figure 47. Building B floor plan.

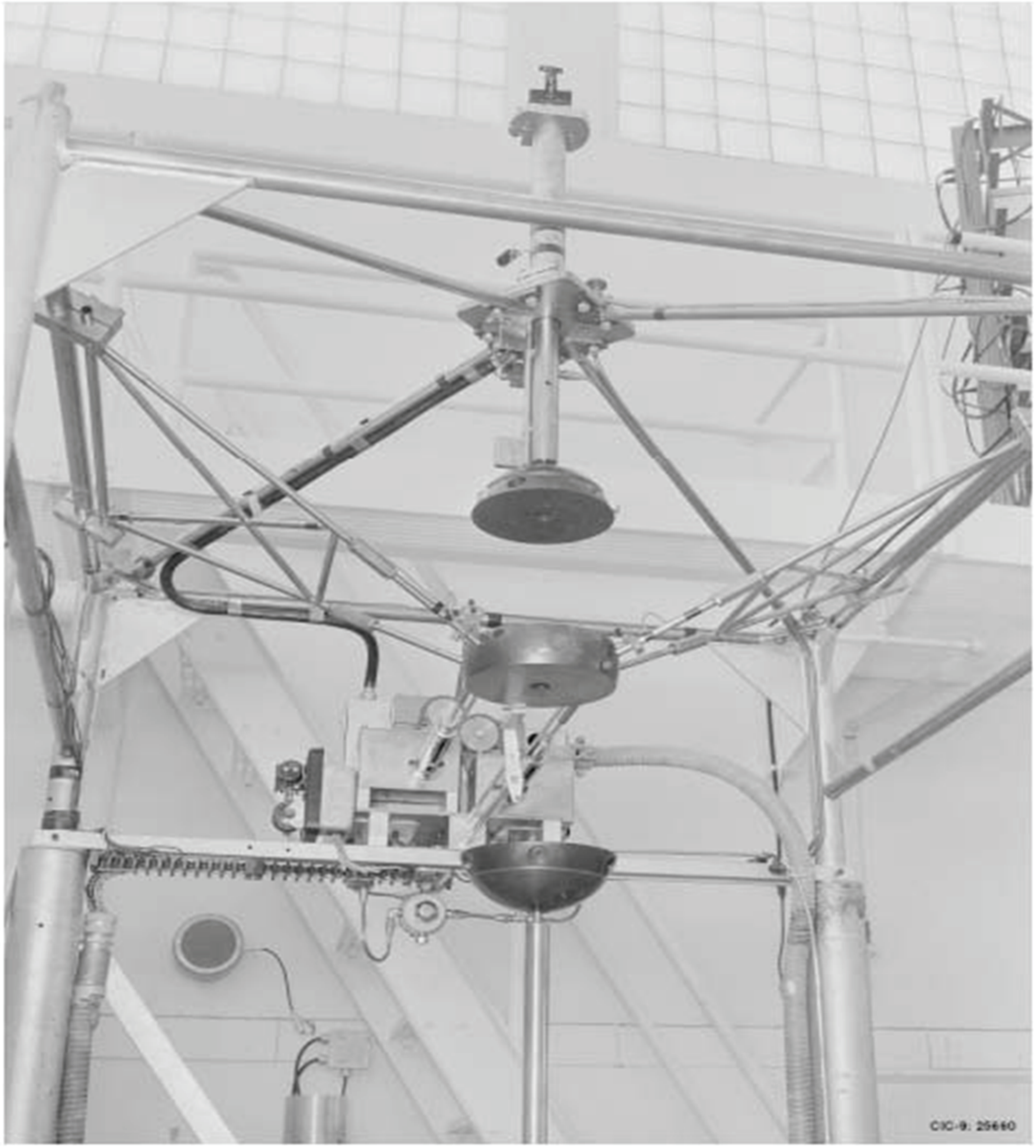


Figure 48. The Los Alamos Scientific Laboratory Lady Godiva assembly (unreflected enriched-uranium sphere) in the scrammed configuration.

Figure 49. Lady Godiva after the excursion of 3 February 1954.

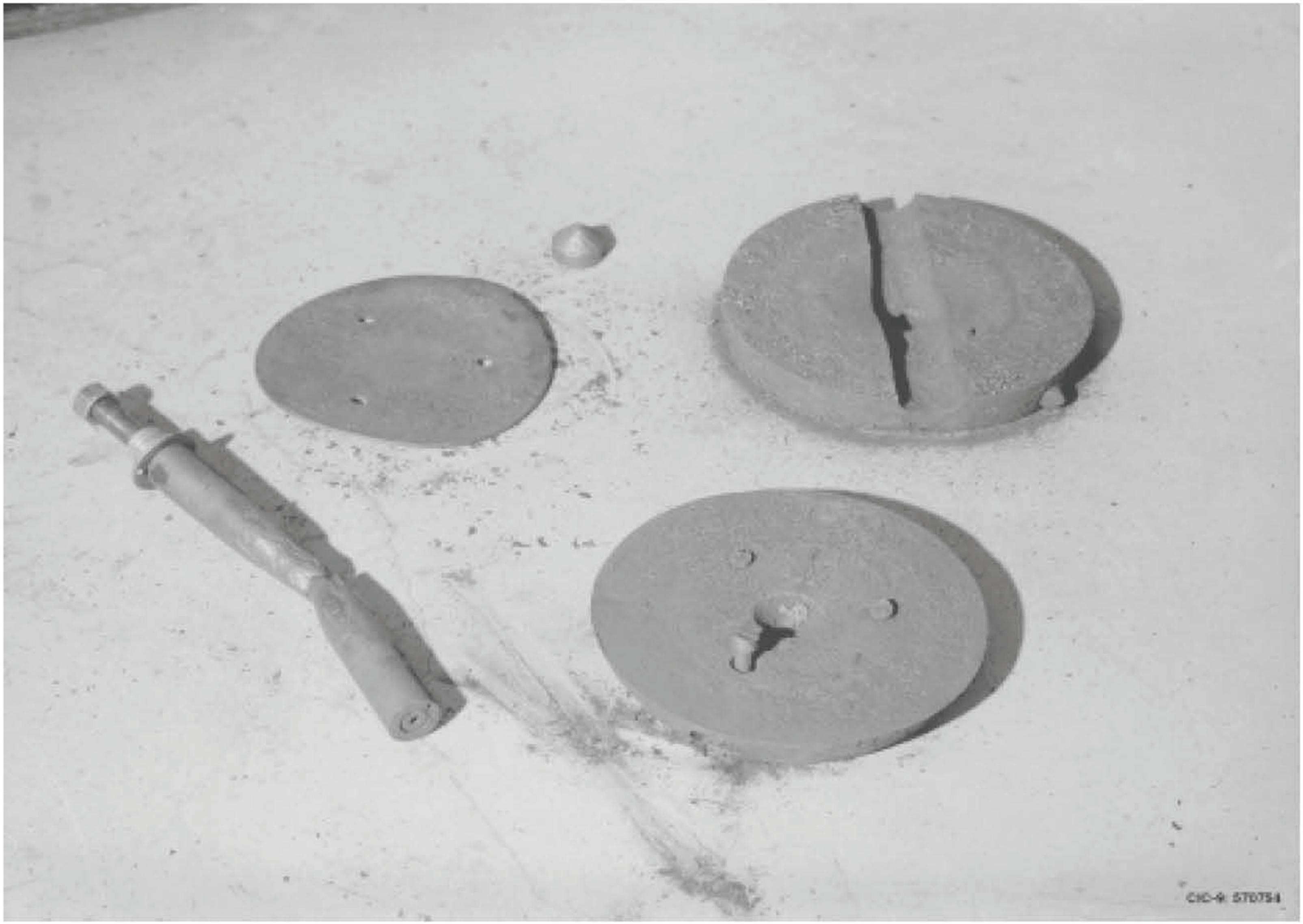


Figure 50. Burst rod and several sections of Lady Godiva showing oxidation and warpage that accompanied the second accident, 12 February 1957.

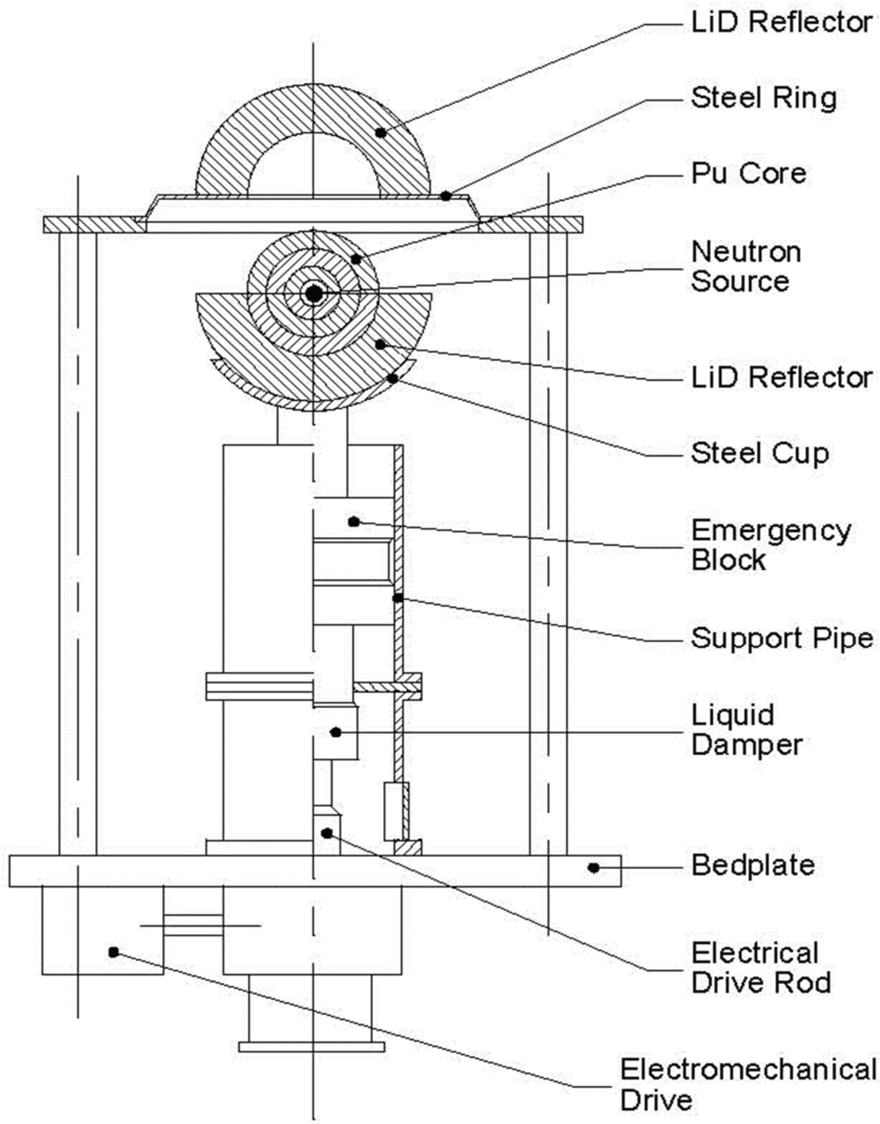


Figure 51. MSKS and assembly involved in the 11 March 1963 accident.

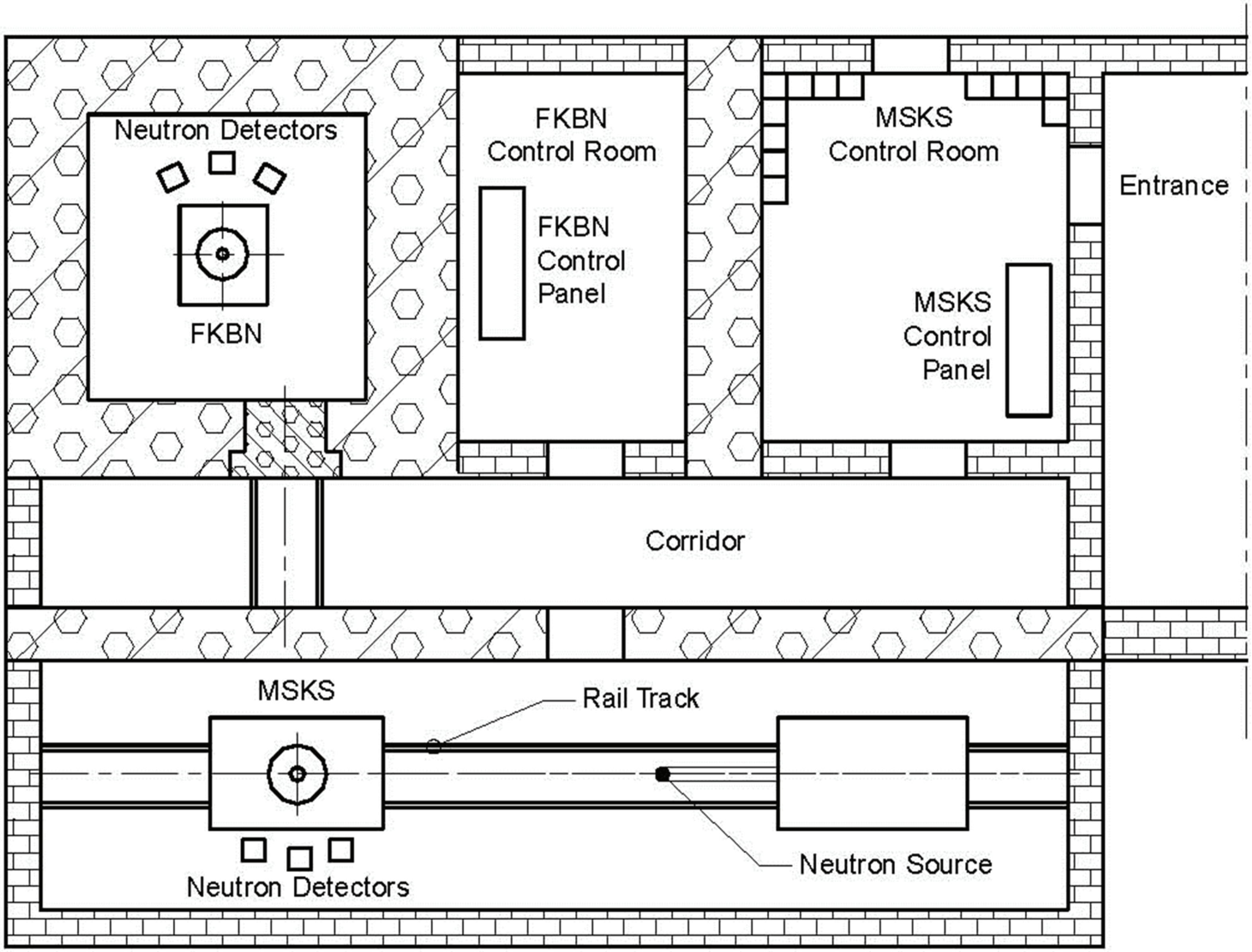


Figure 52. Building B floor plan.

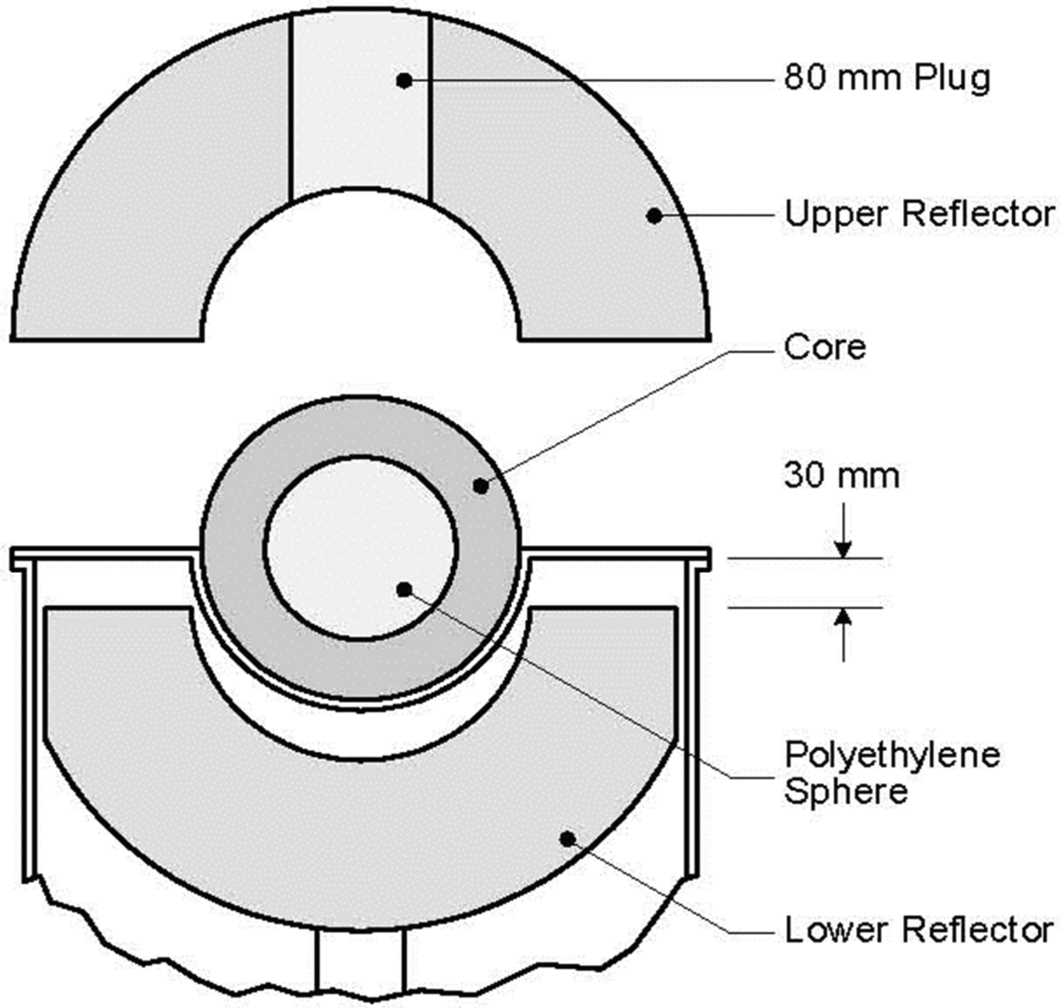


Figure 53. Approximate accident configuration of the FKBN vertical lift assembly machine and core.

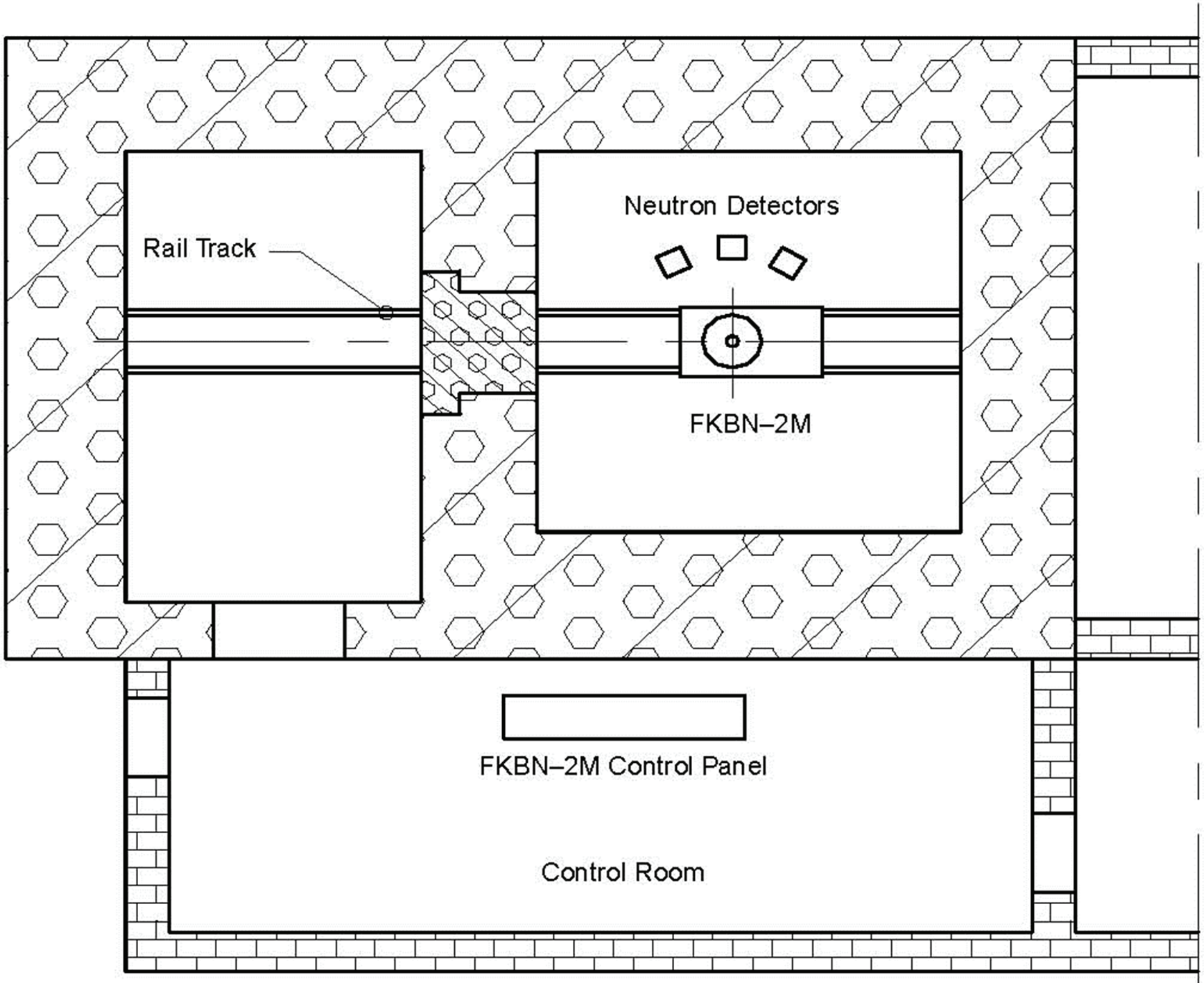


Figure 54. FKBN-2M building layout.

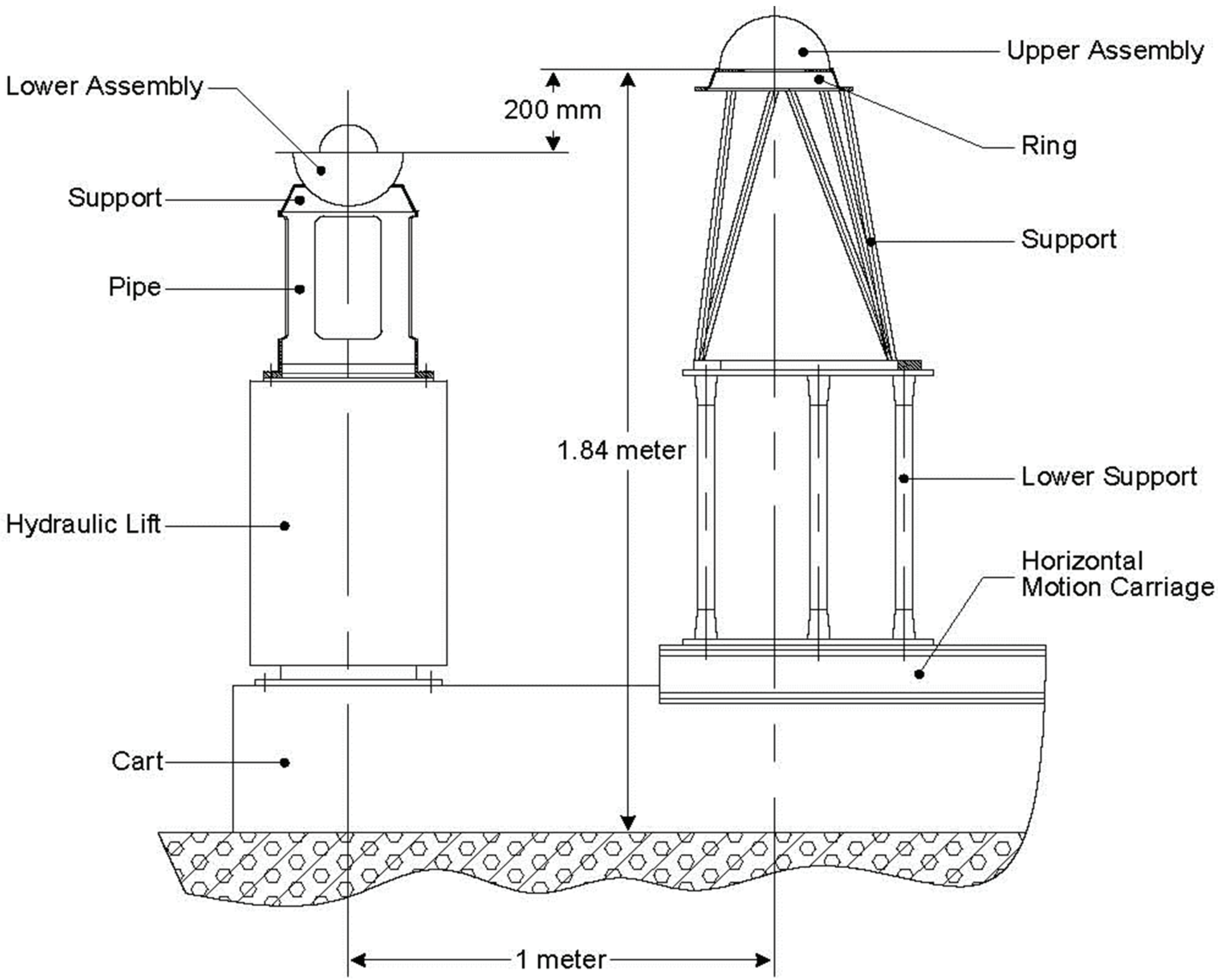


Figure 55. FKBN-2M experimental layout.

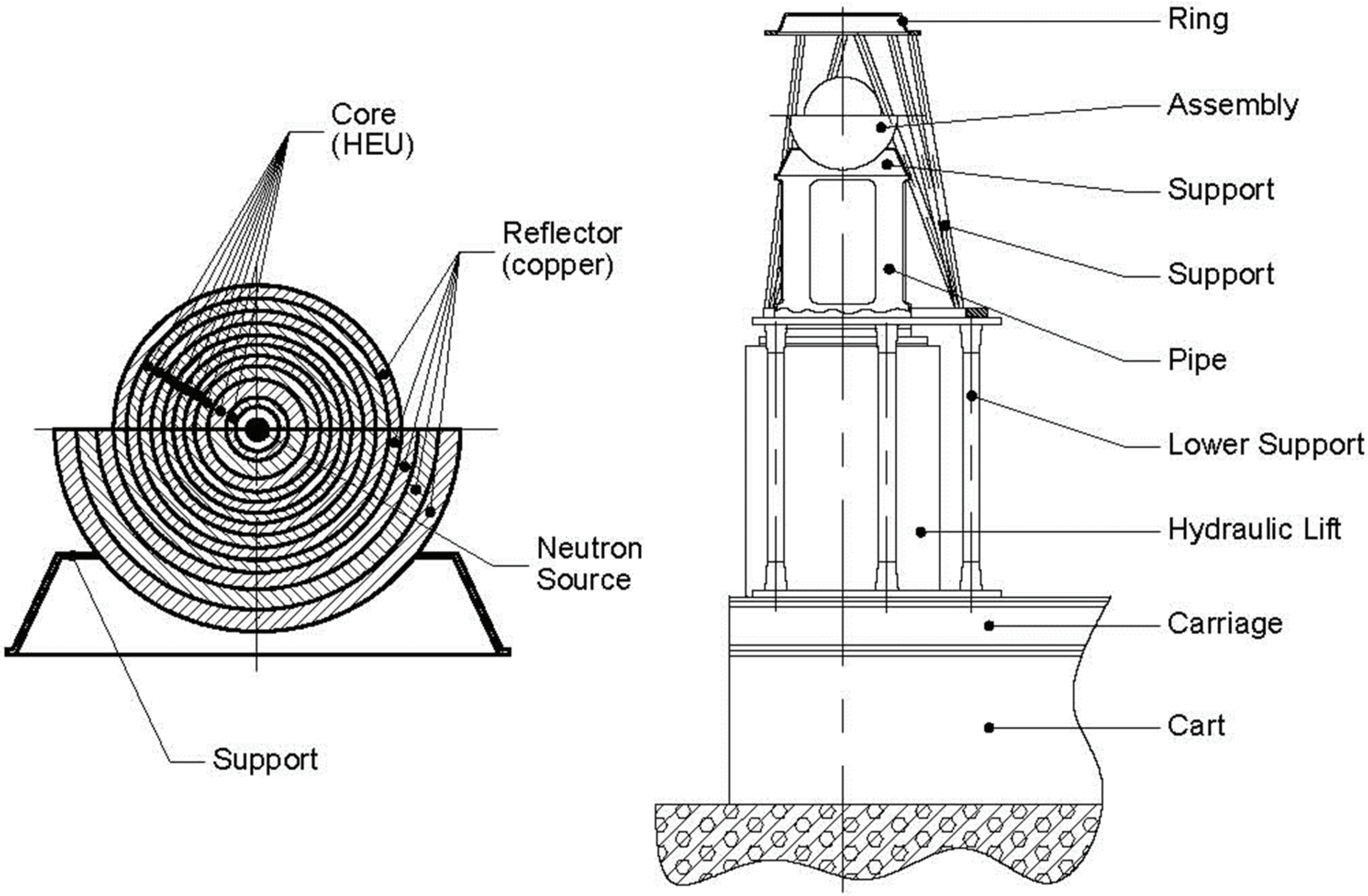


Figure 56. Accident configuration.

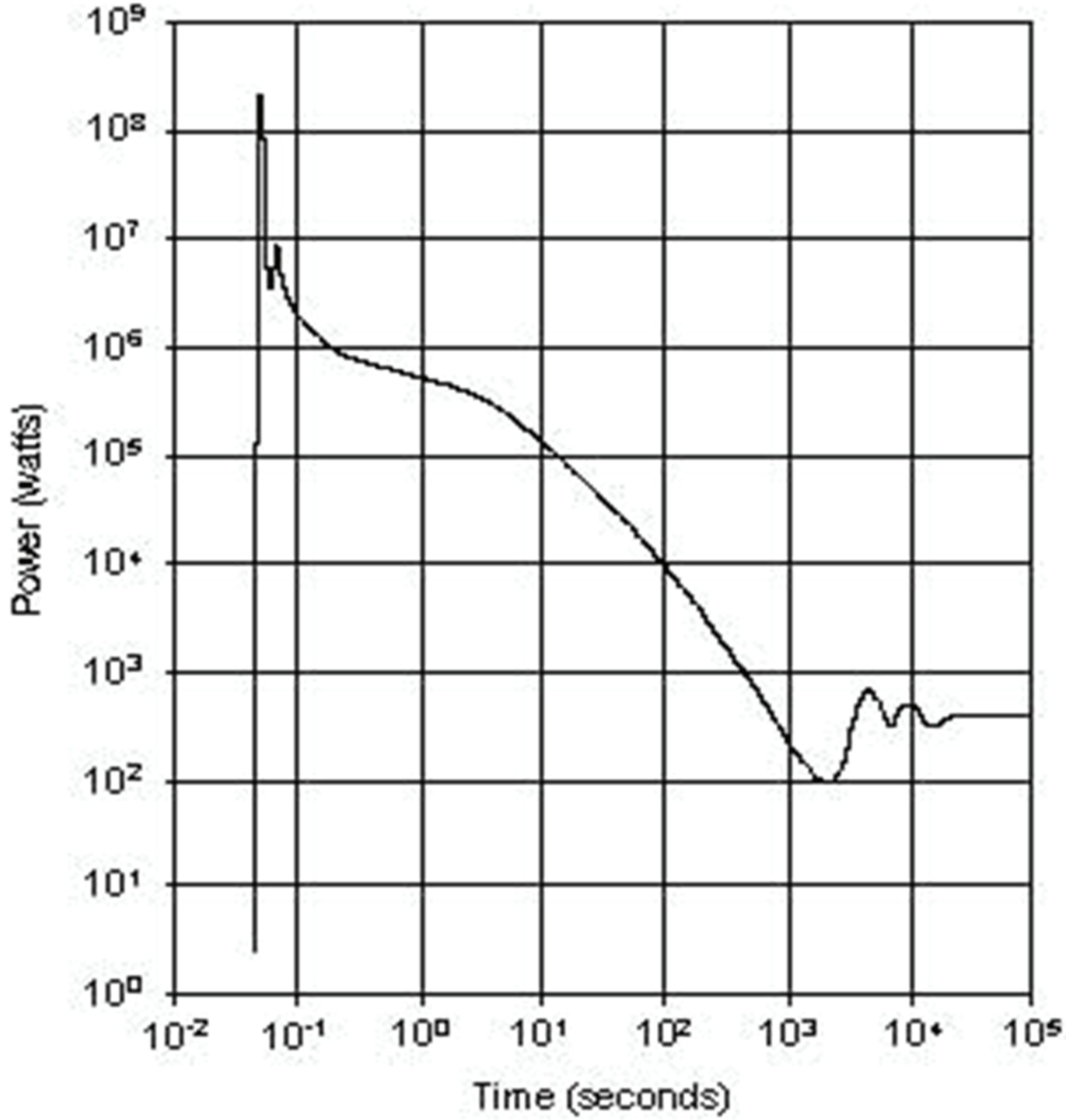


Figure 57. Calculated power history for the accident.

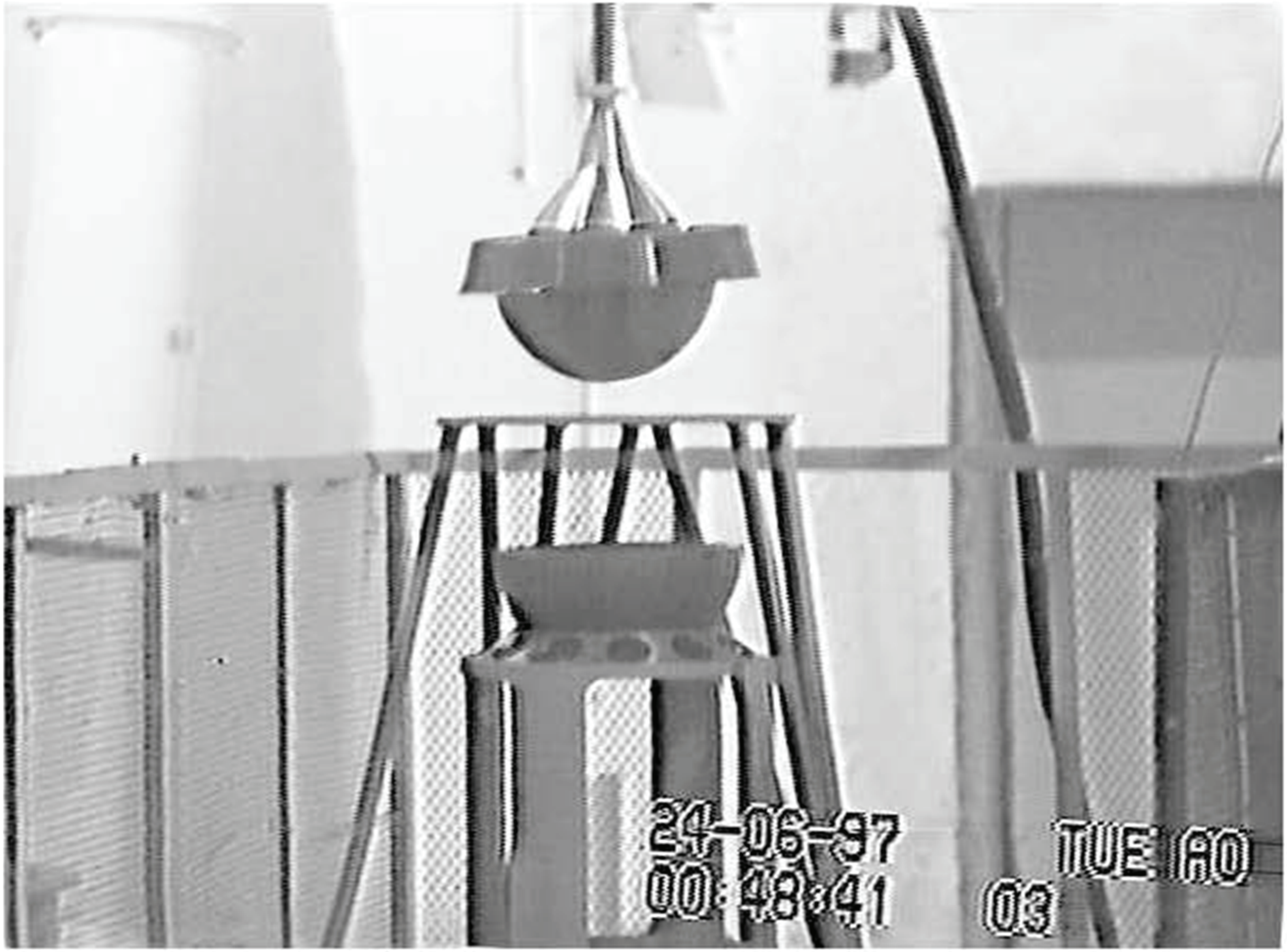


Figure 58. Removal of the main core of the assembly from the lower copper hemishell reflector.

Figure 59. The destructive excursion in BORAX, 22 July 1954.

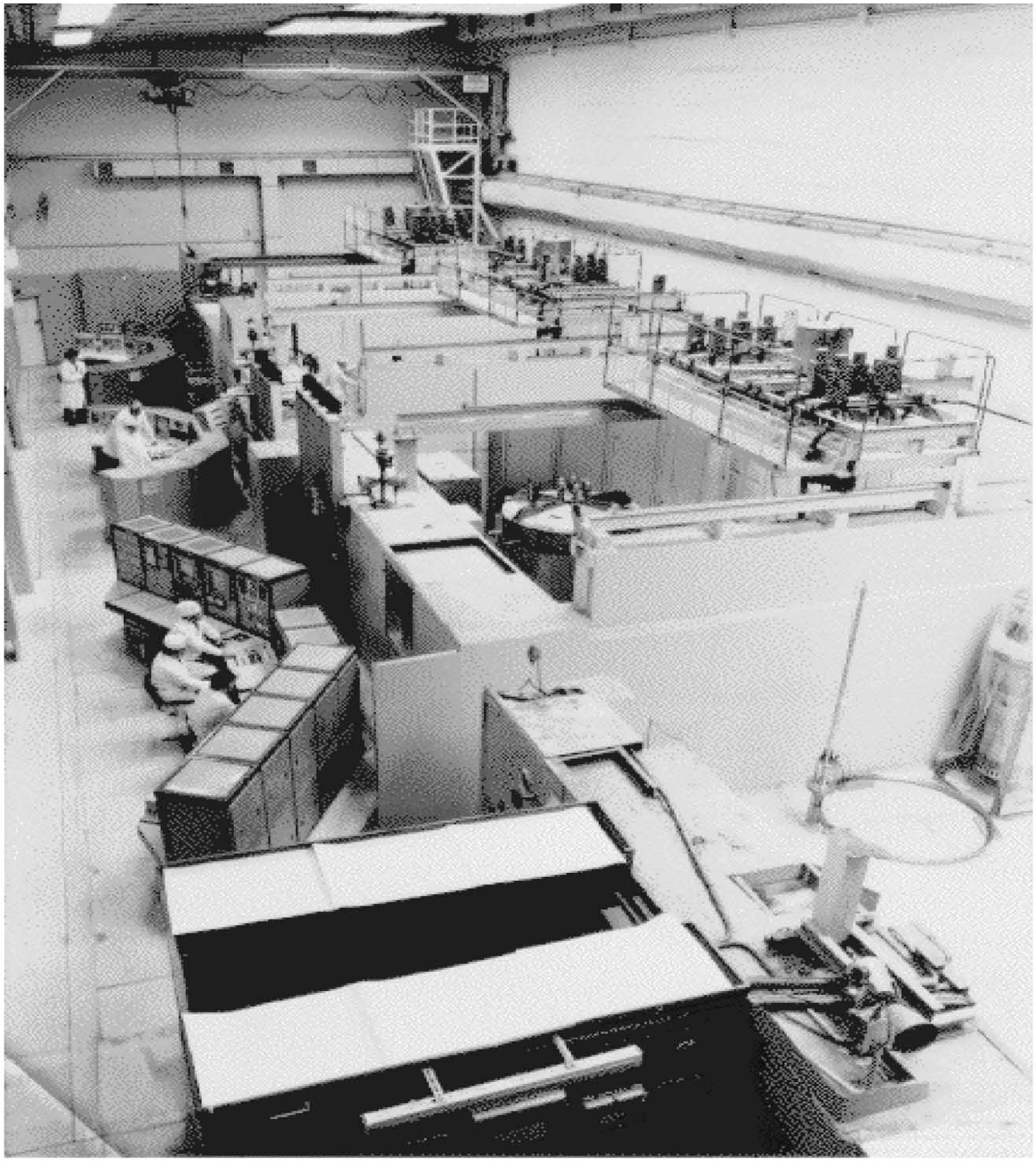


Figure 60. Photograph of the SF-7 control and experimental rooms where the first accident occurred.

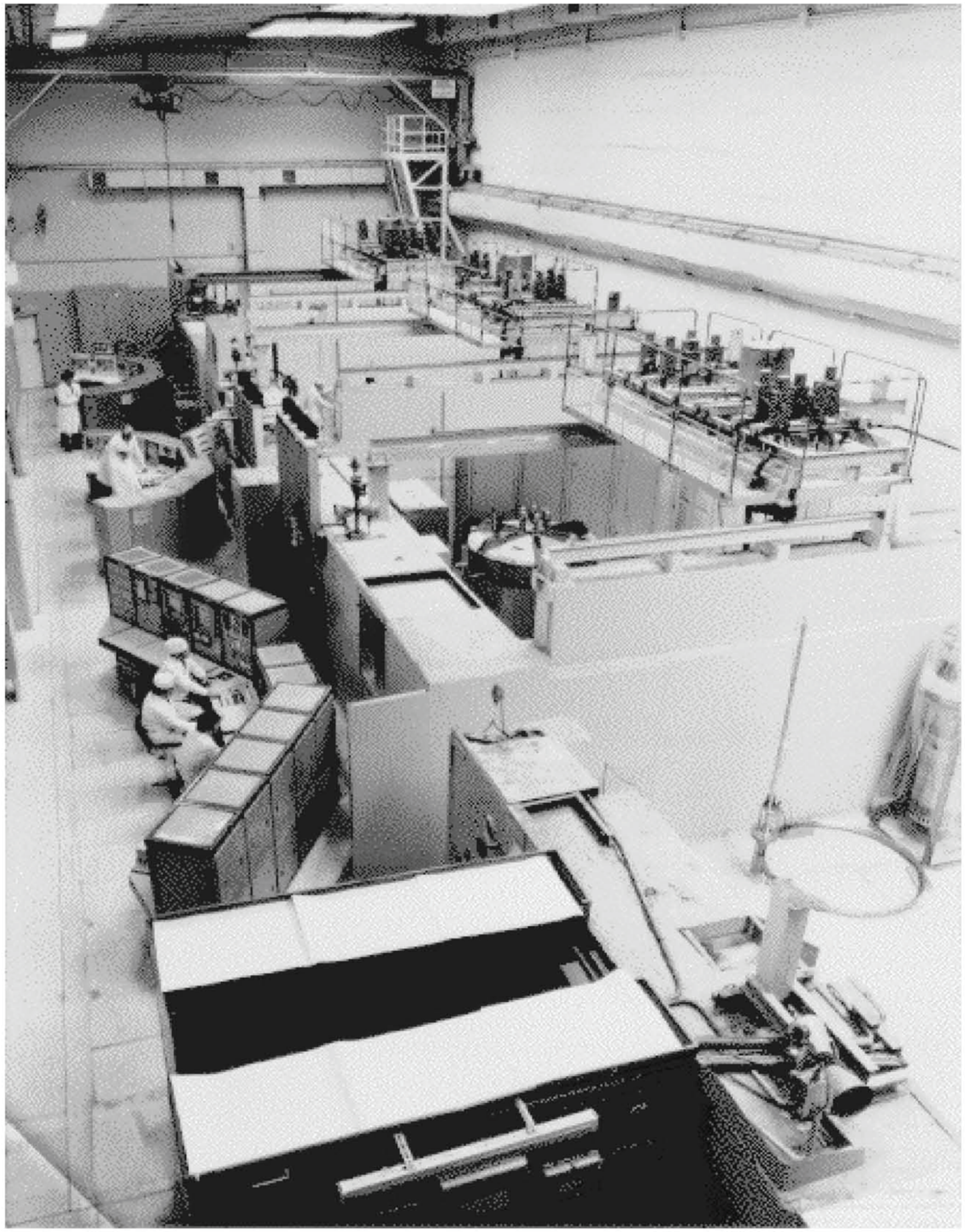


Figure 60. Photograph of the SF-7 control and experimental rooms where the first accident occurred.

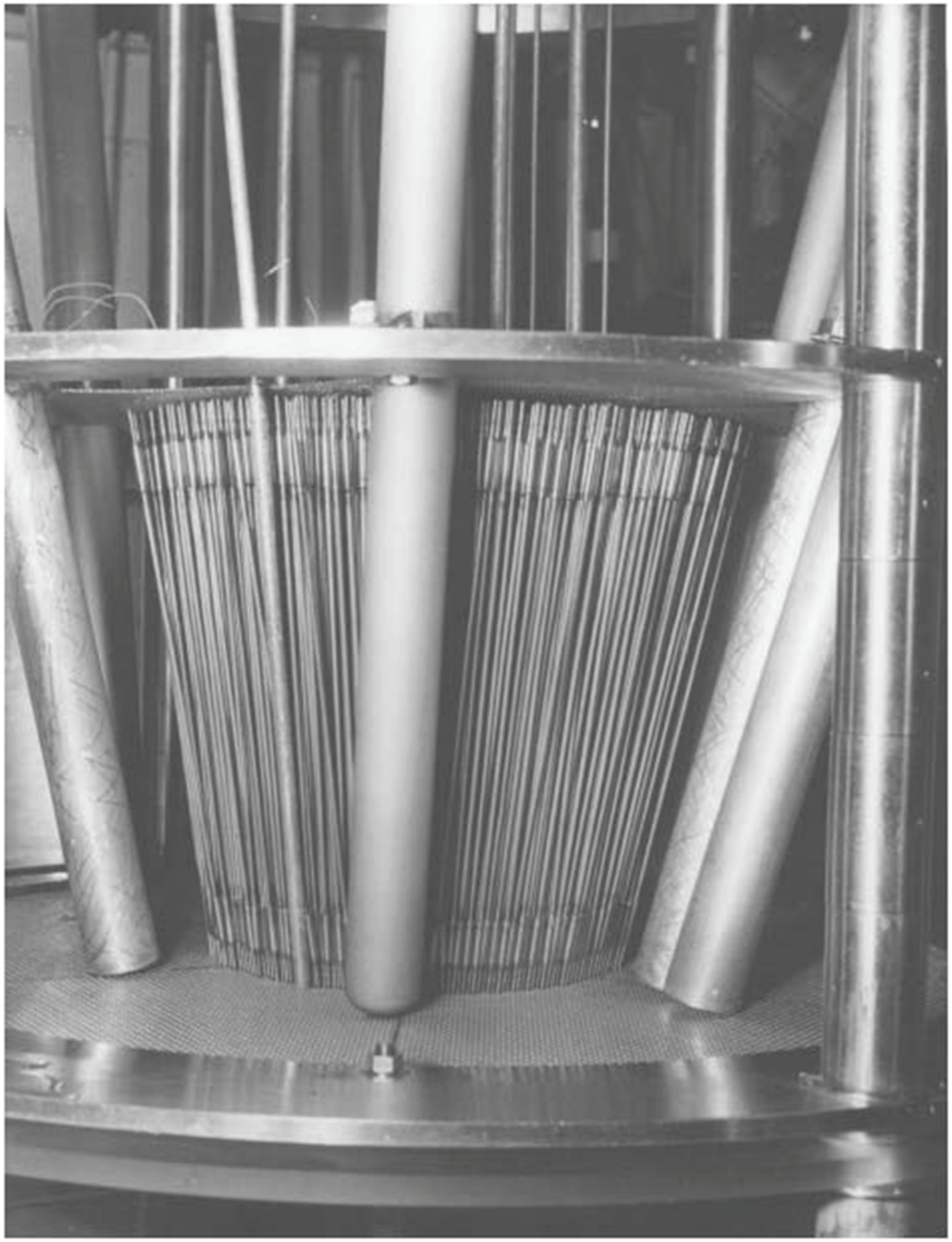


Figure 61. Mockup of the accident configuration for the 26 May 1971 accident.

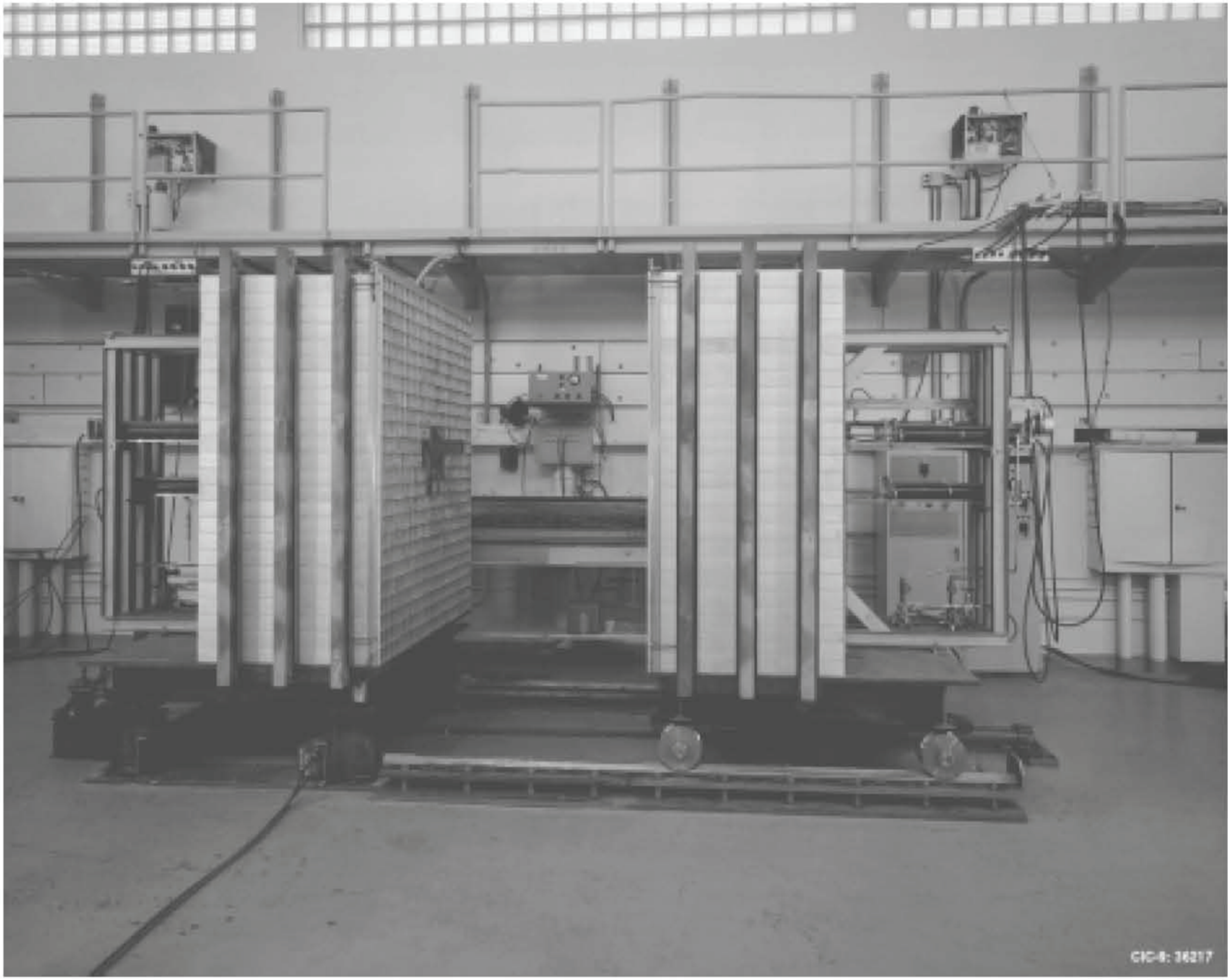


Figure 62. The LASL Honeycomb assembly machine. The movable section (right) is in the withdrawn position and the aluminum matrix is only partially loaded.

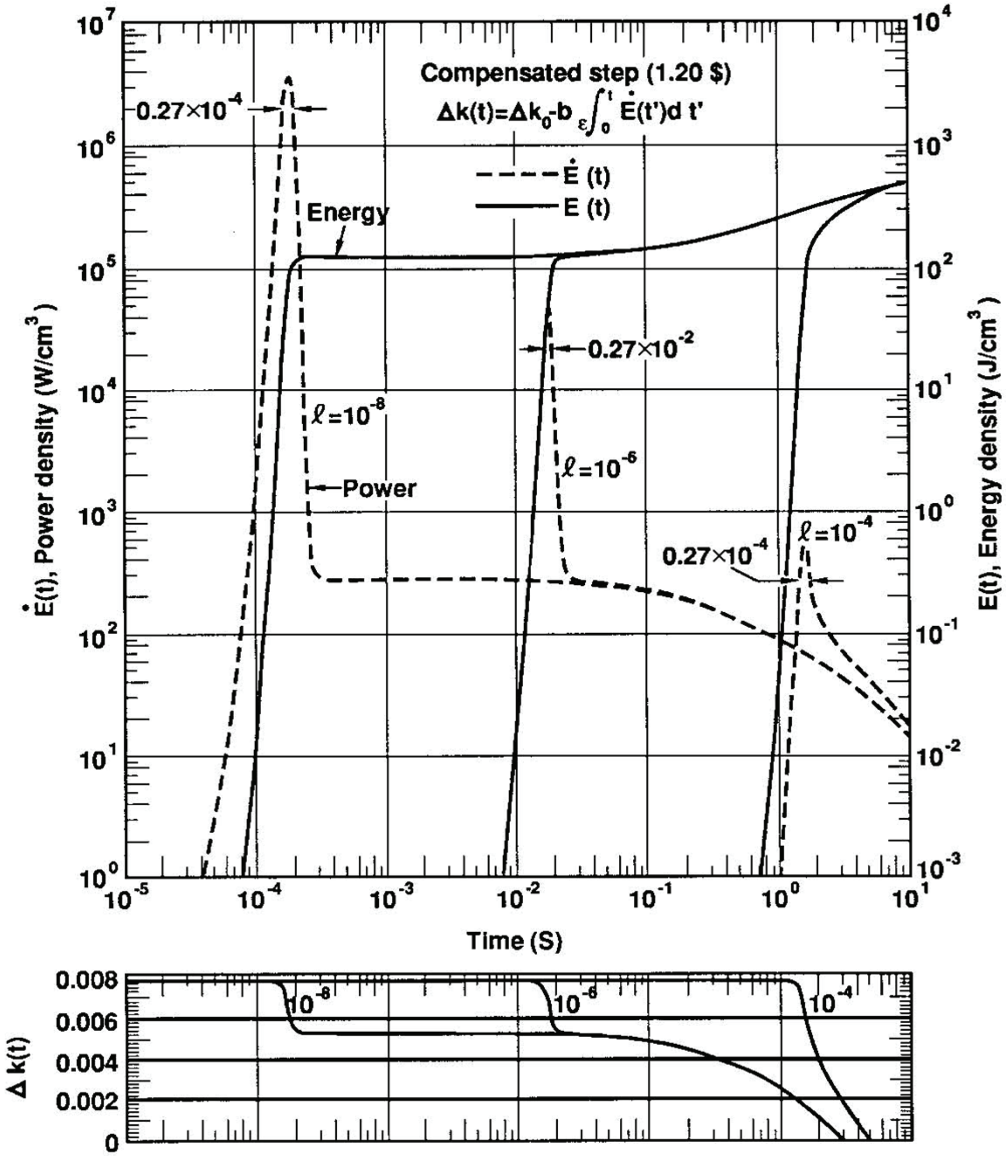


Figure 63. Energy model computation of power and energy release vs time. The initial reactivity is 1.2 $ above delayed critical. Neutron lifetime values are 10^{-8}, 10^{-6}, and 10^{-4} seconds. The bottom panel shows the corresponding curves of reactivity vs time.

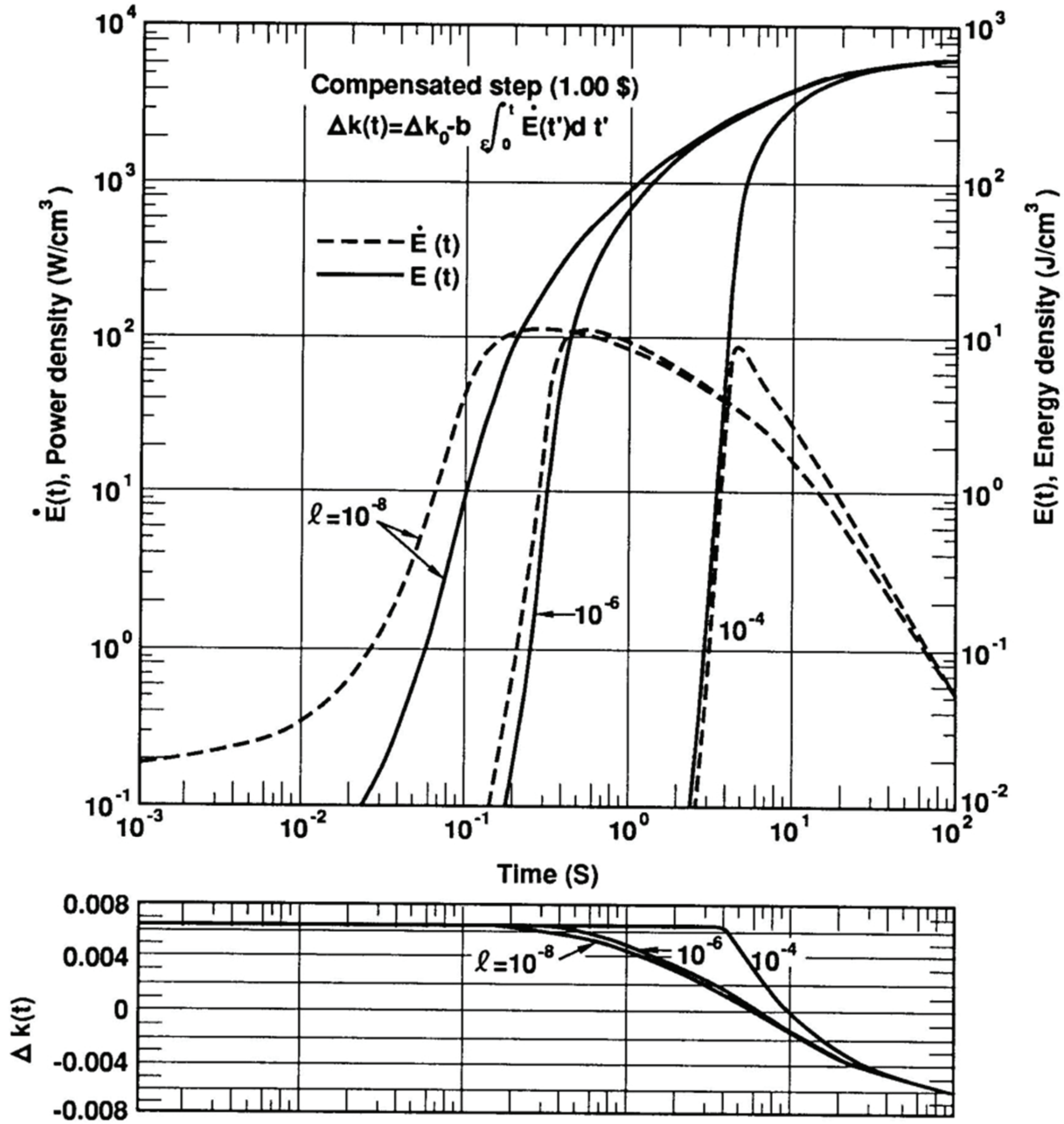


Figure 64. Energy model computation of power vs time. The initial reactivity is 1.0 $ above delayed critical. Neutron lifetime values are 10^{-8}, 10^{-6}, and 10^{-4} seconds. The bottom panel shows the corresponding curves of reactivity vs time.