CRITICALITY ACCIDENTS

HISTORY AND CURRENT IMPACTS

- Vignettes from Russia and Lessons Learned for Everyone
- Interplay with Accident Simulation Experiments
- Impacts on ANS-8 Standards and Federal Regulations

Thomas P. McLaughlin, Consultant - Retired Los Alamos

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LA-13638

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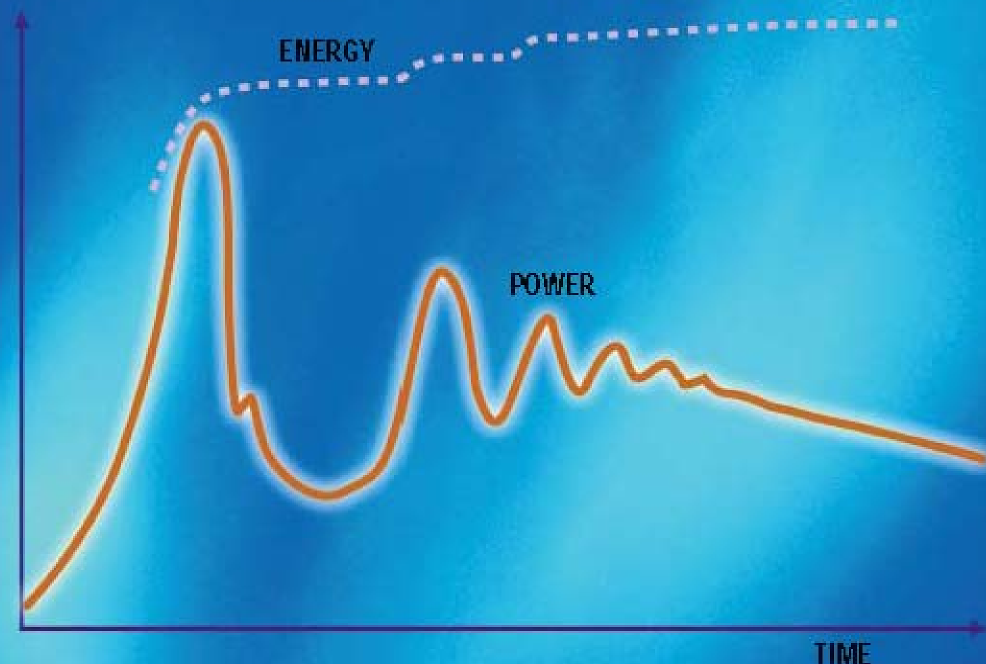
A Review of Criticality Accidents

2000 Revision



Los Alamos
NATIONAL LABORATORY
Los Alamos, New Mexico 87545

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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	Process Operations
~ 50,000 Experiments	22 Accidents
38 Accidents	21 Solution; 1Metal
12 Fatalities	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

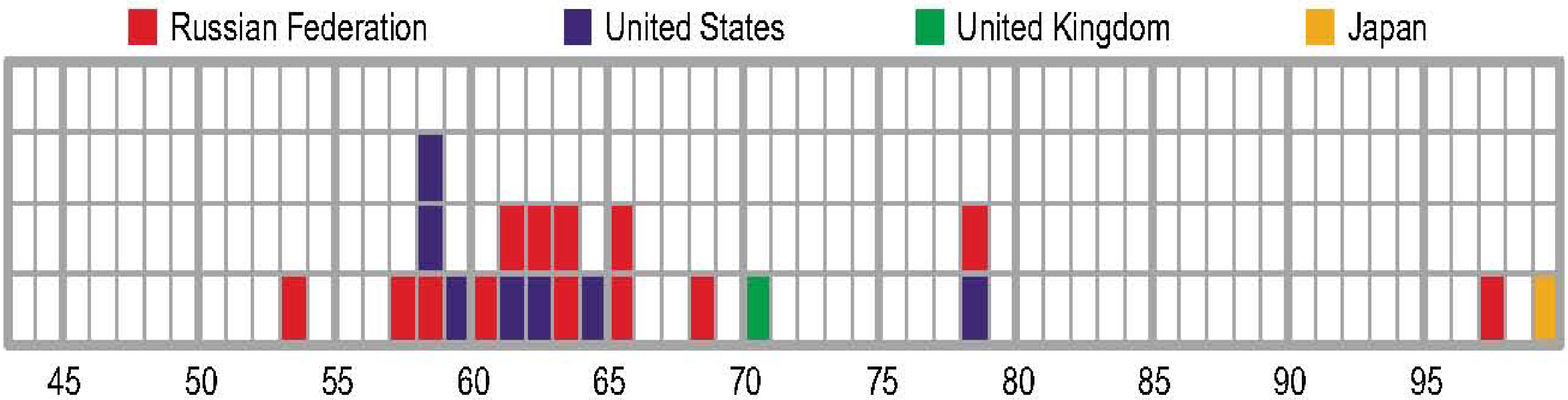


Figure 1. Chronology of process criticality accidents.

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

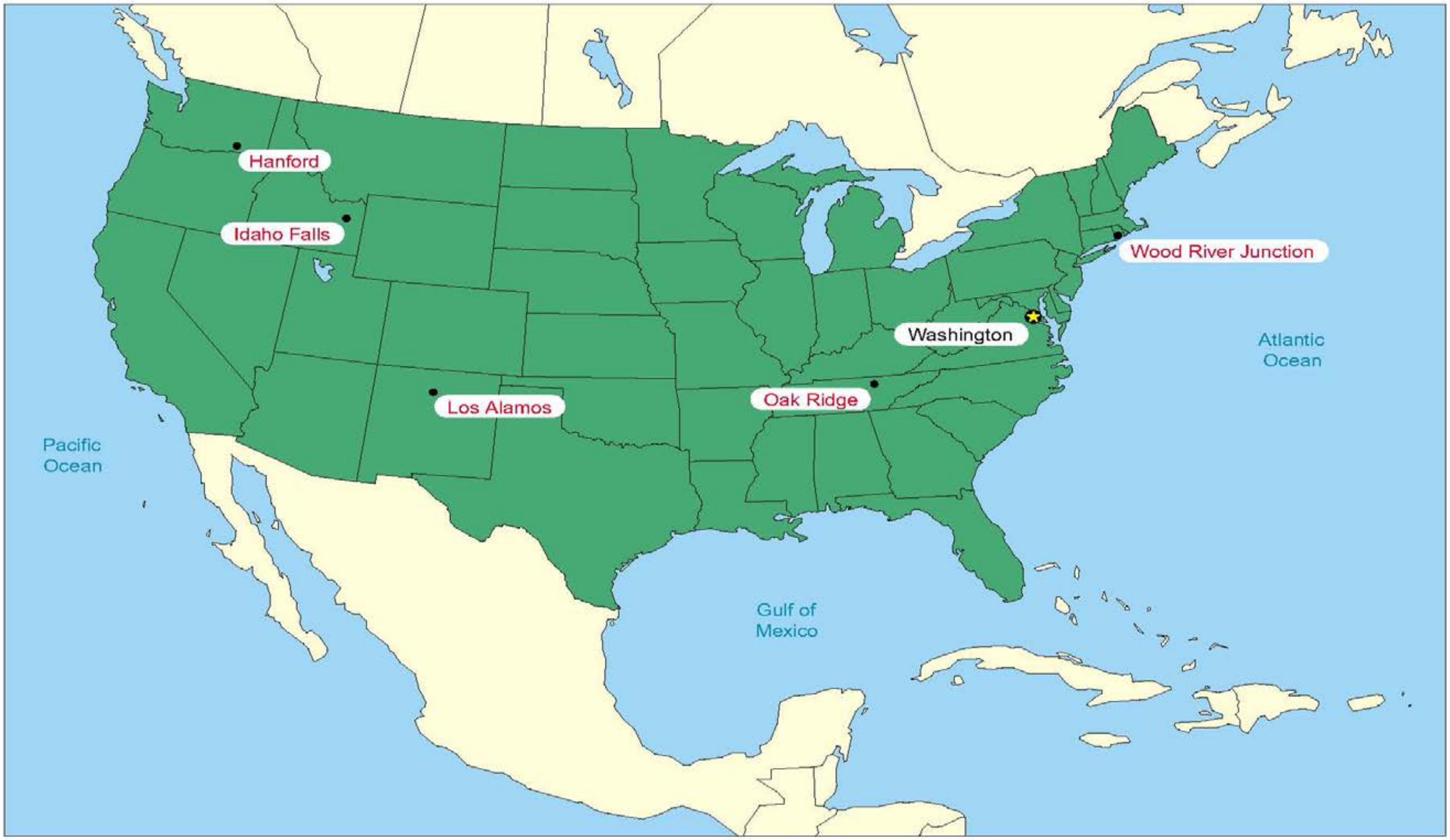


Figure 3. Map of the United States showing the sites of the process criticality accidents, and the capital, Washington.

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
- Local 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

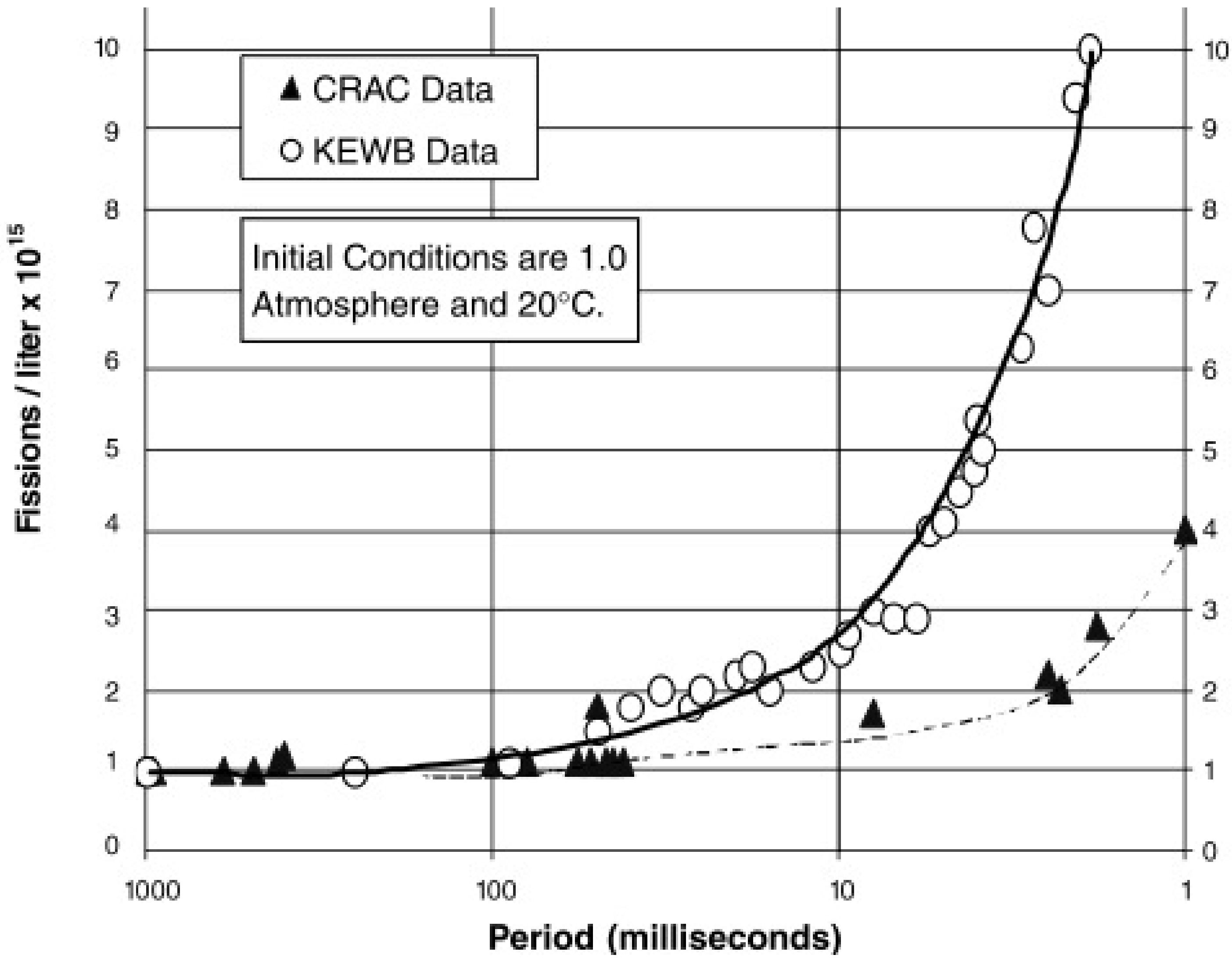
- Likelihoods of criticality accidents are extremely low, but will never be zero.
  - **Elimination of unfavorable geometry process vessels has been a key factor**

- Diligence is required to maintain a proper, acceptably low, accident risk **while balancing the need for process ease and efficiency.**

NEW(?) INSIGHTS

- Accident frequency down dramatically since mid-60’s
- ANS-8 Standards and Federal Regulations essentially unchanged for ~50 years
- **We are remiss to not be reaping benefit of lower accident likelihoods/risks**

MAXIMUM SPECIFIC FIRST SPIKE YIELD VS PERIOD



MAXIMUM SPECIFIC FISSION YIELD - FIRST 10 MINUTES

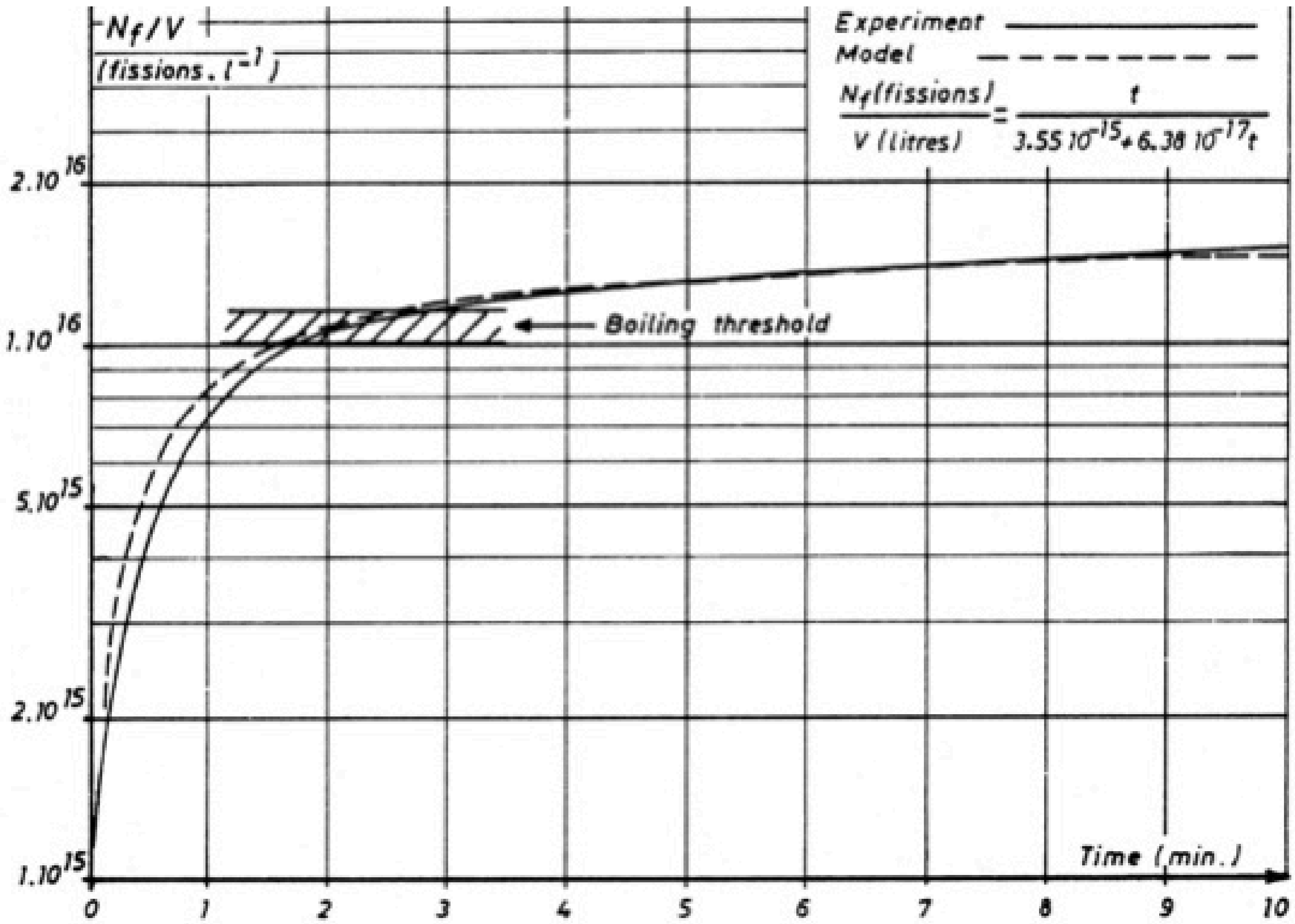


Figure C.2 – Maximum specific fission yield resulting from criticality solution excur-

CHRONOLOGY OF PROCESS ACCIDENTS

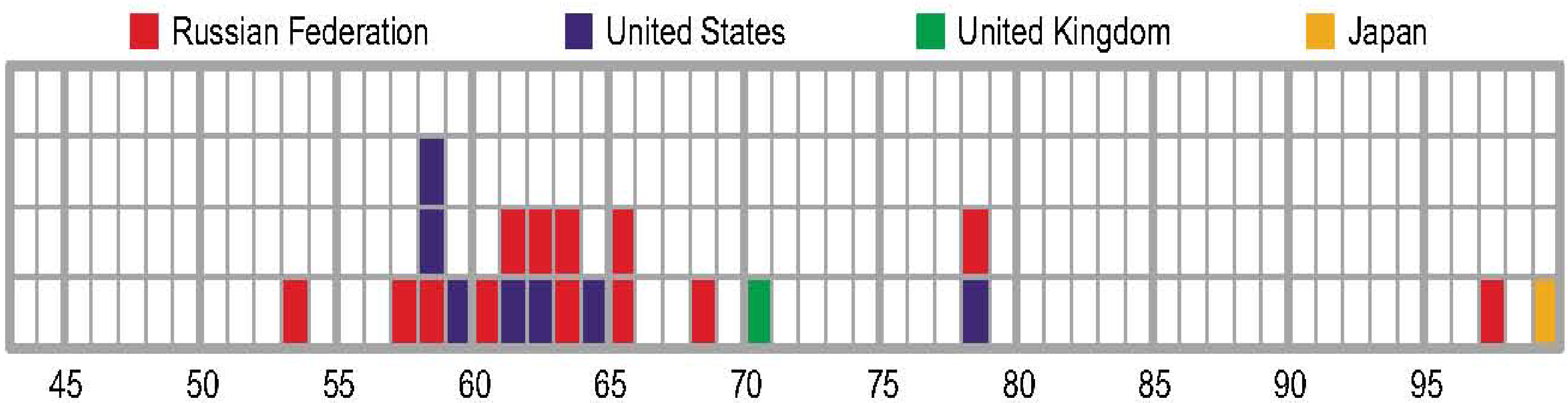


Figure 1. Chronology of process criticality accidents.

CRITICAL VOLUMES AND CONCENTRATIONS

- 20 Liters - ONE
- **30-80 Liters - SIXTEEN**
- > 100 Liters - FOUR

- < 100 g/l - NINETEEN
- > 100 g/l - TWO

DELAYED CRITICAL VS PROMPT CRITICAL ACCIDENTS

- **No First Spike = 7 = "Slow Cooker"??**
  - All occurred in Russia – MC&A?
- Yes - First Spike (~1.0+15 fissions/l) = 9
- Unknown (no data) = 5

OBSERVATIONS

- Criticality Accidents Do NOT Occur in Favorable Geometry Vessels
- **Unfavorable Geometry Vessels ~100% Removed from Rich Solution Process Operations During 60's in Both US & USSR (Were they ever in use in UK & France?)**
- NO Hands-On Accidents in US since 1964
- NO Hands-On Accidents in USSR since 1968

CHRONOLOGY OF PROCESS ACCIDENTS

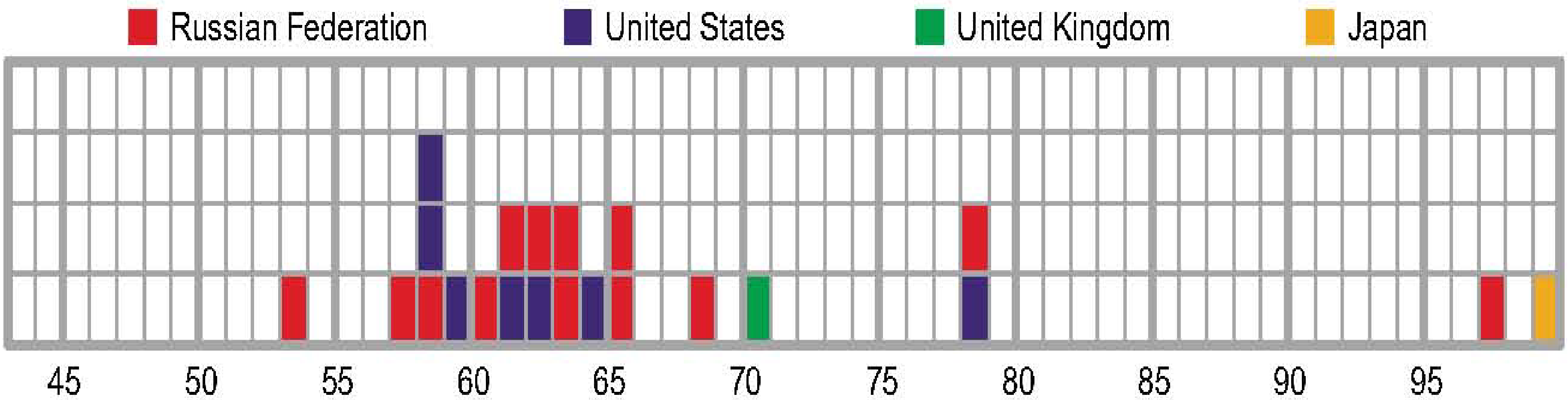


Figure 1. Chronology of process criticality accidents.

CONCLUSIONS

- Accidents in Routine, Rich Solution, Process Vessels “Essentially” Eliminated
  - Thus, Slightly-Above-Delayed-Critical Accidents with Personnel Present “Essentially” Eliminated
  - **That is, Slow Cooker with Personnel Present “Essentially” Eliminated**

WHAT'S LEFT?

- Upset Conditions – Seismic, Fires, ?? - Solutions Flow; Dry Powders Become Moderated …..
- Waste Tank Operations – Unfavorable Geometry
- These situations are **unlikely** to expose personnel

ANS-8 AND REGULATORY IMPLICATIONS ??

- ANS-8.3 “Minimum Accident of Concern”
- ANS-8.1 “Process Analysis” Subsection 4.1.2
- ANS-8.10 General Intent
  - Only “Shielding and confinement” …..or
  - Broadly “When Personnel are not present”??
- ANS-8.23 Applies to all Re-entry operations
  - Including First Responders, Firefighters, etc.

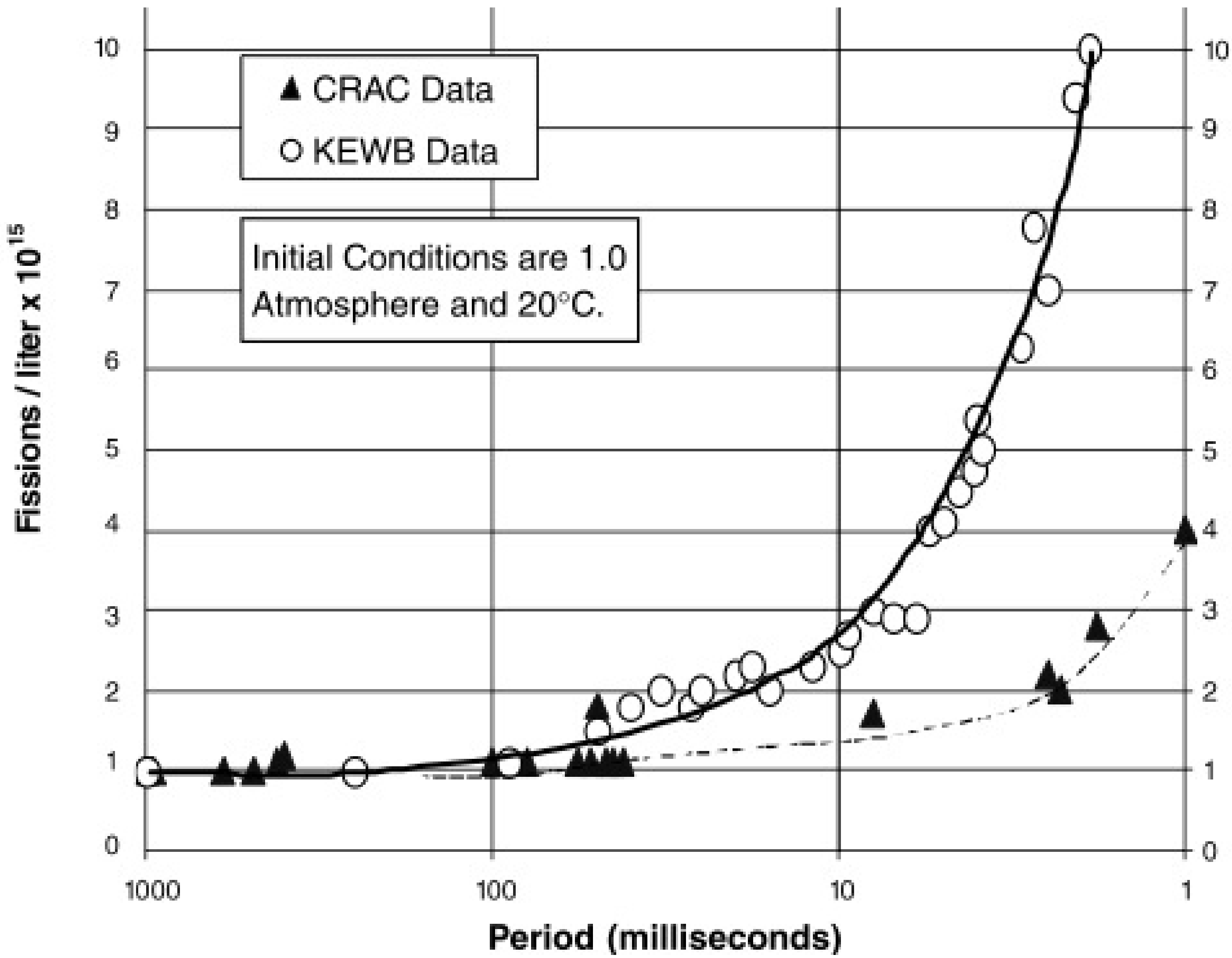
ANS-8.3 - MAC

- Historically/Currently: 20 rad in one minute at 2 meters. This guidance is ~50 years old.
- Developed to detect Slow Cooker, down to “few cents” above delayed critical excursion
- Recent concern WG8.3 that “few cents” not accurate; and thus that 20 rad not accurate

ANS-8.3 - MAC

- If "**Slow Cooker with Personnel Present 'Essentially' Eliminated**"
- What is a realistic, practical MAC?
- ANS-8.3 WG considering/proposing:
  - (Near) Prompt critical first spike (**conservatively**) consistent with Figures C.1 & C.2 of ANS-8.23
  - 1.0 E+15 fissions/liter in **10-second** spike
  - I.e., 1.0E+14 fissions/s per liter
  - **Much easier to detect than 20 R/minute**

MAXIMUM SPECIFIC FIRST SPIKE YIELD VS PERIOD



MAXIMUM SPECIFIC FISSION YIELD - FIRST 10 MINUTES

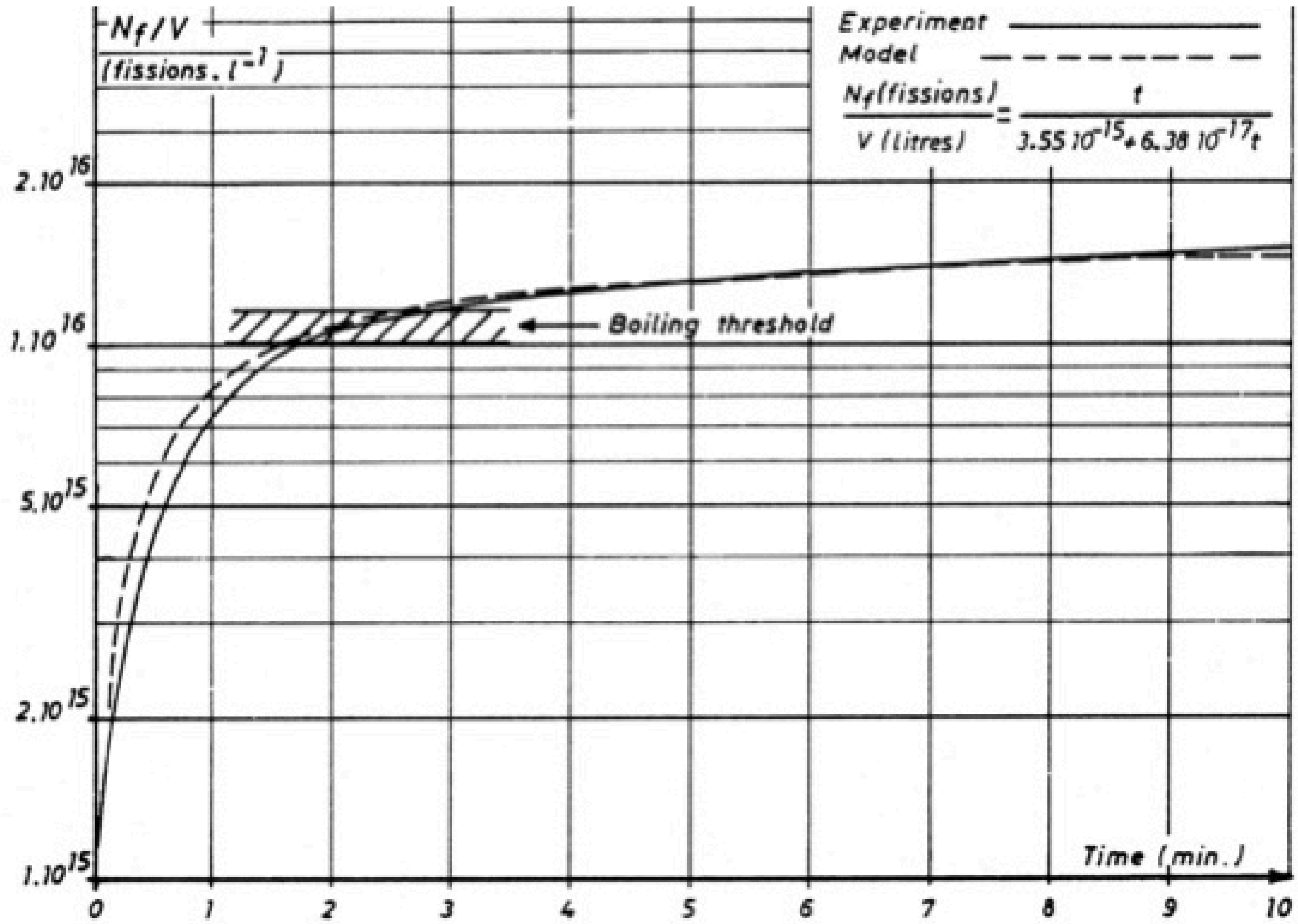


Figure C.2 – Maximum specific fission yield resulting from criticality solution excur-

ANS-8.1 – PROCESS ANALYSIS

- **Historically/Currently**: "Before a new operation with fissionable material is begun or before an existing operation is changed, it **SHALL** be determined that the entire process will be subcritical for **all** normal and credible abnormal conditions."

ANS-8.1 – PROCESS ANALYSIS

- DOE/CSSG considering adopting and proposing to ANS Standards:
  - "… **all** normal conditions and, ***when personnel are present***, under credible abnormal conditions. **When personnel are not at significant risk from the radiation consequences of a criticality accident then the word 'credible' should be replaced by 'unlikely,' consistent with ANS-8.10 guidance. This requirement is not applicable to response and recovery operations for which guidance is provided in ANS-8.23"**

ANS-8.10 – SHIELDING AND CONFINEMENT

- DOE/CSSG considering proposing to ANS Standards:
  - Revise Title, Scope and Contents to make it unambiguous that the standard covers all situations (such as evacuation) when personnel are not at risk of significant radiation exposure from a criticality accident.
- DOE/CSSG considering adopting this (always intended?) philosophy

ANS-8.23 – EMERGENCY PLANS AND PROCEDURES

- DOE/CSSG considering proposing to ANS Standards:
  - Make it clear in appropriate locations in ANS-8.1 and 8.23 that 8.23 guidance applies to all re-entry situations, including firefighters and other emergency response personnel
- DOE/CSSG considering adopting this (always intended?) philosophy

CONCLUSIONS

- We have been remiss in not applying lessons learned from history
- ANS-8 and Federal Regulatory guidance MUST be based on technical reality as we know it and understand it
- ANS-8 and Federal Regulatory guidance MUST be cost-effective and practical – NOT "attempting" to attain ZERO RISK

MAYAK 1953

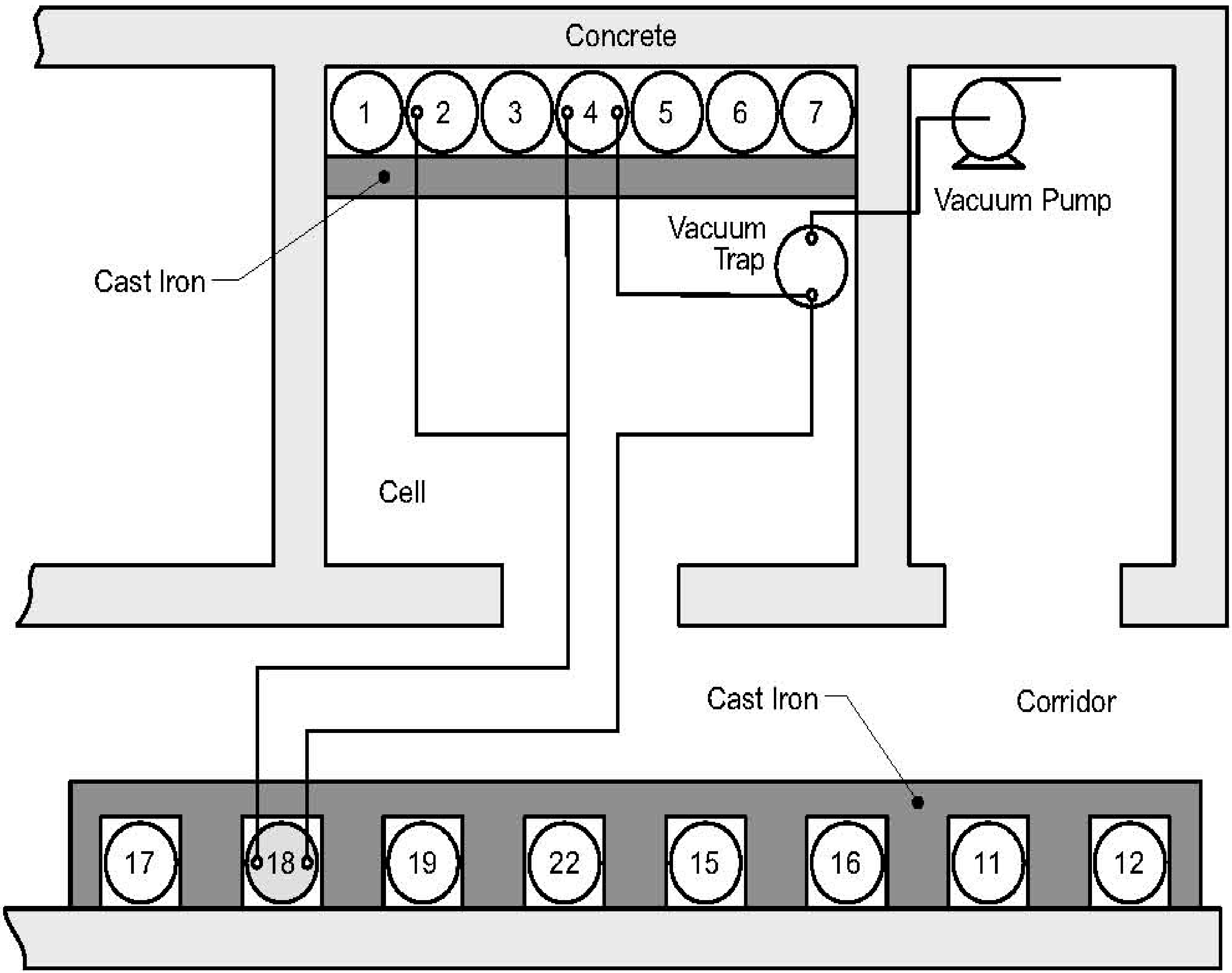


Figure 6. Layout of vessels and equipment in the staging area.

MAYAK 1957

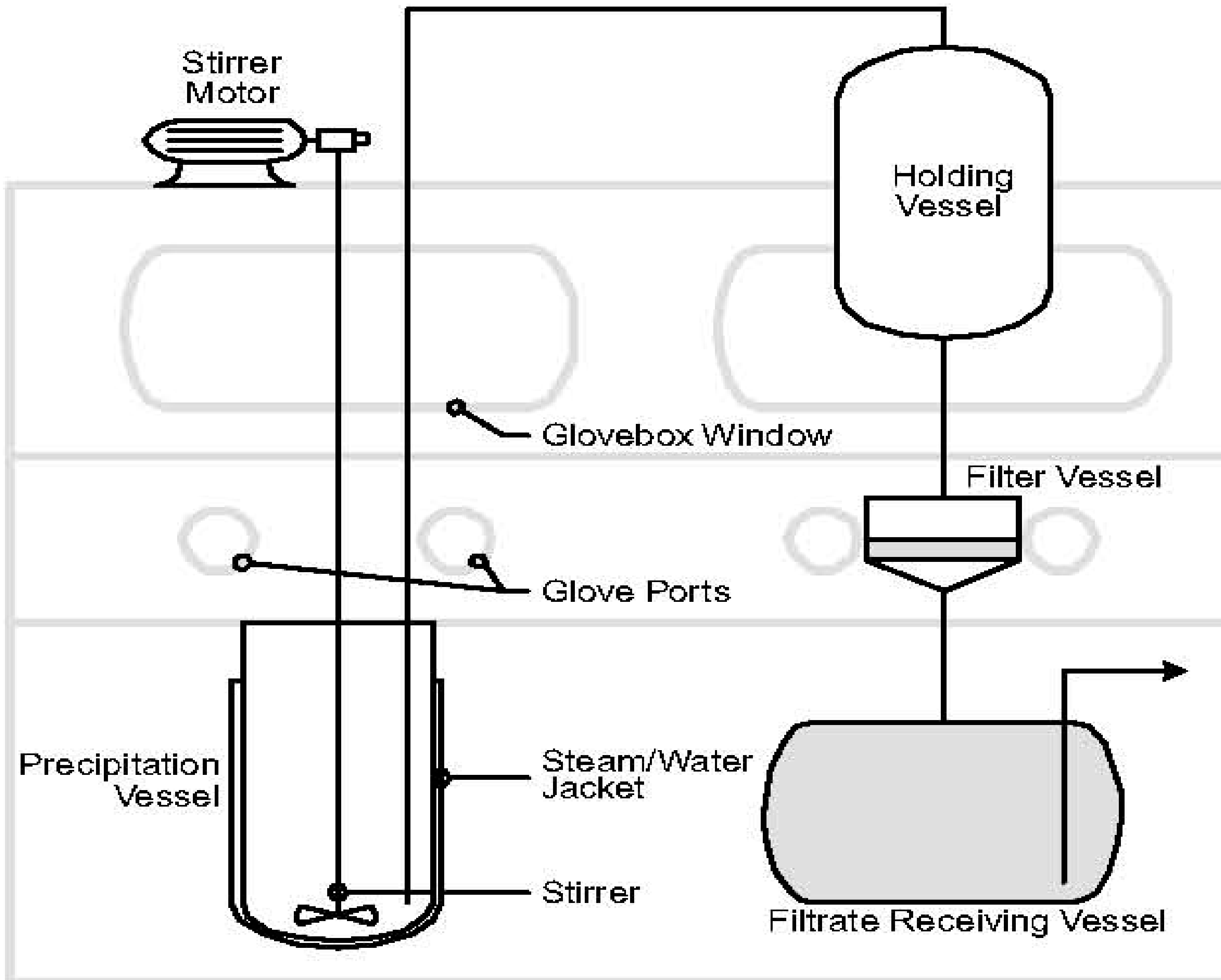


Figure 7. Equipment layout for the oxalate precipitation and filtration process.

MAYAK 1958

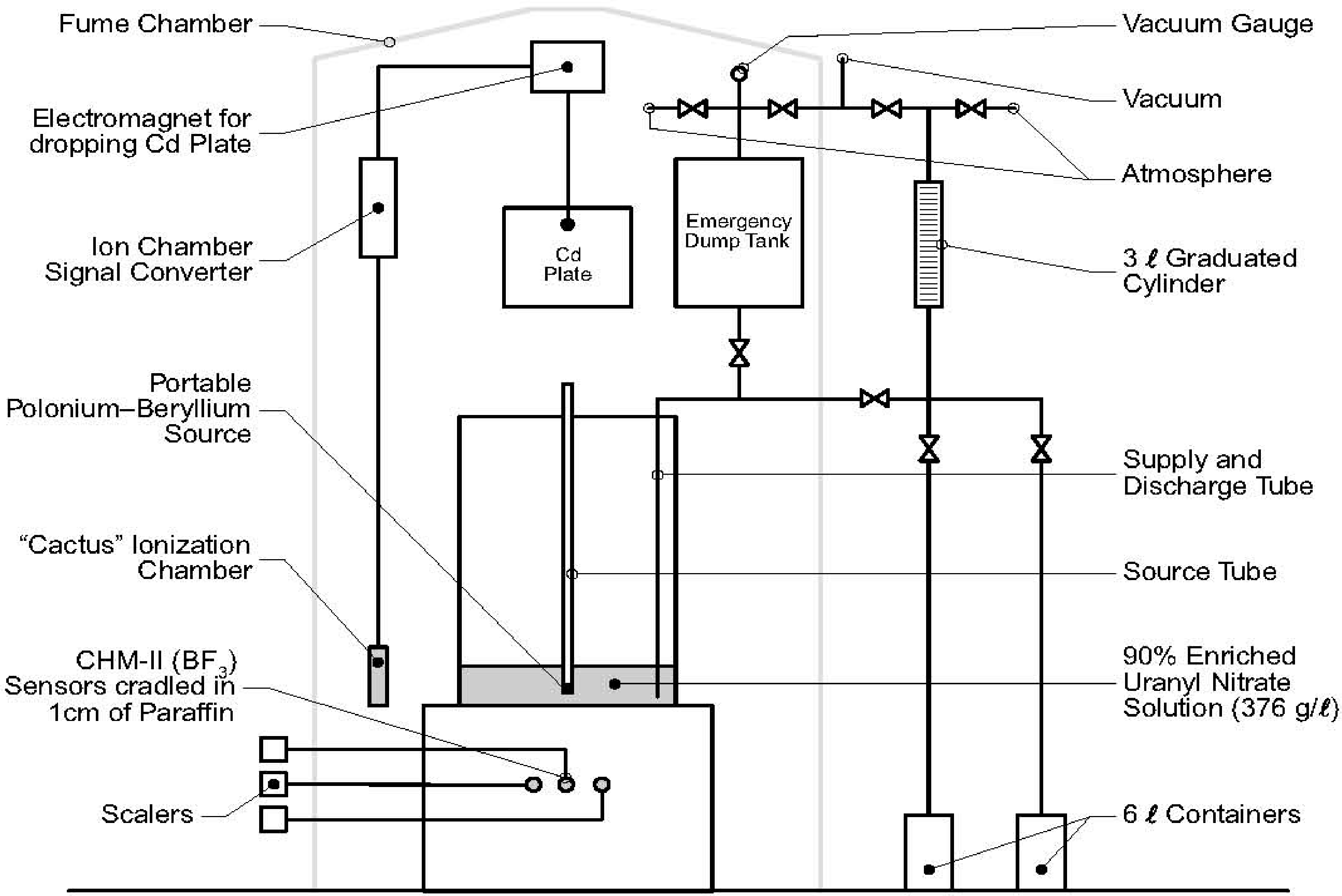


Figure 8. Layout of the experimental equipment

OAK RIDGE, Y-12 1958

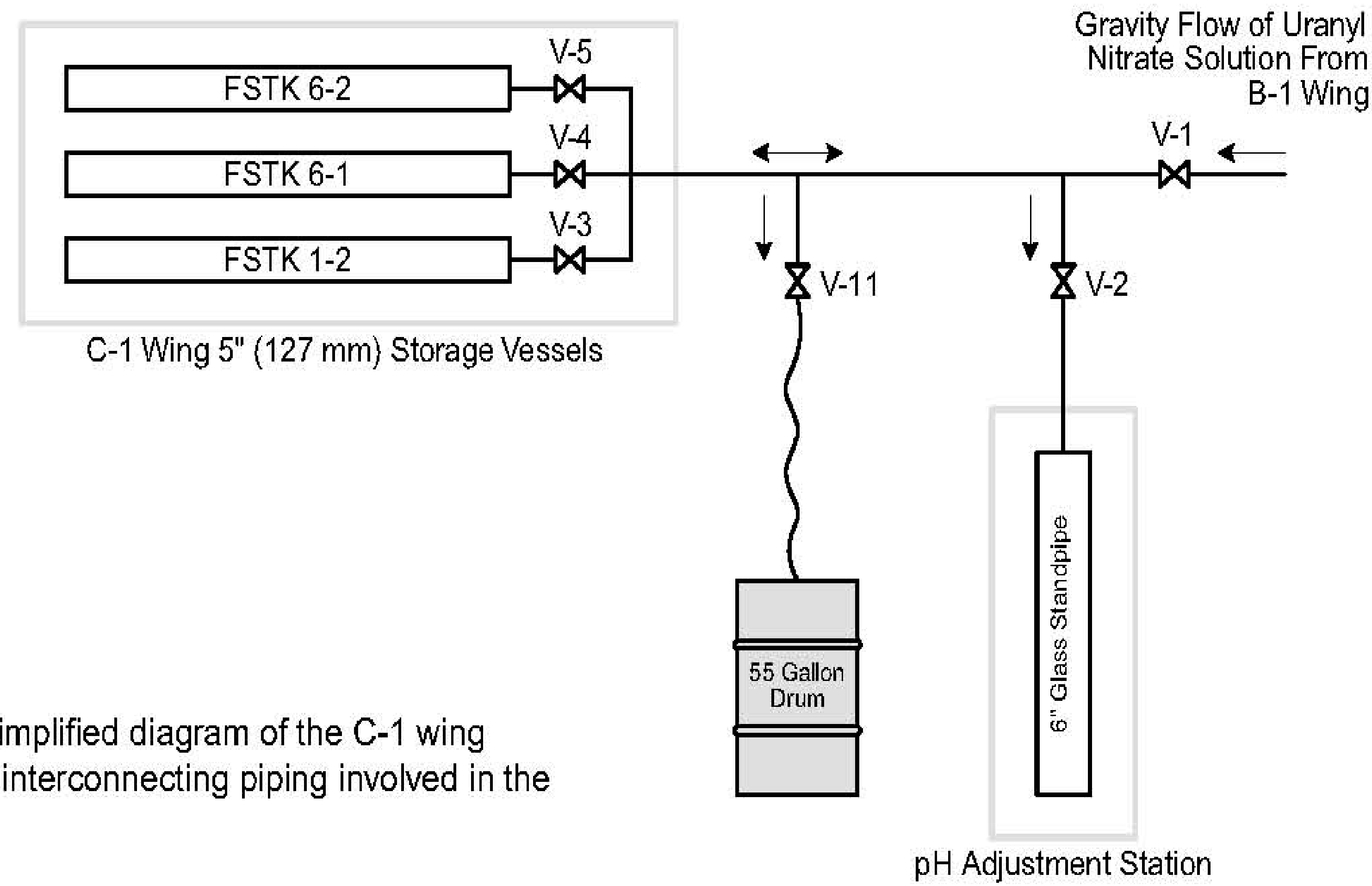


Figure 9. Simplified diagram of the C-1 wing vessels and interconnecting piping involved in the accident.

LOS ALAMOS 1958

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

LOS ALAMOS 1958

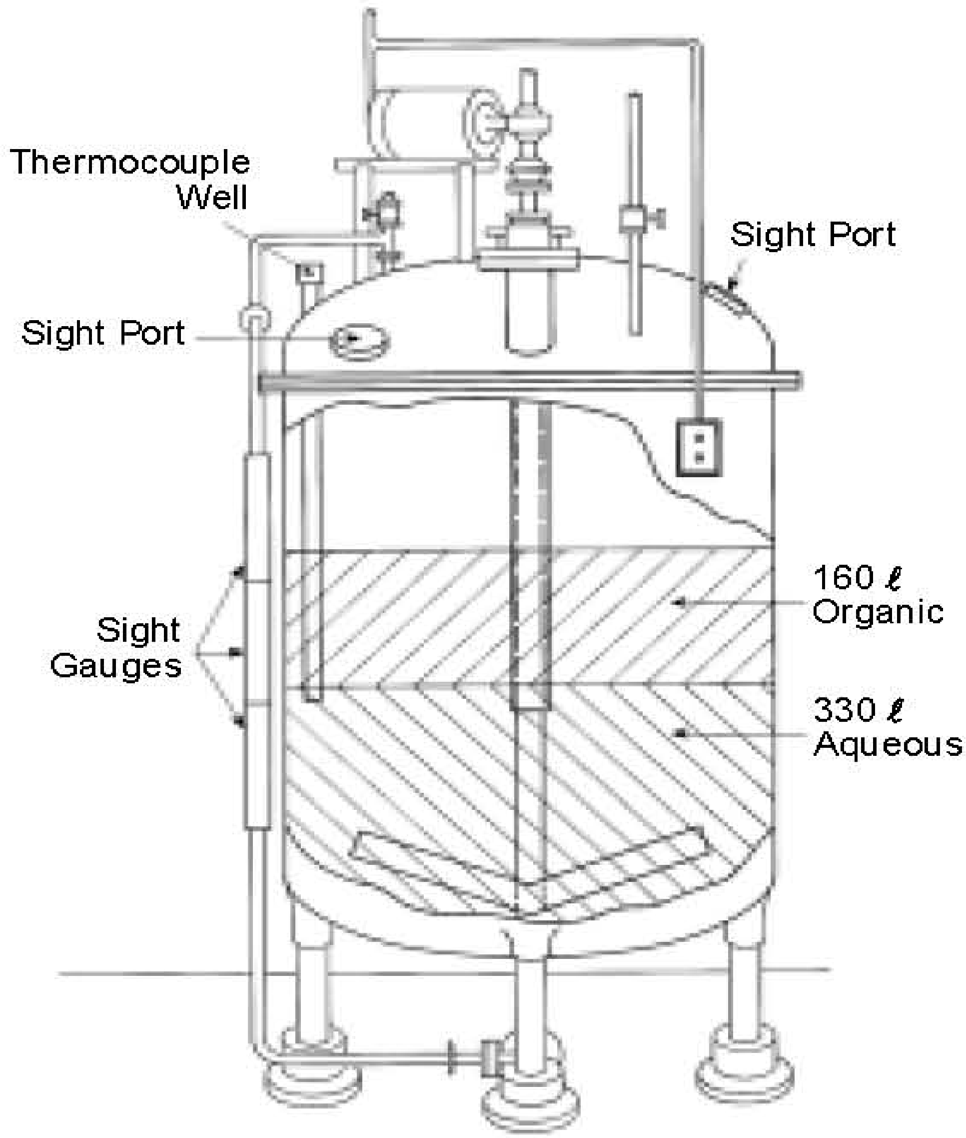


Figure 11. Configuration of solutions (aqueous and organic) in the vessel before the accident.

IDAHO, ICPP 1959

No Figure in LA-13638

MAYAK 1960

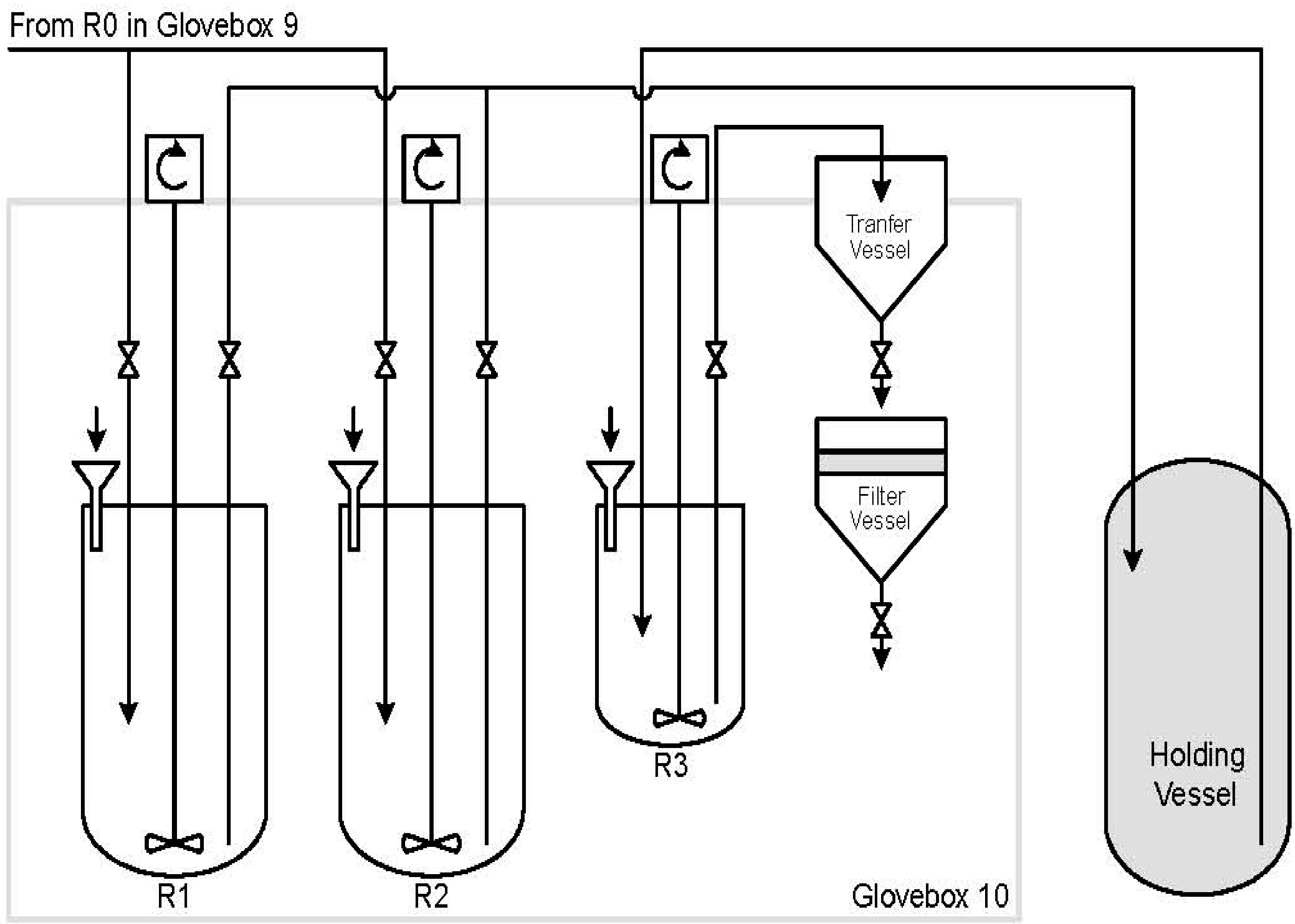


Figure 13. Layout of vessels in Glovebox 10 and the holding vessel external to the glovebox.

IDAHO, ICPP 1961

No Figure in LA13638

TOMSK, SCC 1961

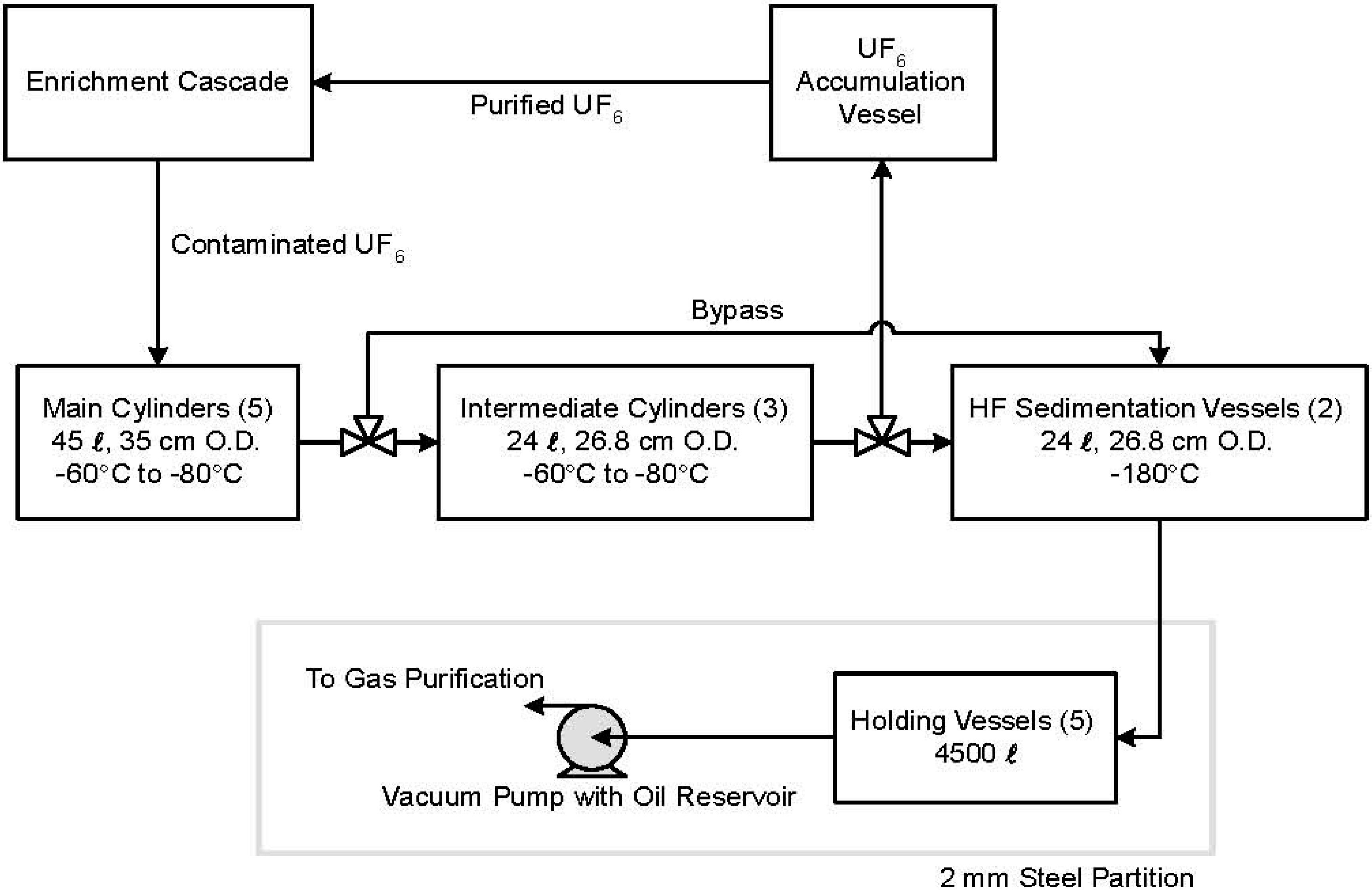


Figure 14. Layout of DSS–6.

TOMSK, SCC   1961

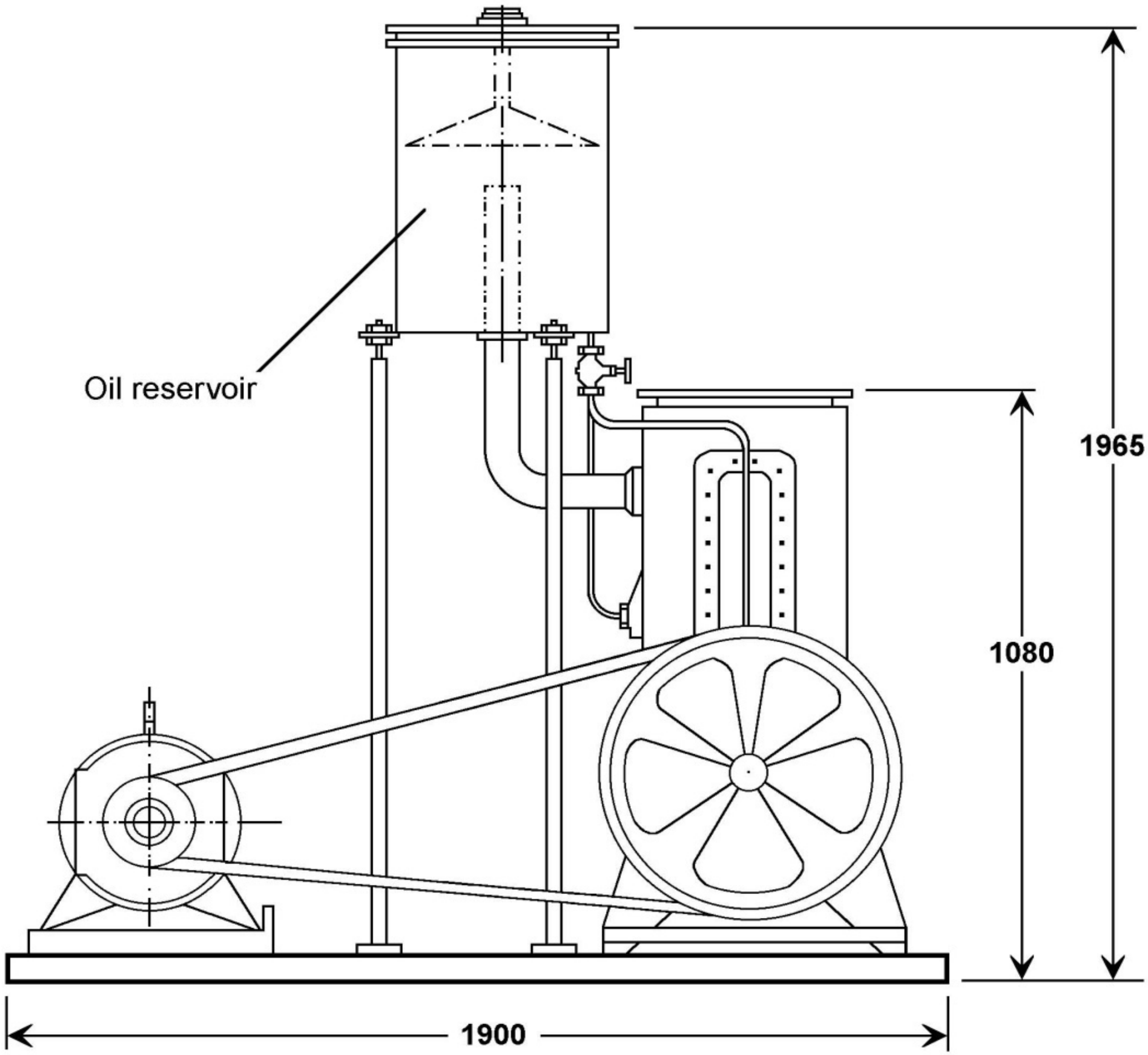


Figure 15. Vacuum pump diagram showing oil reservoir (Dimensions are in mm).

TOMSK, SCC 1961

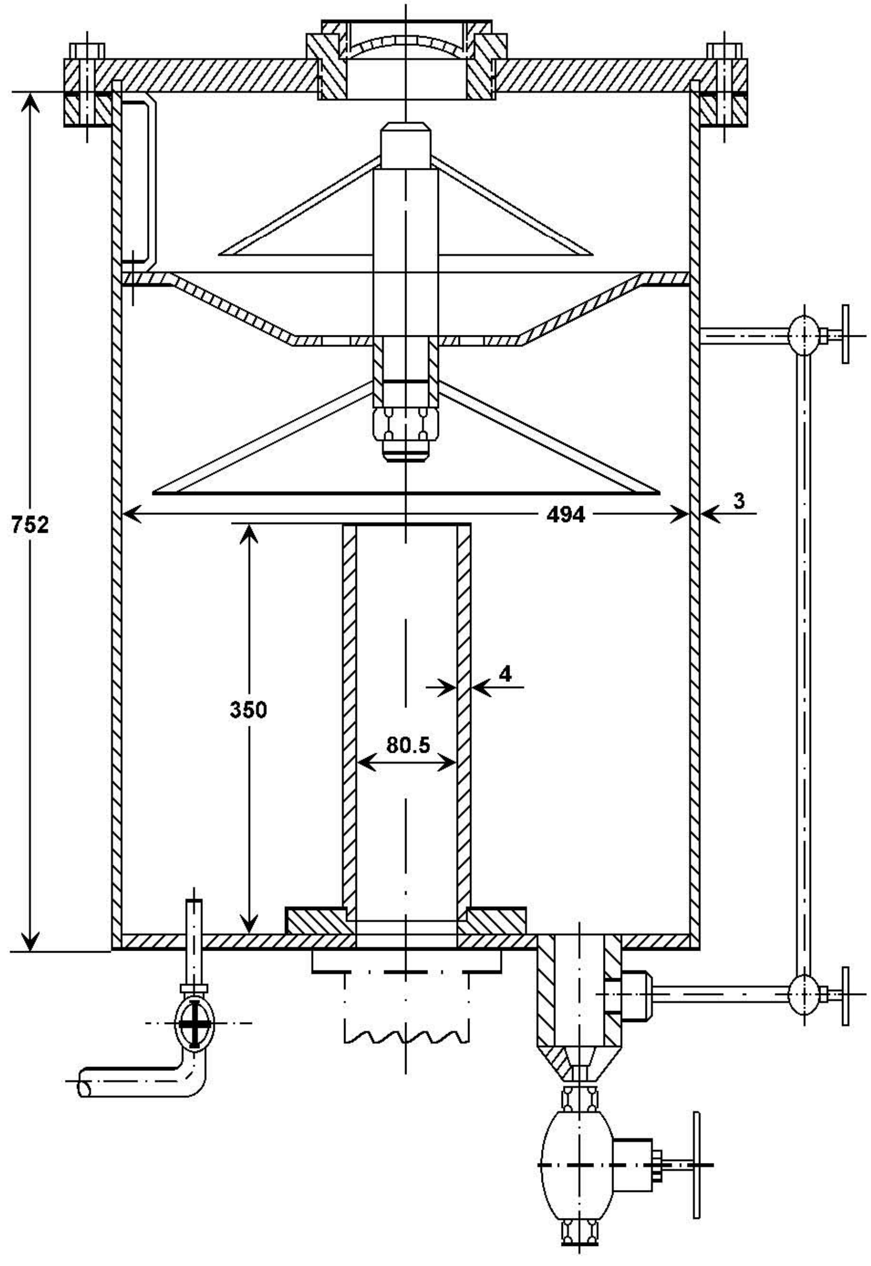


Figure 16. Oil reservoir (Dimensions are in mm).

HANFORD 1962

No Figure in LA-13638

MAYAK 1962

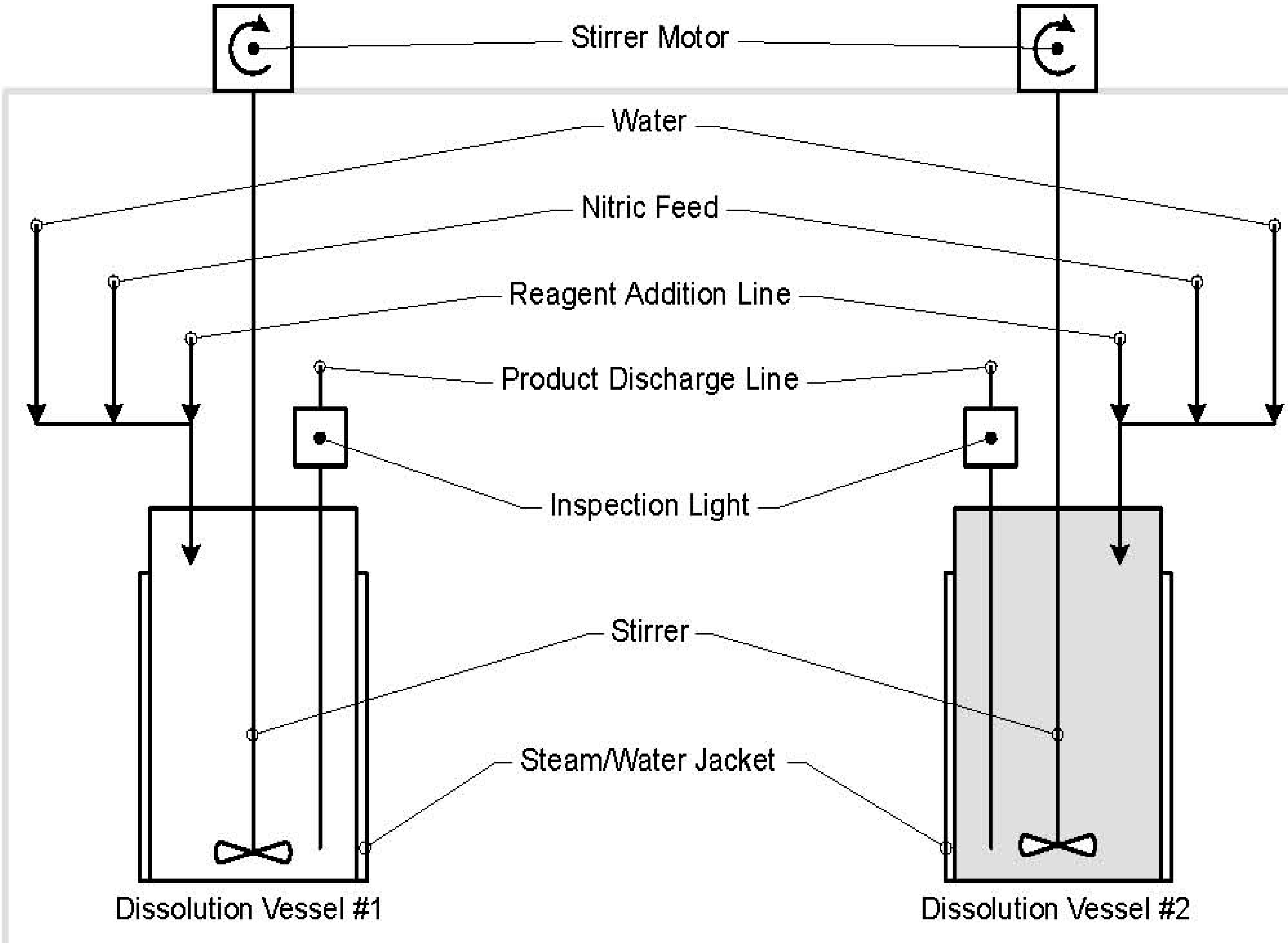


Figure 17. Layout of glovebox equipment.

TOMSK, SCC Jan. 1963

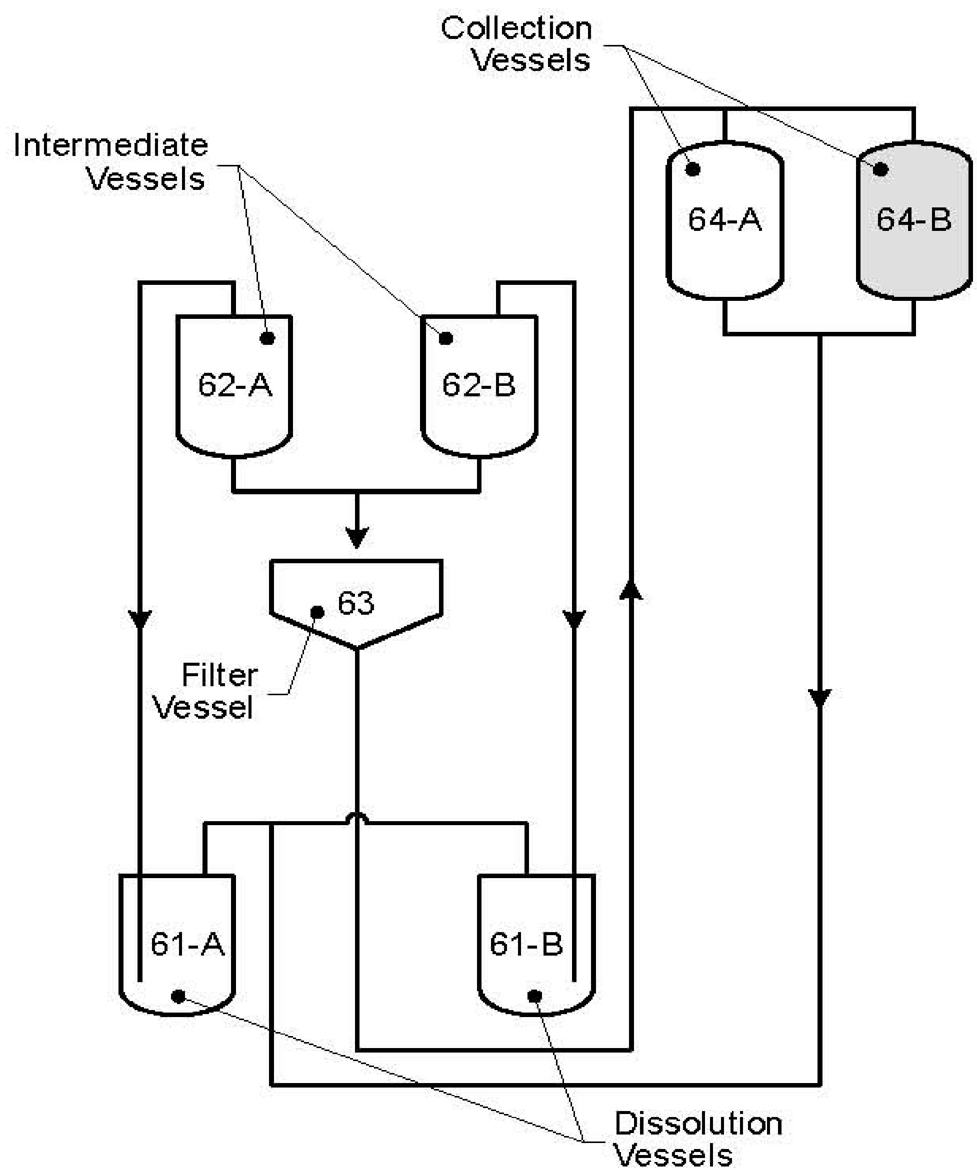


Figure 18. Process vessels and material flow diagram.

TOMSK, SCC Dec. 1963

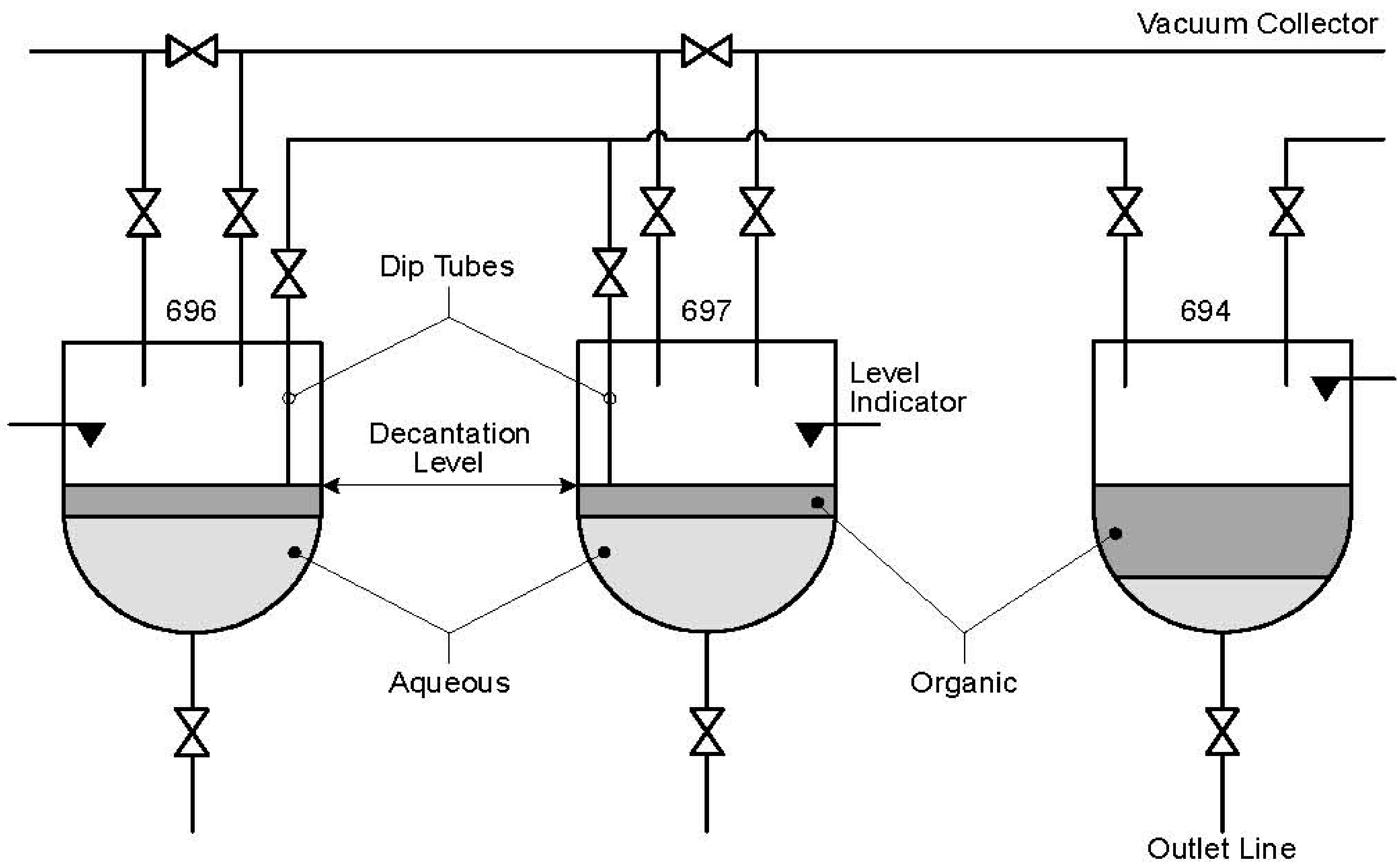


Figure 19. Schematic of vessels showing organic and aqueous solutions (not intended to imply the exact conditions at the time of the accident).

WOODRIVER JCT, RI (UNF) 1964

No Figure in LA-13638

ELECTROSTAL 1965

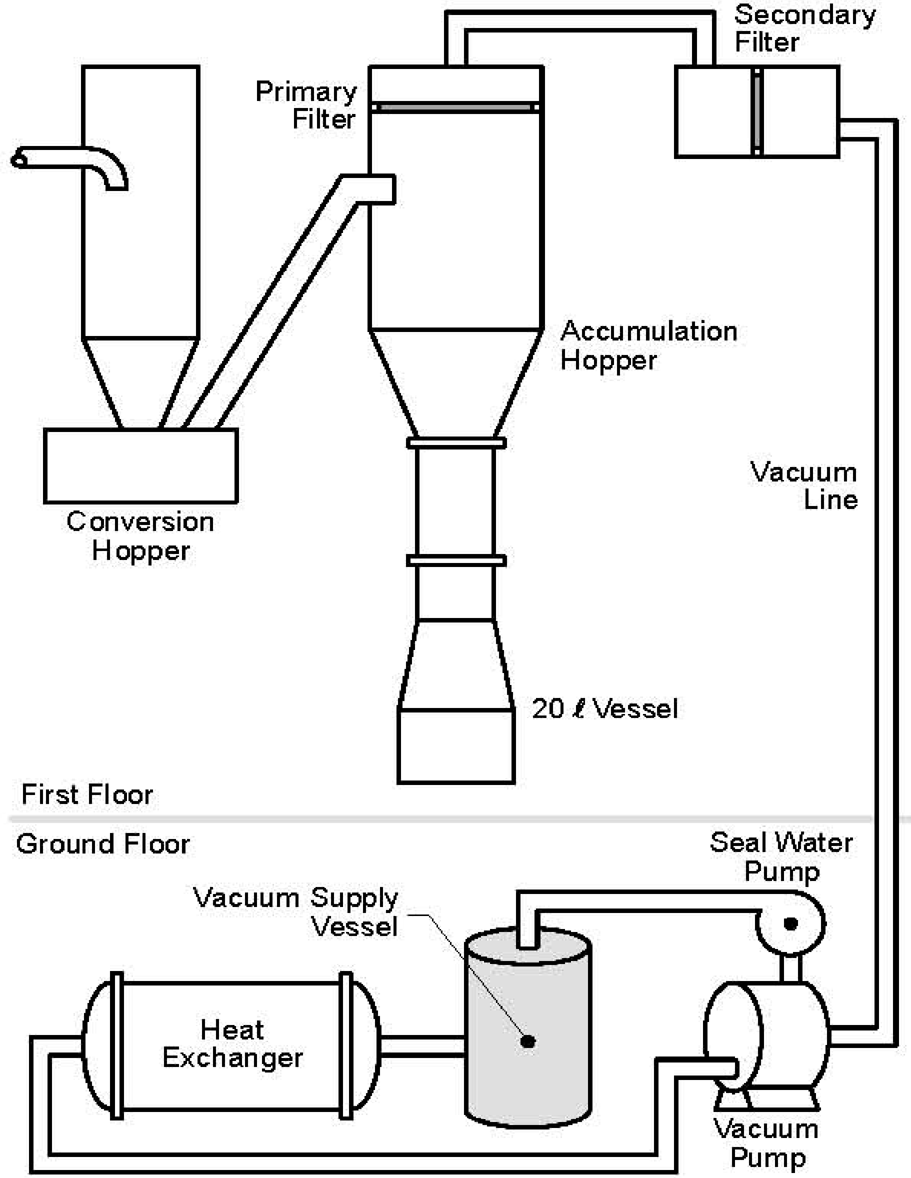


Figure 20. Layout of UF_6 to uranium oxide conversion equipment and associated vacuum system.

MAYAK 1965

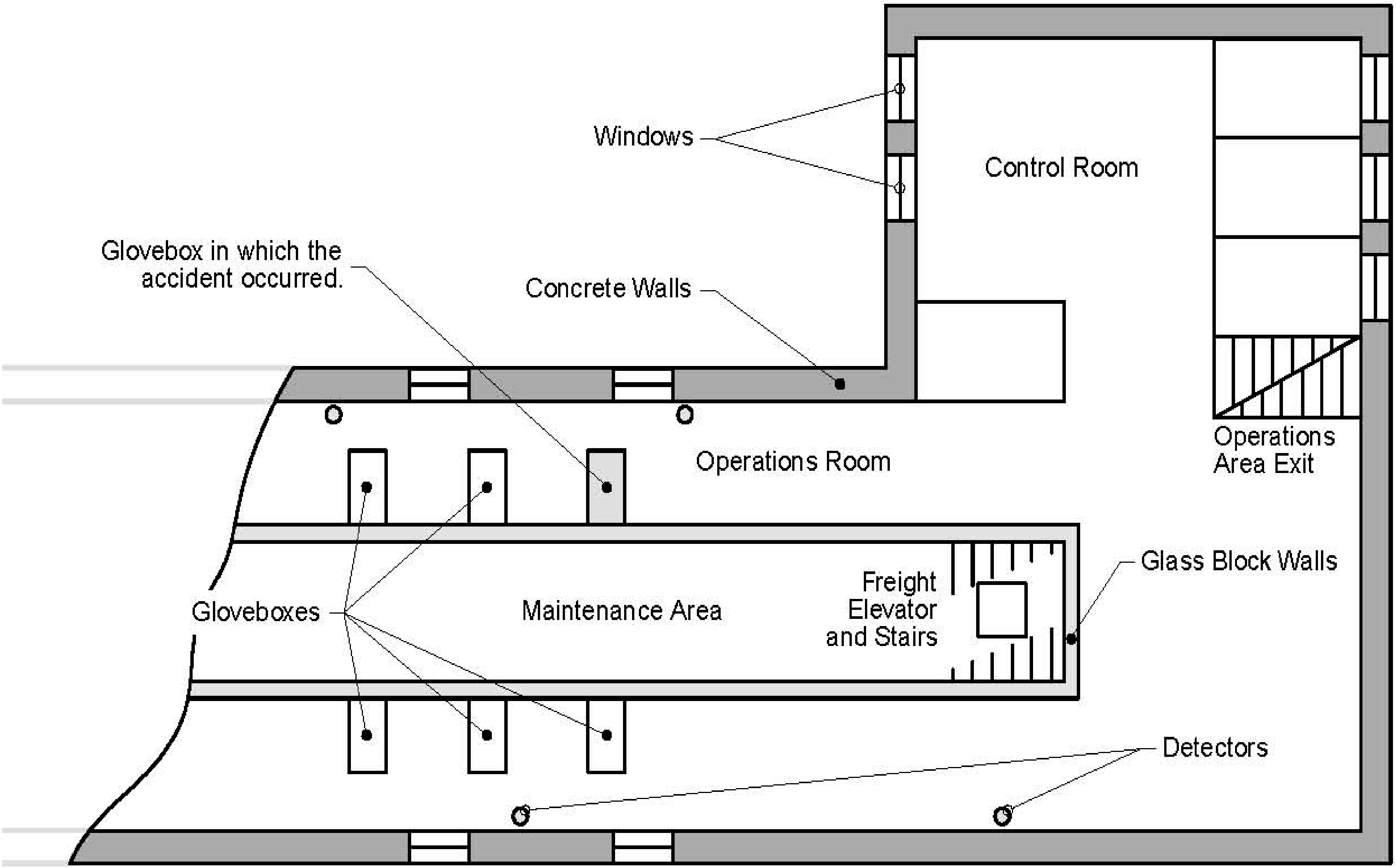


Figure 21. Residue recovery area layout.

MAYAK 1965

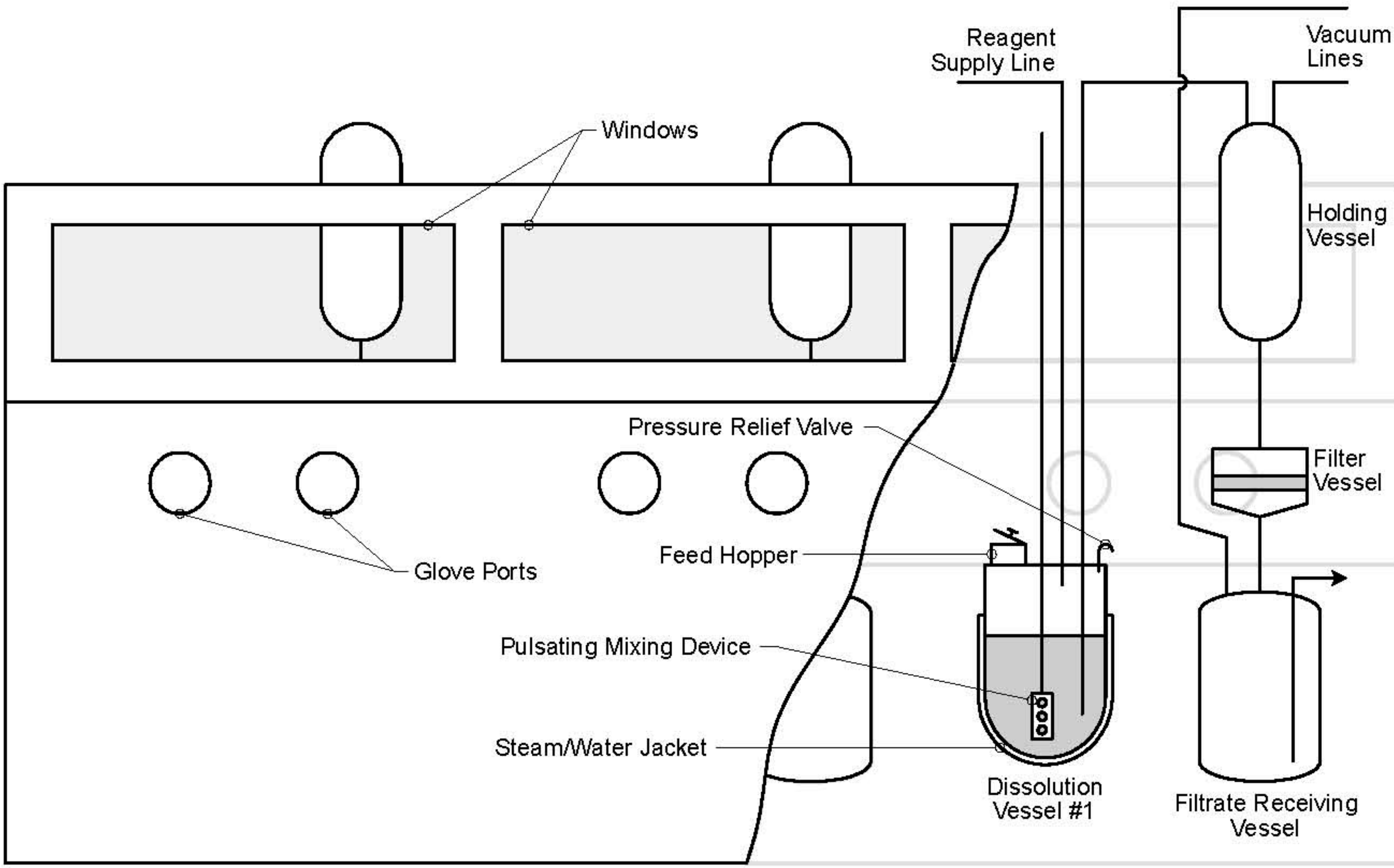


Figure 22. Layout of dissolution glovebox.

MAYAK 1968

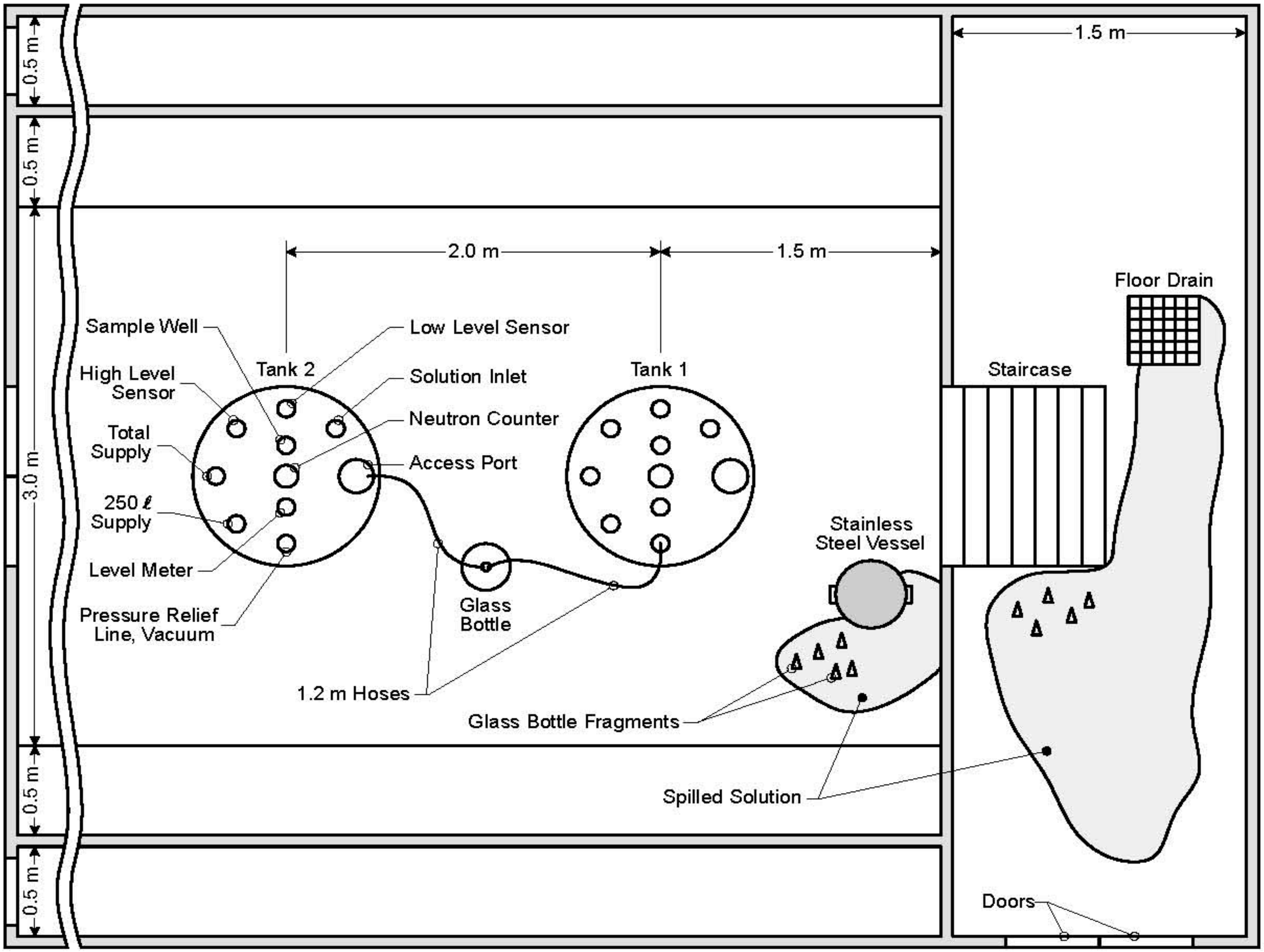


Figure 23. Plan view of the tanks involved in the accident.

MAYAK 1968

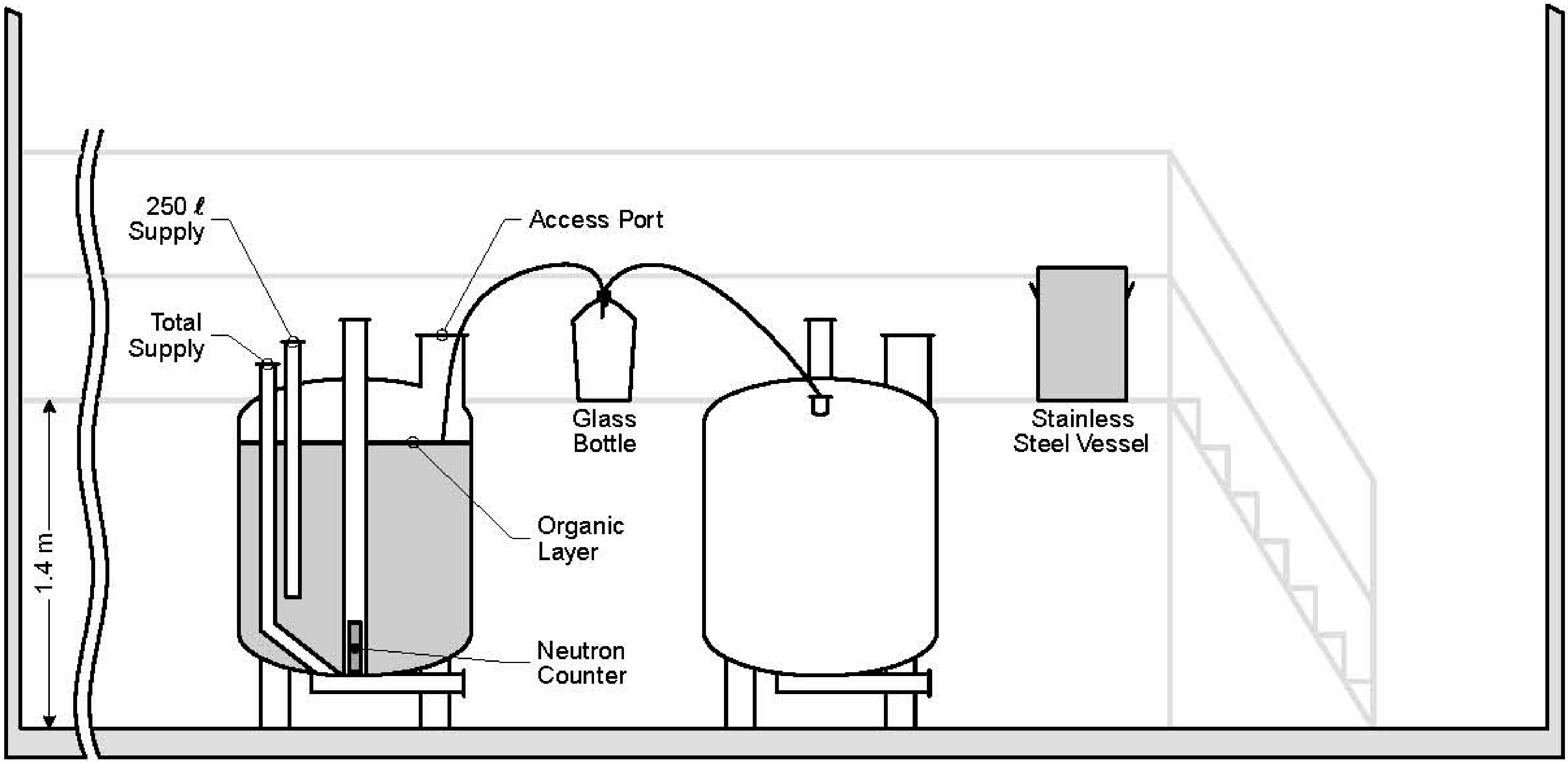


Figure 24. Elevation view of the tanks involved in the accident.

WINDSCALE WORKS, UK 1970

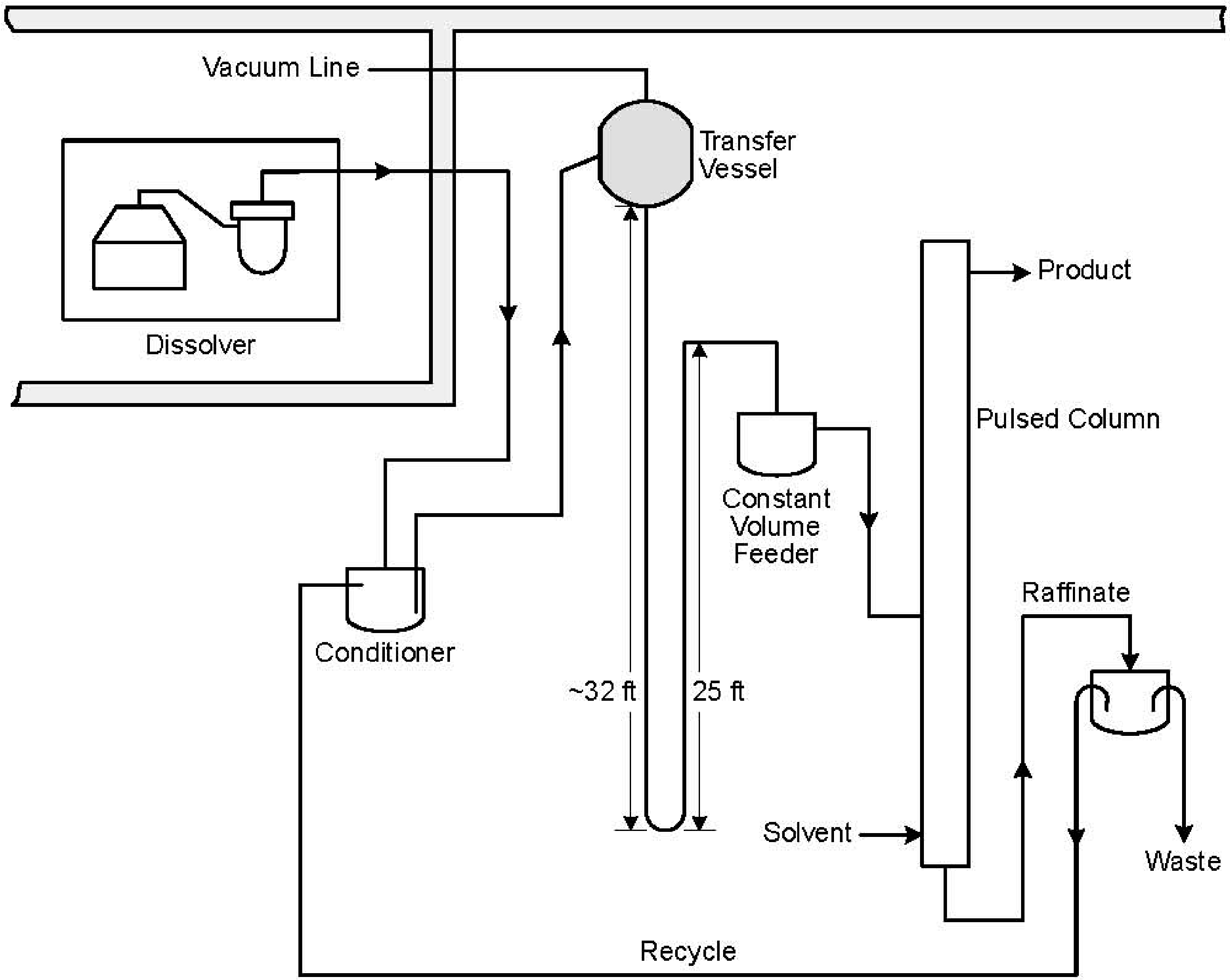


Figure 25. Process equipment related to the criticality accident.

WINDSCALE WORKS, UK 1970

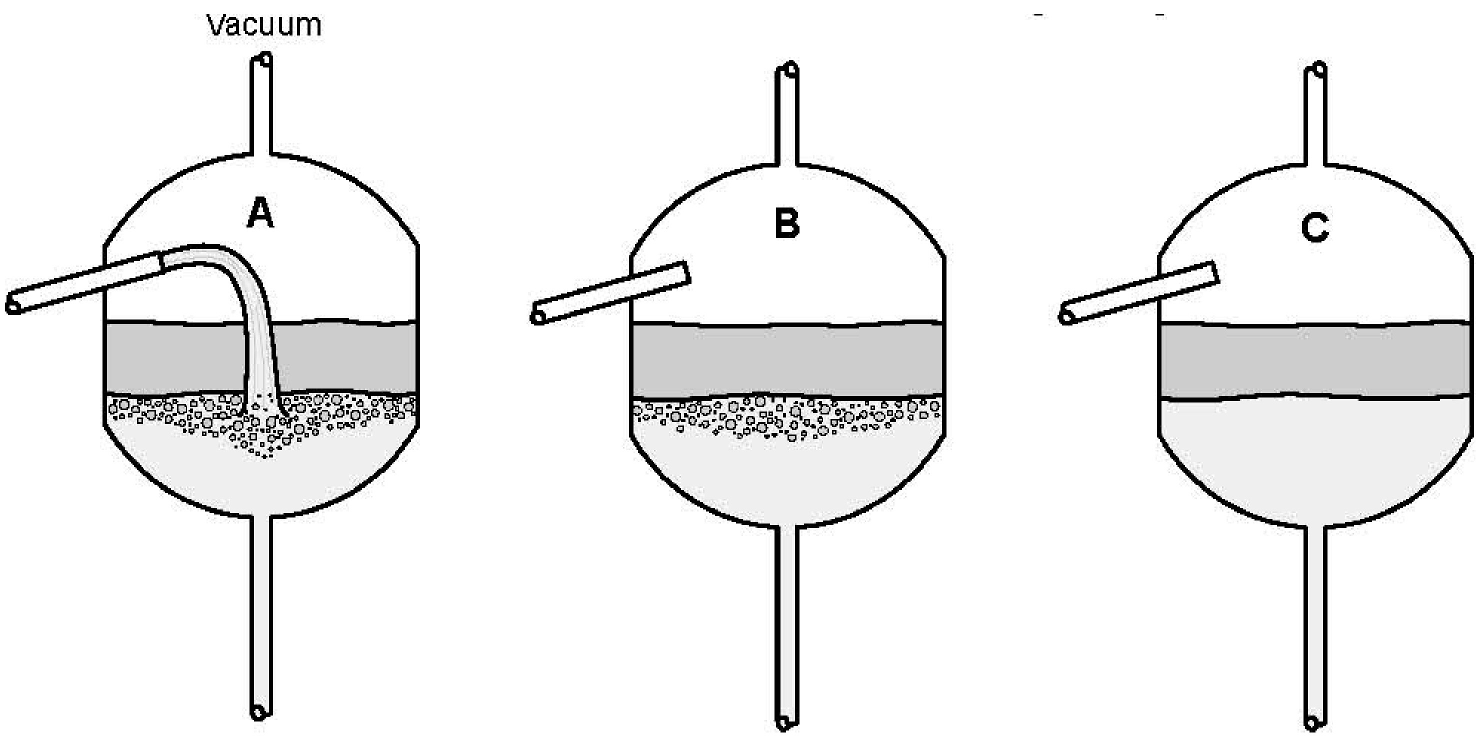


Figure 26. Solution transfer as re-constructed from the transparent plastic mockup of the transfer vessel. Configuration (B) is the postulated state at the time of the accident.

IDAHO, ICPP 1970

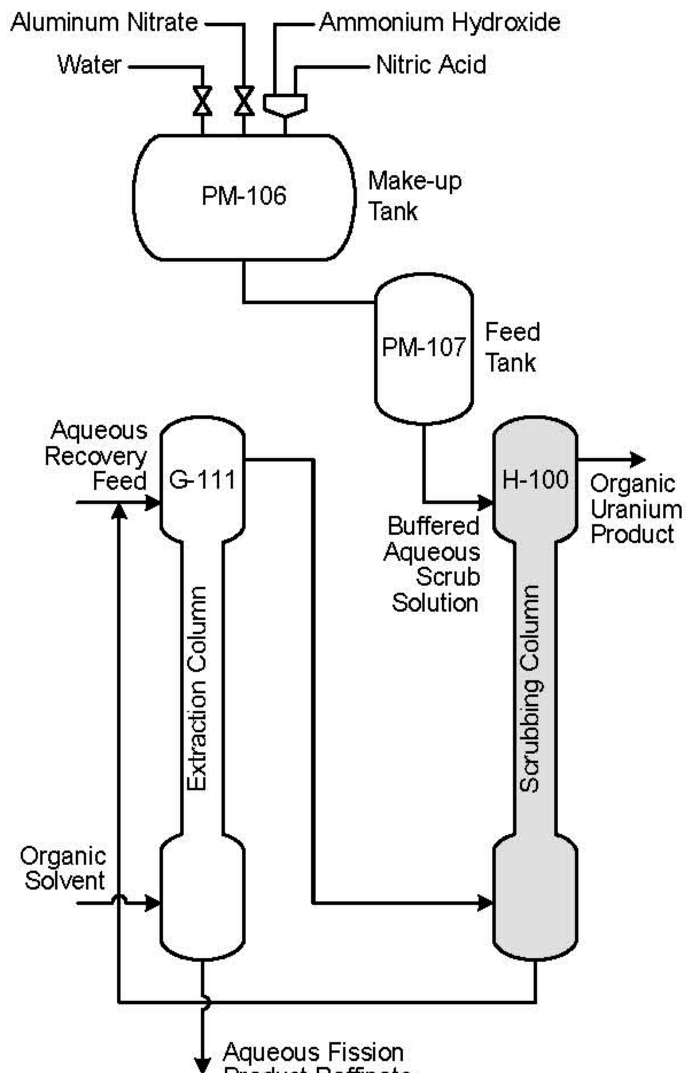


Figure 27. First cycle extraction line equipment. The accident occurred in the lower disengagement section of the H-100 column.

TOMSK, SCC 1978

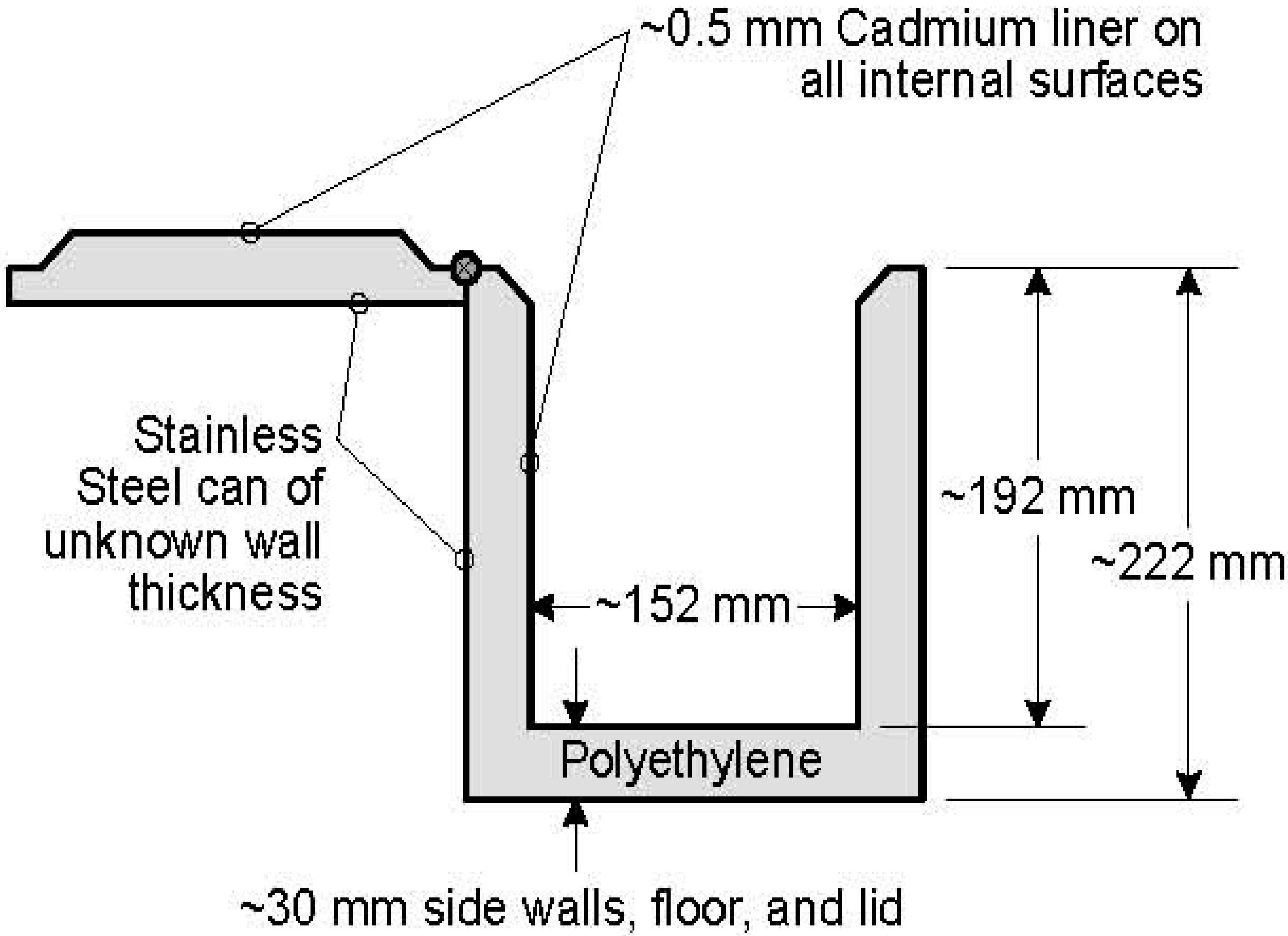


Figure 28. Storage container.

TOMSK 1978

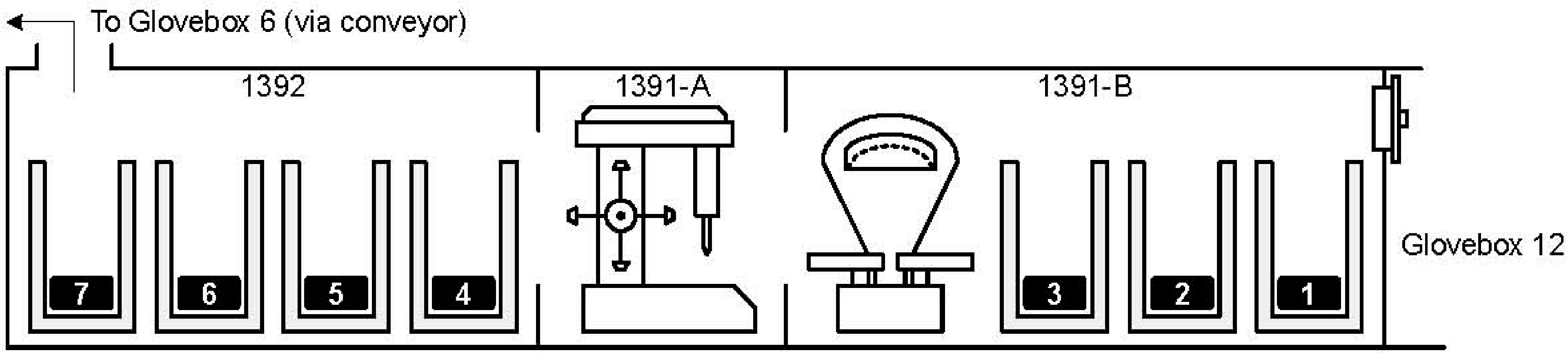


Figure 29. A simplified layout of Glovebox 13.

TOMSK 1978

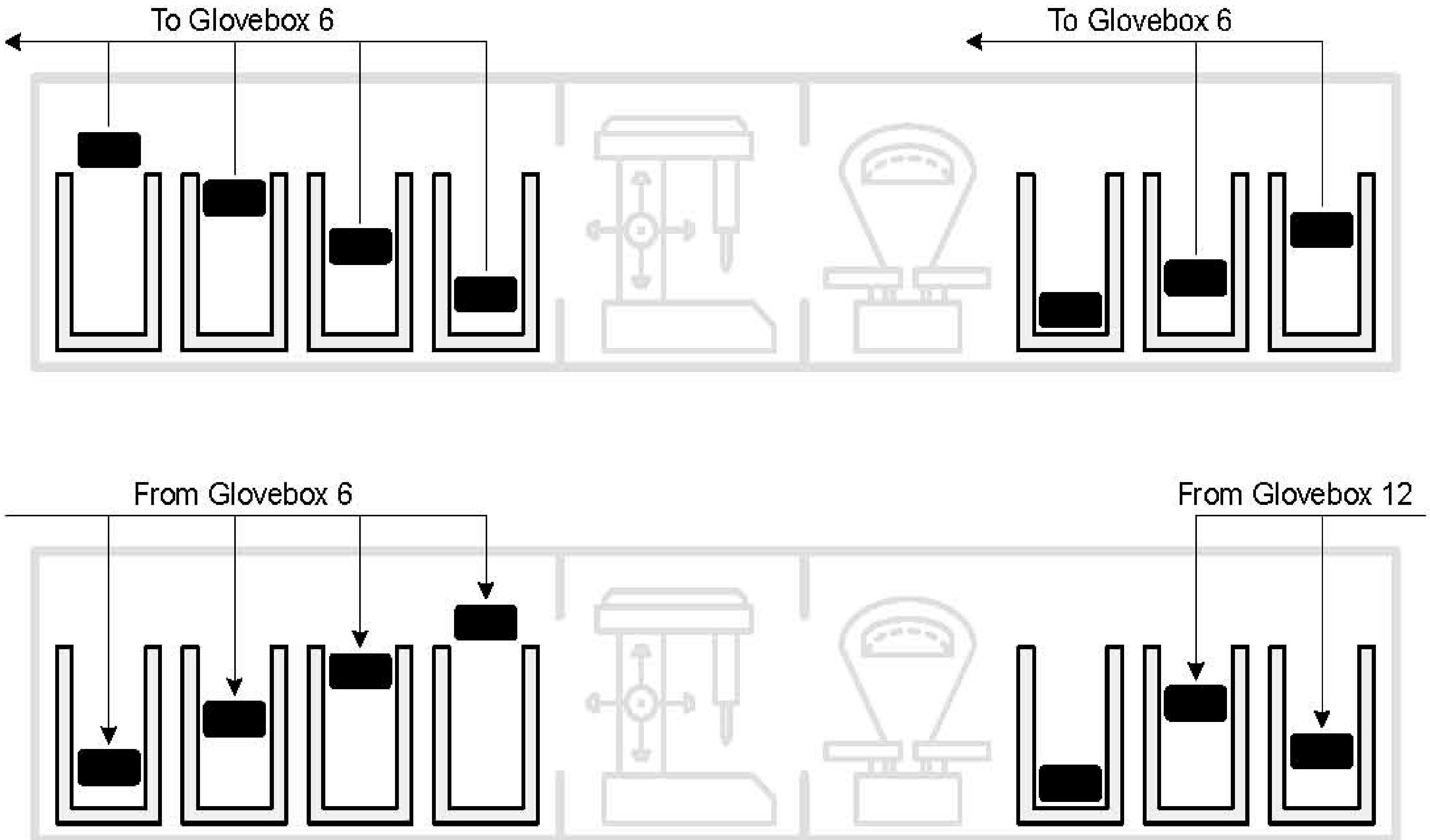


Figure 30. Intended sequence for the transfer of ingots from and to Glovebox 13.

TOMSK 1978

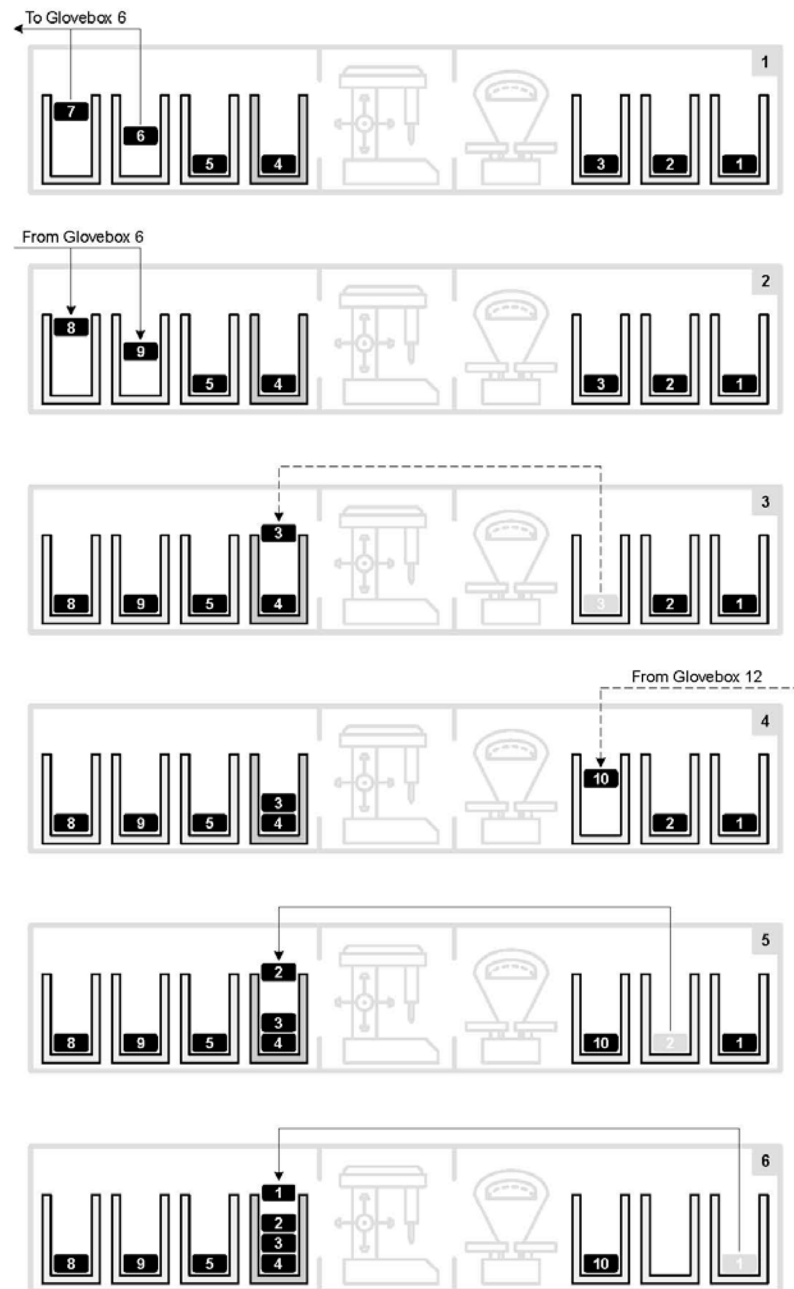


Figure 31. Actual order of ingot transfers from and to Glovebox 13. The solid lines represent the actions of operator A and the dotted lines the actions of operator B.

NOVOSIBIRSK 1999

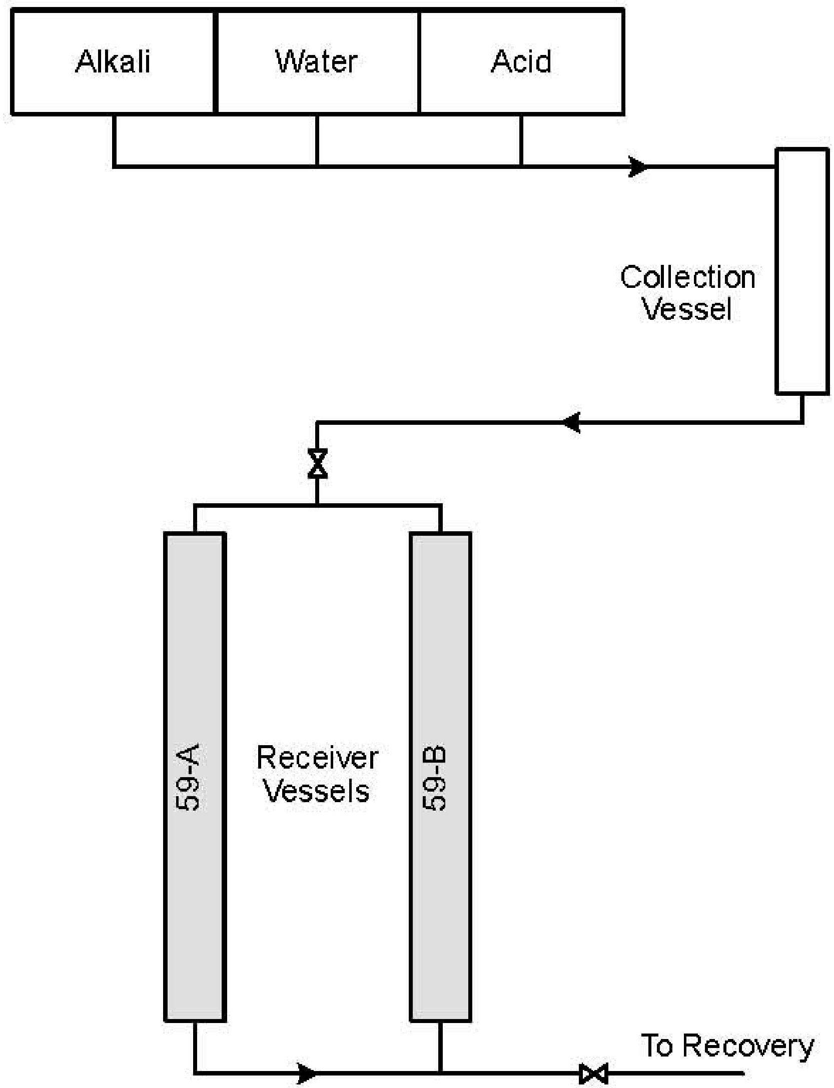


Figure 32. Major components of the chemical-etching process.

NOVOSIBIRSK 1999

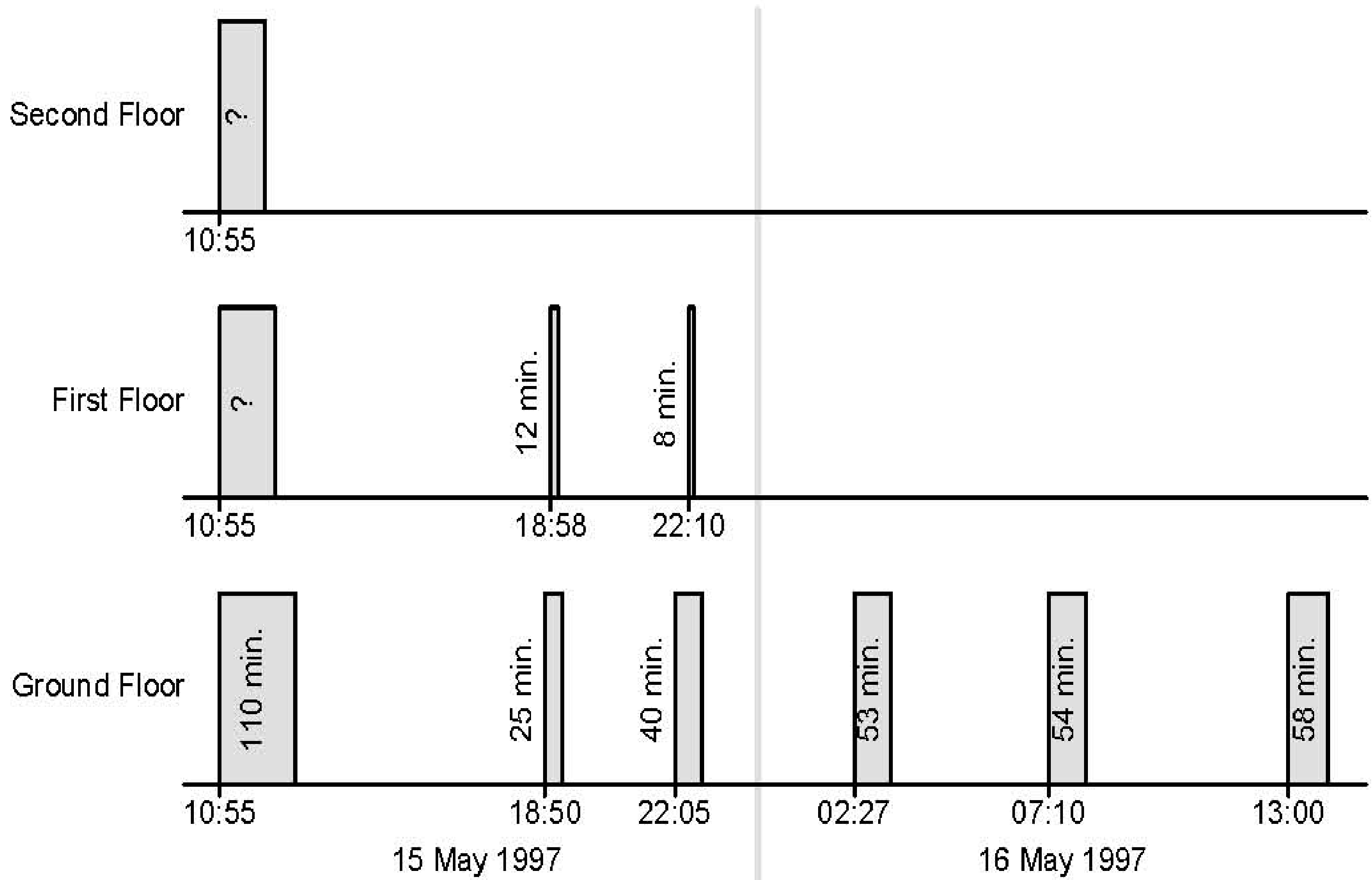


Figure 33. Sequence of alarms and duration that the radiation levels exceeded the alarm level (36 mR/h).

TOKI-MURA, JCO, JAPAN 1999

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

TOKI-MURA, JCO, JAPAN 1999

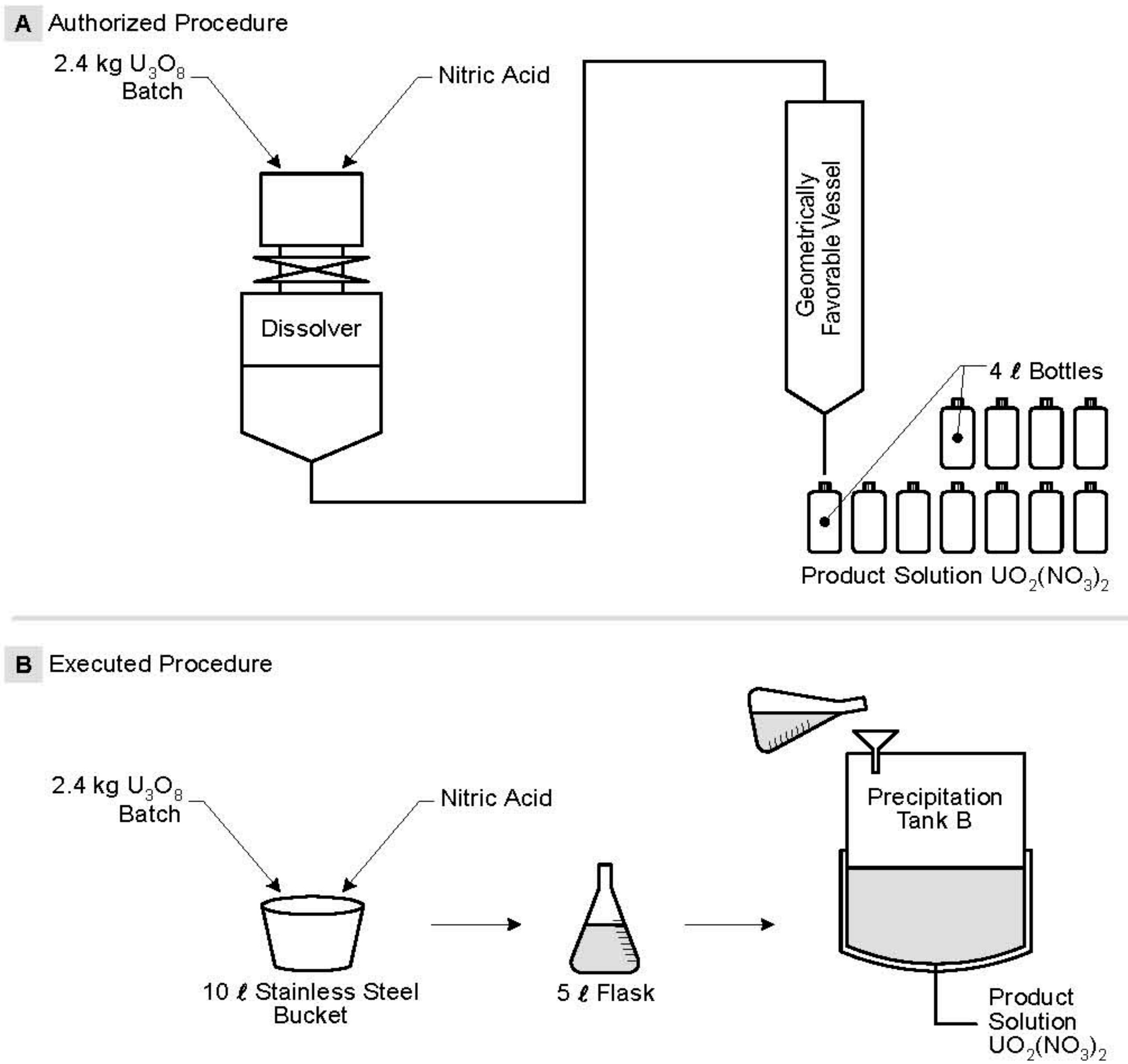


Figure 34. Authorized and executed procedures.