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SAFETY ANALYSIS OF THE OPERATION OF THE HIGH-RADIATION-LEVEL EXAMINATION LABORATORY

A. R. Olsen
J. P. Nichols
Sigfred Peterson

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Metals and Ceramics Division

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Date Issued

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1. SUMMARY

This report presents the description of the High-Radiation-Level Examination Laboratory (HRLEL) and an evaluation of the consequences of the most serious accidents that could possibly occur in the facility. The HRLEL is built and equipped to permit remote disassembly and complete examination of highly irradiated materials, including reactor fuel elements, other reactor components, and irradiation experiments within the completely contained complex of shielded cells. The structural and mechanical features of the building have been reviewed in the light of proposed operations and credible accidents. The resulting data outline the effects of such accidents on personnel and the environs from the viewpoints of possible radiation exposure and contamination. The maximum credible effects are presented along with the contingent controls that reduce the probability of such accidents ever happening to near zero.

The HRLEL is equipped and operated to prevent the spread of radioactive materials and the penetration of radiation beyond the cell complex. Irradiated materials are examined on the first level in stainless steel-lined cells, which are shielded with 3 ft of barytes concrete to safely accommodate nearly a megacurie of gamma emitters and a relatively large quantity of alpha activity. The supporting cells on the second level for the storage and decontamination of equipment are an integral part of the primary containment complex but are shielded with only 2 ft of normal concrete for gamma ray protection. Although essentially unshielded, the glove-maintenance area used for repairing decontaminated equipment is also part of the primary containment complex. The building surrounding the sealed-cell complex is also sealed and equipped with air locks to provide a second layer of containment. The offices and a cold laboratory are outside of this secondary containment zone.

The safe operation of the facility requires protection of the building personnel and the environs from direct radiation and contamination. This safety is ensured by the construction and equipment of the building as well as the management and regulation of the experimental and supporting operations. The particular hazards associated with each

experiment will be assessed and suitable precautions will be taken before the material involved is introduced into the cell complex.

Exposure to direct radiation under normal operation is continually monitored and easily controlled by limiting exposure time and, when necessary, by the use of supplemental shielding. Spread of and exposure to incidental contamination are controlled by constant monitoring and confinement. The strategic arrangement of sealed doors, change rooms, and air locks, in combination with strict enforcement of traffic patterns, minimizes the spread of contamination. Gaseous and particulate contamination is controlled by segregated ventilation systems with automatically controlled pressure gradients and CWS-filtered exhausts. Automatic alarms respond to abnormal values of the constantly monitored radiation levels, air contamination, and air-pressure differences.

Irradiated materials enter and leave the cell complex only through air locks between a central charging cell and the easily decontaminated charging area, handled by procedures developed to prevent the spread of radioactive contamination. Equipment that has become contaminated by contact with irradiated materials can be decontaminated and repaired without being moved from the primary containment complex. New equipment is introduced and decontaminated equipment is removed through the air lock surrounding the glove-maintenance room. All potentially contaminated liquid waste is monitored and high-level liquid waste is retained in a holdup tank before transfer to the plant waste system. Solid waste is sealed in cans and removed through the air locks to shielded transfer casks.

Conceivable hazards that are credible in the operation of the HRLEL, although highly improbable, have been evaluated. These include penetrating radiation doses, criticality incidents, fires, and chemical explosions.

The HRLEL cells were built to attenuate the penetrating radiation from fission products in irradiated reactor fuel elements, such as those from the HFIR, PRDC, EGCR, and PBRE. A maximum dose rate of 0.75 mrem/hr normally permitted in the operating areas can be maintained with sources containing from 10^4 to 10^5 curies of mixed fission products. By use of special procedures, unit shielding, and careful control of personnel exposure, dose rates of 7.5 mrem/hr will be tolerated when it becomes

necessary to examine sources up to 10^6 curies, such as a full HFIR core. This element, after 5 months decay, causes a dose rate of 5.9 mrem/hr at the operating surface.

Since neutrons are not well attenuated by the HRLEL shielding, particularly the windows, careful restraints must be imposed on the admission to the cells of such materials as heavy transplutonium species and combinations of alpha emitters with light elements. For example, an HFIR target containing 350 μg Cf^{252}, emitting 3.5×10^9 neutrons/sec, would cause a neutron dose of 25 rem/hr at the outside surface of the window. This dose will be reduced to 2.5 mrem/hr by 8 in. of water between the source and the window.

The most serious accident that could conceivably occur in the HRLEL is a criticality incident. While the cell shielding will satisfactorily attenuate the gamma radiation from such an event, the windows provide only limited attenuation of neutrons. Maintaining an accurate inventory and forbidding the presence of more than the recommended maximum safe mass of fissile material in the cells will prevent criticality incidents. Fissile materials in excess of the safe unmoderated maximum will never be permitted in the cells, but some fuel elements requiring examination, notably the HFIR type, exceed the safe mass limit for moderated fissile materials. When it is necessary to have more than the safe moderated mass in the cells, strict controls are placed on the amount of moderator present. In such cases, since solid-moderated excursions could produce lethal neutron doses in the operating area, no more than 500 kg of solid carbon or 35 kg of beryllium will be allowed in the cells. Although work with potentially critical masses will be in strict compliance with procedures approved for the specific materials in the cell at the time, it is conceivable that a liquid moderator such as water or oil could accumulate and a criticality burst of 10^{18} fissions could occur. Such a burst could produce a dose up to 250 rem at the operating surface of the window. Until the maximum conceivable amount of moderator is evaporated, recurring bursts up to a total of 10^{19} fissions are conceivable, giving a dose up to 250 rem 13 ft from the operating surface. Personnel in the operating area would evacuate before the second burst. Release of 100% of the volatile

fission products from 10^{19} fissions would require minor decontamination of a downwind area of 0.8 square mile.

Fires in the HRLEL could be serious because they could disperse radioactive material in the cell air and raise the cell pressure to reverse the leakage and thus contaminate the building and environment. Combustible materials that could sustain fires include the graphite matrix of certain fuel elements, liquid alkali metals from other fuel elements, and organic liquids used in the cells as coolant, lubricant, hydraulic fluid, and solvent. Because of the great variety of materials and operations in the cells, no automatic fire-protection system has been installed. For each operation presenting a fire hazard, appropriate defensive measures will be taken, although these precautions have been neglected in the calculations presented. The fire that would burn the longest and disperse the most radioactivity would be the combustion of a graphite-base fuel element. However, the rate of burning would be too slow to cause a pressure surge that would spread contamination outside the cell except for the very small fraction (about 8 curies out of an estimated 10^5 in a fuel element) that could pass the exhaust filters. The sharpest pressure surge (over 50 in. H_2O gage) would be from a sodium fire, but the conceivable amount of sodium present could sustain the fire for only one minute. A slower but longer burning oil fire could produce about 38 in. H_2O gage cell pressure in about 4 min and maintain pressure in the cell above that in the operating area for 15 min. Although such a fire would disperse far less radioactivity than the graphite fire, the pressure transient can result in leakage to the operating area, leading to a combination of ingestion and exposure equivalent to doses over 50 rem, before evacuation. Another serious possibility is that the pressure surge would burst the exhaust filters, releasing sufficient activity to the stack to create a significant downwind dose. No lethal doses would result from any of these fires. However, the consequences are sufficiently serious that, when in-cell conditions could permit a fire, appropriate preparations for rapid extinguishment are made.

Conceivable in-cell conditions could result in explosions. Although precautions will be taken to avoid these conditions, it may be possible that hydrogen from radiolysis or electrolysis of water would oxidize

explosively, sodium escaping from a fuel element would react explosively with water, or up to 10^{18} fissions would occur in a criticality burst. None of these events would produce shock waves equal to that of an explosion of 3 lb TNT, which the cell walls, windows, doors, and filters would withstand. There could be a brief surge of cell pressure above building pressure that would cause a dose in the operating area equivalent to no more than 0.25 rem and would release less than 0.1 curie from the stack.

In each case the most conservative hazard evaluation, the one producing the maximum hazard, has been used. The results all indicate tolerable exposure of personnel and levels of contamination of the environs.

2. INTRODUCTION

2.1 Purpose and Use

The new High-Radiation-Level Examination Laboratory, Building 3525, will be used for metallographic, metallurgical, mechanical, chemical, and physical testing of materials, including reactor fuel elements, irradiated to high levels. The materials to be examined are confined to a series of leaktight shielded cells, designed to protect personnel from gamma radiation and to prevent the spread of radioactivity, in a building designed as an effective secondary barrier to the spread of radioactive contamination.

The proposed technical functions include visual observation, mensuration, nondestructive testing, measurement of burnup and induced activity, sampling and analysis of fission gases, evaluation of corrosion and related measurements, disassembly and cutup, metallographic examination, determination of mechanical properties, and x-ray diffraction analyses. Provision is made in the shielded complex for storage and remote decontamination of equipment. Partially decontaminated equipment may be repaired through glove ports while it is still in the primary containment area.

During the design and construction of this facility, the Post-irradiation Examination Group of the Metals and Ceramics Division was charged with the full responsibility for the design and procurement of the experimental equipment, of training personnel, and planning for the eventual operation of the facility. Most of this responsibility has since been transferred to the Hot-Cell Operations Group of the Operations Division. The operational procedures and administrative control outlined in this report are those proposed by the original group and based on years of experience in similar operations here at ORNL and at other AEC sites. It is believed that these are reasonable and will remain essentially unchanged despite the change in operational responsibility. Some minor changes and improvements are sure to evolve during preoperational testing and initial operations with radioactive materials.

The inherent safety features of the facility, with its completely isolated primary containment zone and totally remote operational features, are in a large measure the result of the excellent preconceptual design criteria development by O. Sisman, S. E. Dismuke, and a number of members of the Plant and Equipment Division.

2.2 Location and Distance from Other Facilities

The High-Radiation-Level Examination Laboratory is located at the southeast corner of Fourth Street and Central Avenue. Its location relative to neighboring buildings is shown in Fig. 2.1, a part of the Oak Ridge National Laboratory Permanent Facilities Plan. The distances to neighboring buildings from Building 3525 are shown in Table 2.1.

Table 2.1 Activity Inventories and Personnel in Vicinity of Building 3525

Bldg No.	Name	Distance (ft)	Direction from 3525	Activity Inventory α curies	Activity Inventory β-γ curies	Personnel (Weekdays)
3525	HRLEL			200	10^6	44
3550	Research Laboratory Annex	19	East	1	1	67
3508	Isolation Laboratory	170	South	0.635	2000	13
3515	Waste Processing	119	West			a
3024	Research Shop B	120	Northwest	None	None	34
3026	Loop Dismantling	98	North		2×10^6	20[b]
	Tank Farm	80	West		3×10^8	0

[a]This building located in the waste tank farm is not in use at present.

[b]Normally, three persons present weekends and nights.

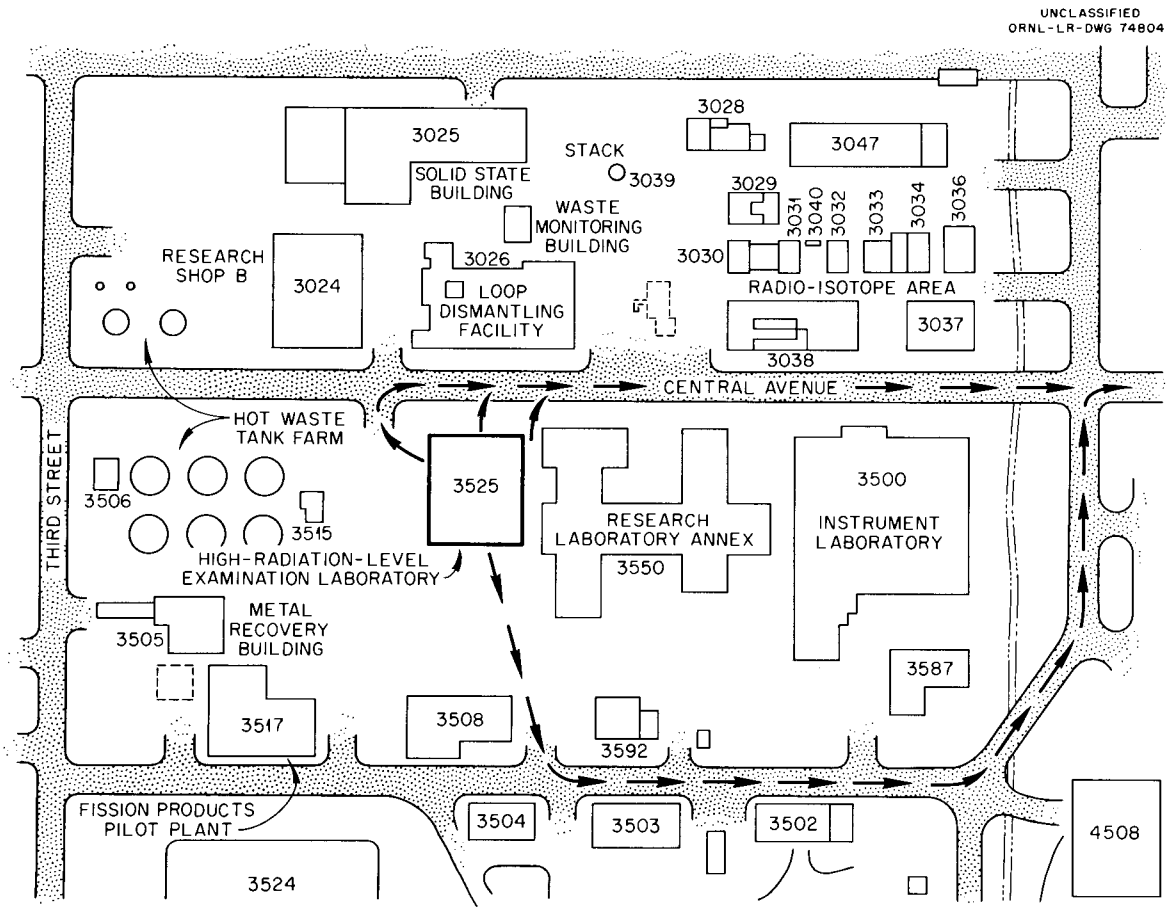

Fig. 2.1. Location of Building 3525 Relative to Surroundings, Showing Evacuation Route.

3. DESCRIPTION OF FACILITY

3.1 Building Description

The High-Radiation-Level Examination Laboratory is basically a two-story brick building with a partial basement for housing some of the essential ventilation equipment. The structure provides a gross floor area of approximately 26,500 ft^2, exclusive of the floor area occupied by the shielded cell complex, which has a working area of 950 ft^2 shielded for high-level gamma activity. The operating and service areas occupy approximately 223,000 ft^3. The primary contained complex is 29,300 ft^3 of which 46.6% is in the working area shielded for high-level gamma activity, 38.8% is in the equipment storage and decontamination areas shielded for intermediate level gamma activity, and 14.6% in the relatively unshielded maintenance areas.

The building is divided into two functional sections and has an enclosed stairwell appended at the rear. The front section, facing Central Avenue, is a single-story office and laboratory area; and the two-story structure to the immediate rear houses the cell complex, the operating areas, and the other supporting activities. The detailed arrangement of functional areas is shown in Figs. 3.1, 3.2, 3.3, and 3.4. Figures 3.5 and 3.6 show vertical sections through the building.

Besides affording primary containment of radiological hazards in the cell complex, the laboratory building provides a second layer of confinement by the physical arrangement of barriers and ventilation control. The office section, for instance, is separated from the operating area by a wall; and routine traffic between these areas is routed through a change room. This barrier wall has observation windows for direct viewing of the cell face from the office corridor. Similar restrictions on personnel access and the selective use of air locks and air vestibules[1] throughout the laboratory prevent the spread of contamination between

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[1]An air vestibule is a space closed off from two or more adjacent areas by gasketed doors. A means to prevent simultaneous opening of more than one door converts an air vestibule into an air lock.

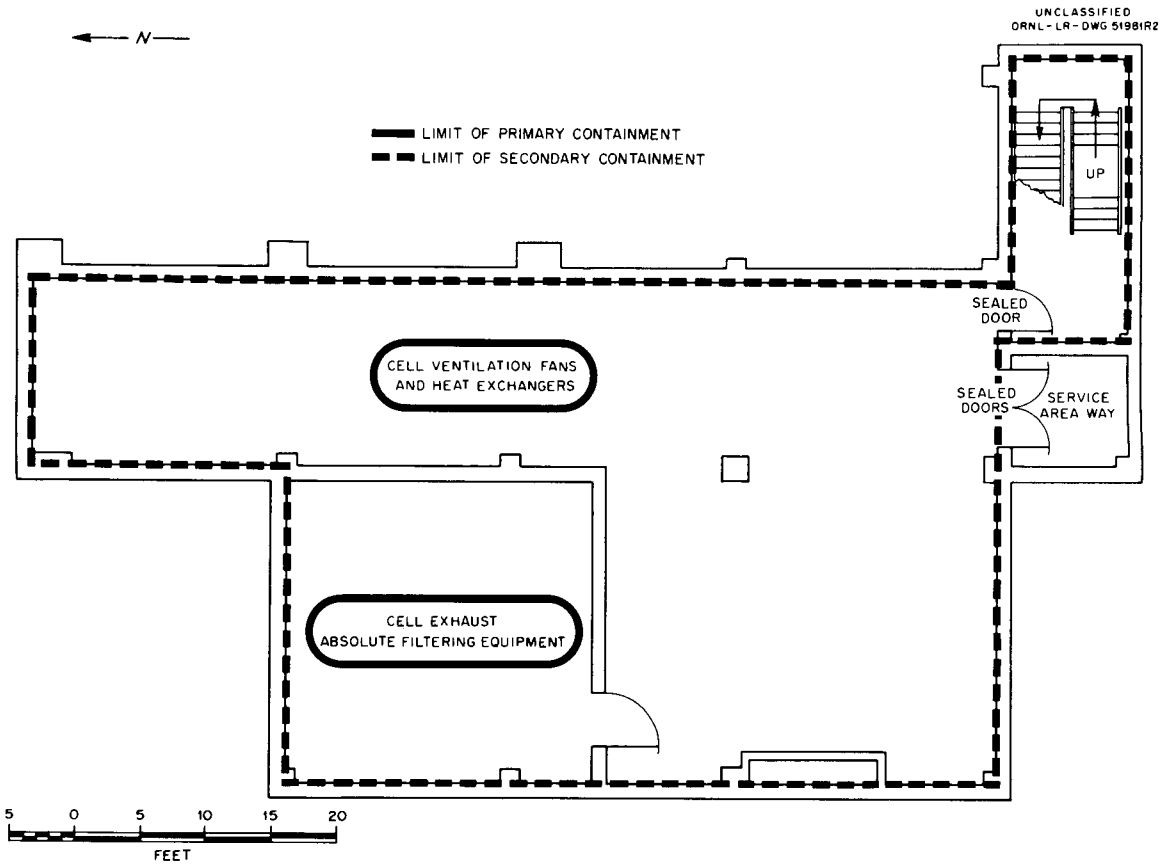


Fig. 3.1. Basement Plan of Building 3525, Showing Containment Zones.

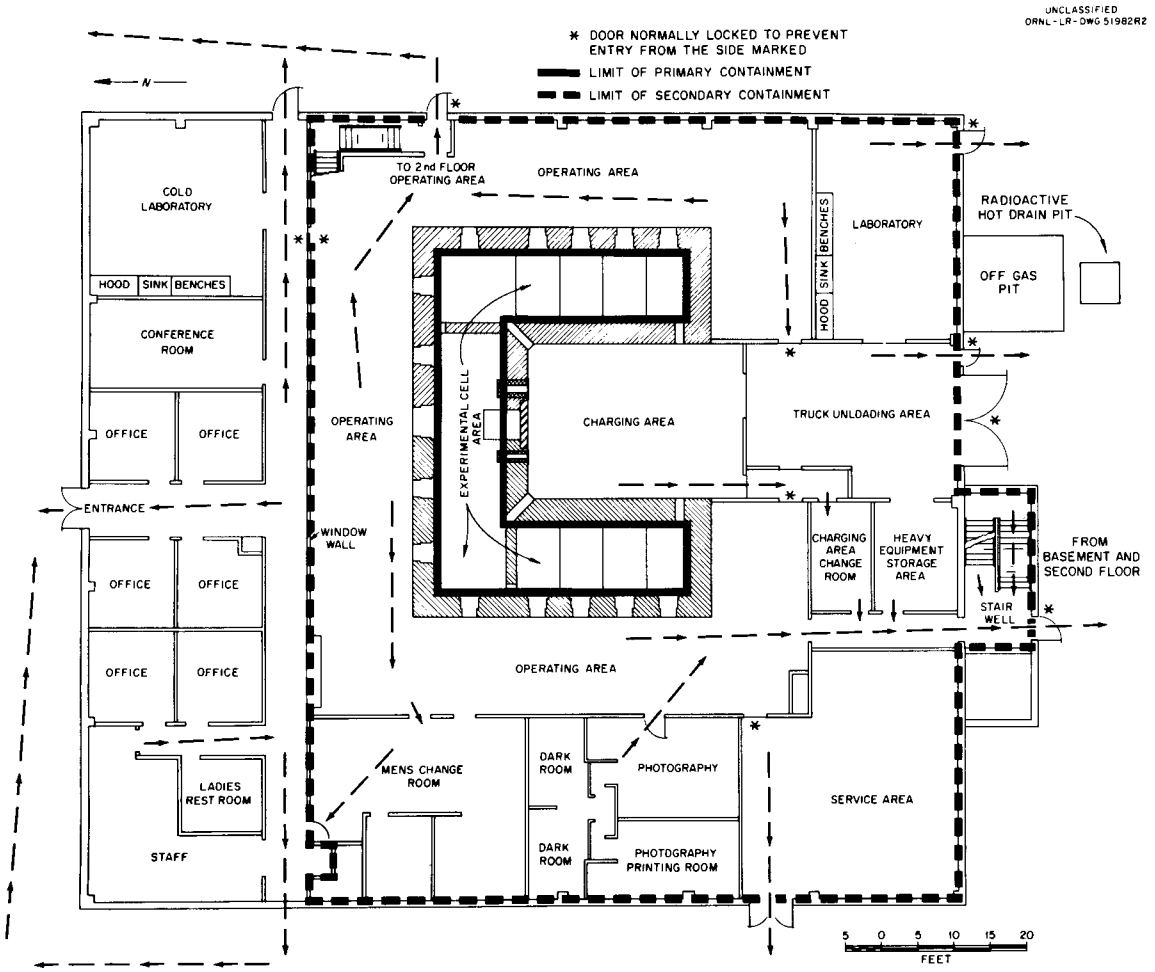


Fig. 3.2. First-Floor Plan of Building 3525, Showing Evacuation Routes and Containment Zones.

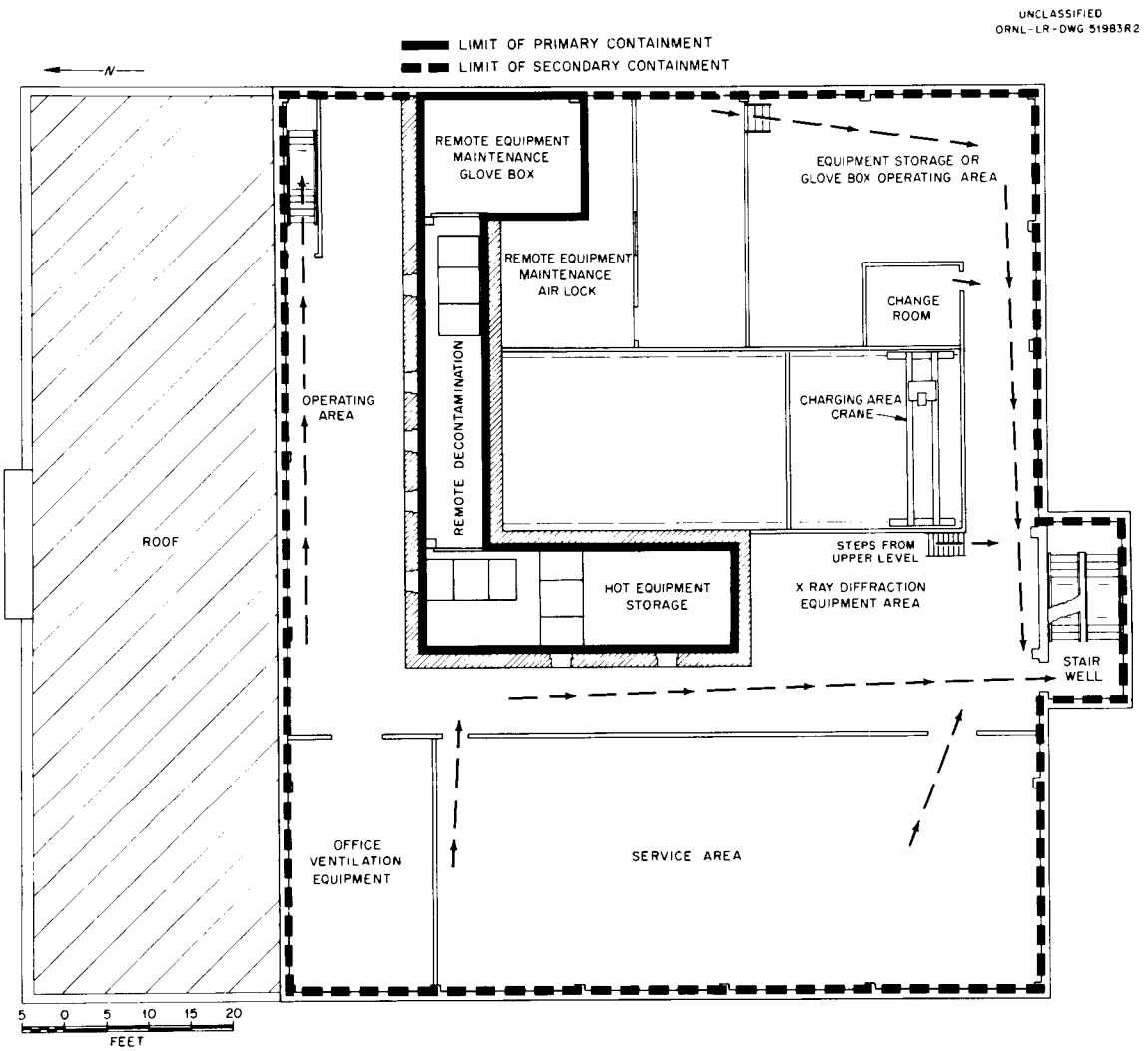


Fig. 3.3. Second-Floor Plan of Building 3525, Showing Evacuation Routes and Containment Zones.

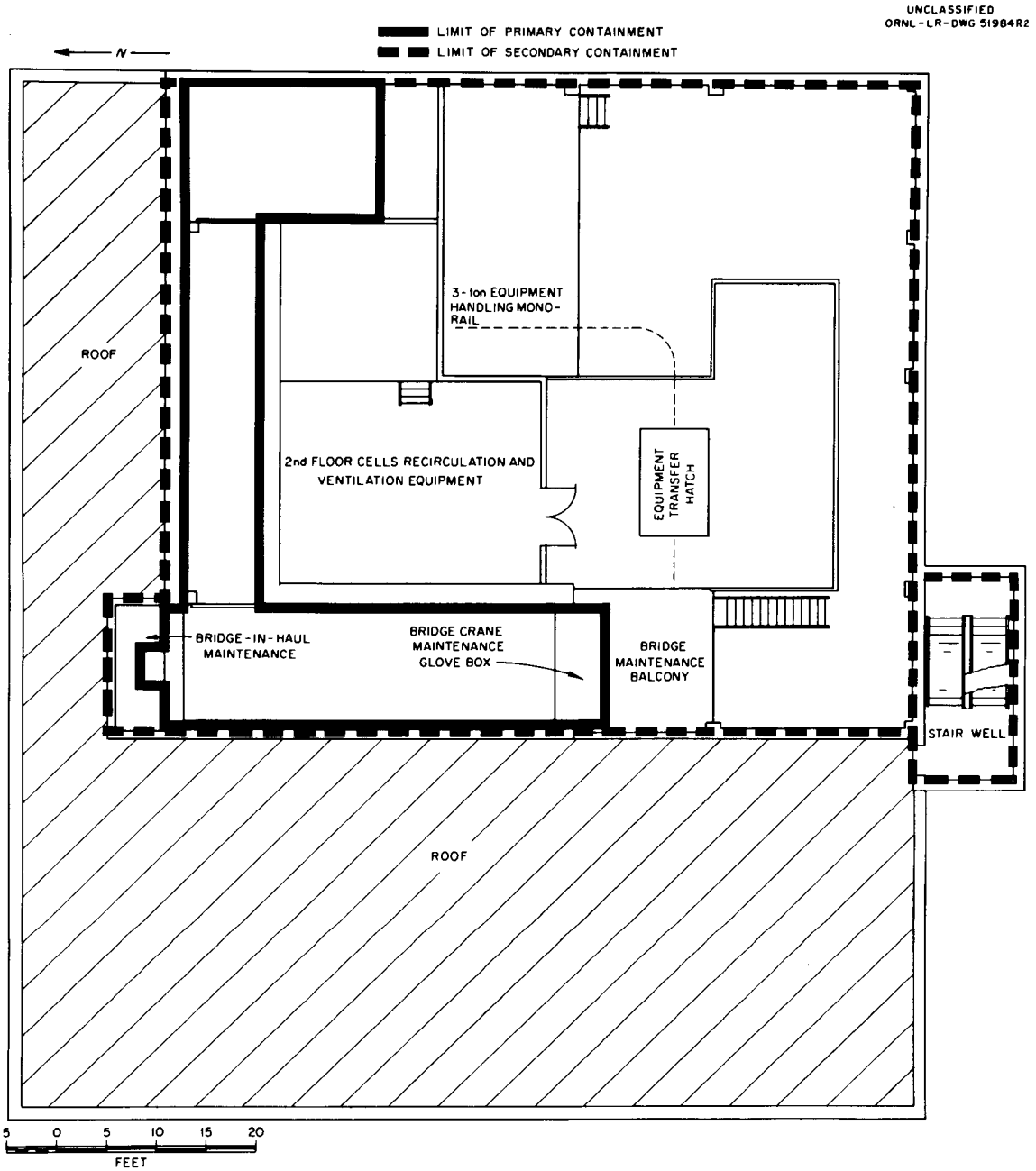
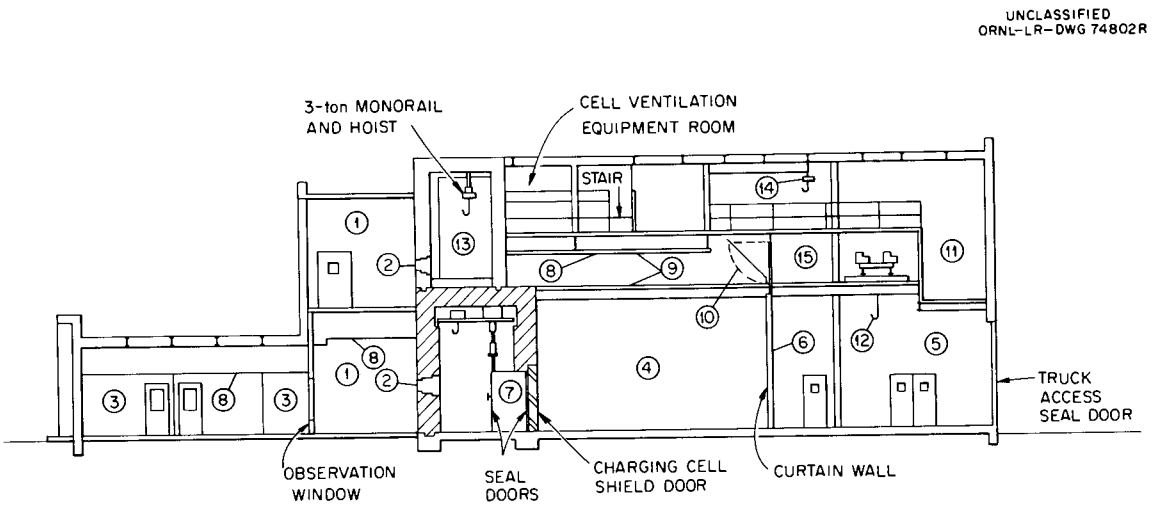
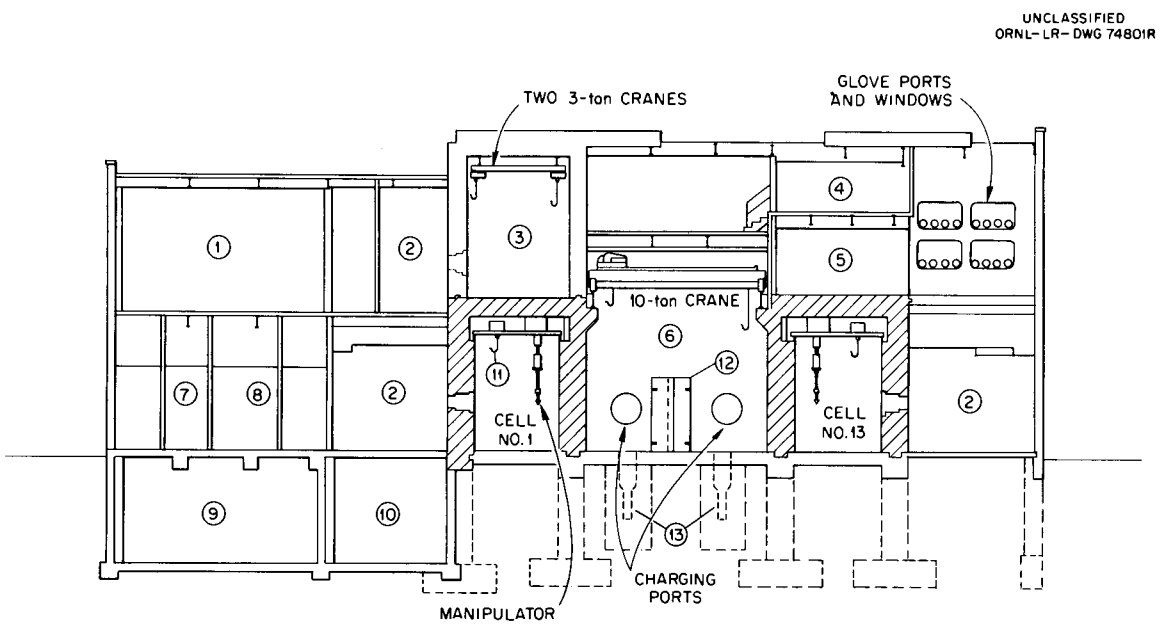


Fig. 3.4. Plan of the Second-Floor Upper Level of Building 3525.



1. OPERATING AREA
2. VIEWING WINDOW
3. CORRIDOR
4. CHARGING AREA
5. TRUCK UNLOADING AREA
6. SLIDING DOOR
7. AIR LOCK
8. HUNG CEILING
9. CRANE RAILS
10. CRANE SWING DOOR
11. LOW LEVEL STORAGE
12. 10-ton CRANE
13. DECONTAMINATION AREA
14. 3-ton MONORAIL
15. EQUIPMENT HATCH

Fig. 3.5. North-South Split Vertical Section Through Building 3525.



1. LOW LEVEL VENTILATION EQUIPMENT ROOM
2. OPERATING AREA
3. HOT EQUIPMENT STORAGE AREA
4. VENTILATION EQUIPMENT ROOM
5. AIR LOCK
6. CHARGING AREA
7. DARK ROOM
8. PHOTO LAB
9. CELL EXHAUST FILTER ROOM
10. CELL EXHAUST FAN ROOM
11. 3-ton TOP RIDING CRANE
12. CHARGING CELL SHIELD DOOR
13. STORAGE WELLS

Fig. 3.6. East-West Vertical Section Across Building 3525.

various operating areas. The office and cold-laboratory section has its own separate, filtered-air supply and exhaust system. The remainder of the laboratory outside the cell complex is subdivided into: (1) the charging area; (2) the equipment-maintenance air-lock areas; (3) the operating area; (4) the truck unloading area, the photographic rooms, and the main change room; and (5) the rooms housing supporting mechanical equipment. Thus, the various operational areas are listed in order of decreasing probability of radioactive contamination. Preset air balances and some automatic control establish an air-migration pattern from the least- to the most-probable contamination zone. All air exhausted from the facility must first pass through CWS absolute filters.

3.2 The Shielded Cell Complex

The shielded cell complex, which is the very heart of the facility, is centrally located and occupies the full building height. The main cells, which are designed to handle a large variety of primary operations, are located on the first floor, while direct supporting functions that require shielding are located above on the second-floor level. The arrangement of the integrated shielded areas is shown in Figs. 3.7 and 3.8. The ventilation of these areas is described in Section 3.6.

The primary cell structure consists of three straight-line banks which for functional purposes are arranged in the form of a "U." Each completely enclosed bank can be further subdivided by the remote insertion of "splash" barriers, should additional control be required to prevent the internal spread of particulate matter to adjacent work areas. Thus subdivided, each operating cell is 6 ft wide by 10 ft deep and 14 ft high, except that the two corner cells, with right-angle viewing, and the charging cell are wider. Figure 3.9 is a vertical section through a typical first-floor cell. The 13 cells on this level are served by 15 viewing windows (each corner cell has two) and a pair of master-slave manipulators located at each window station. The shielding windows are the oil-filled, lead-glass variety and of proper thickness and density to match the 3 ft of high-density concrete shielding provided by the cell walls. The inside surfaces of the cell banks are lined with stainless

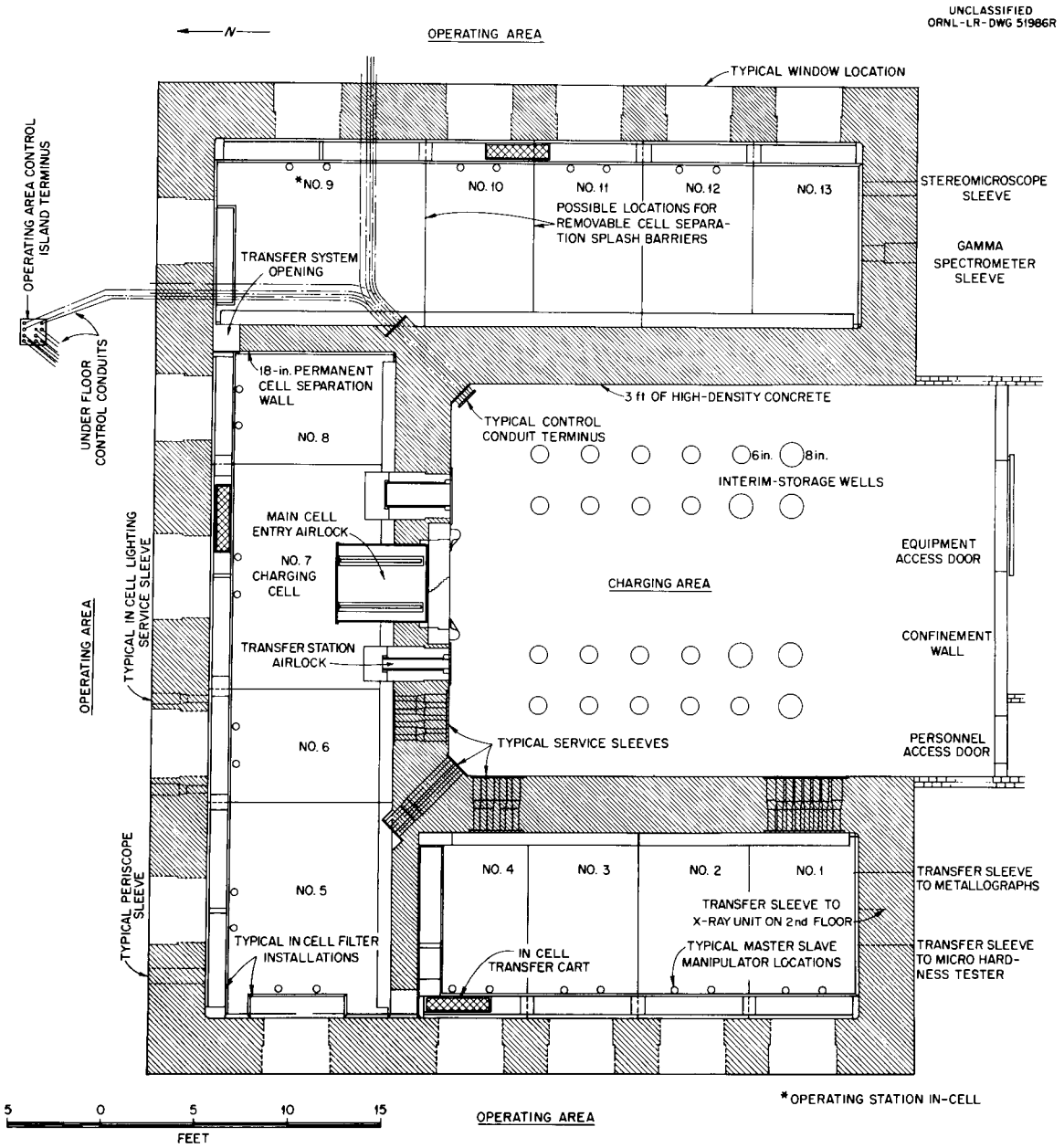


Fig. 3.7. Experimental Cell Bank on First-Floor Level of the HRLEL, Building 3525.

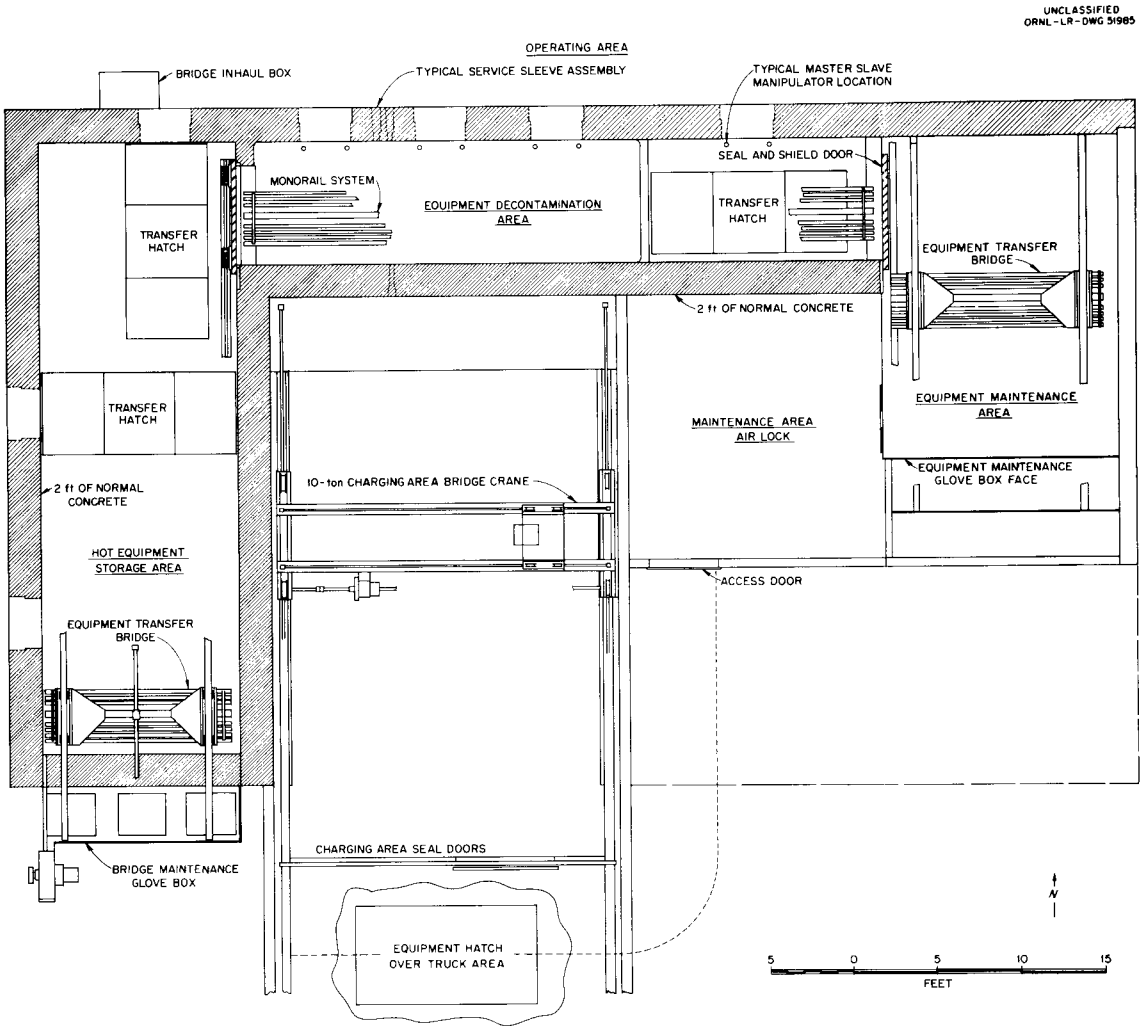


Fig. 3.8. Shielded Area for Equipment Storage and Maintenance, HRLEL, Building 3525.

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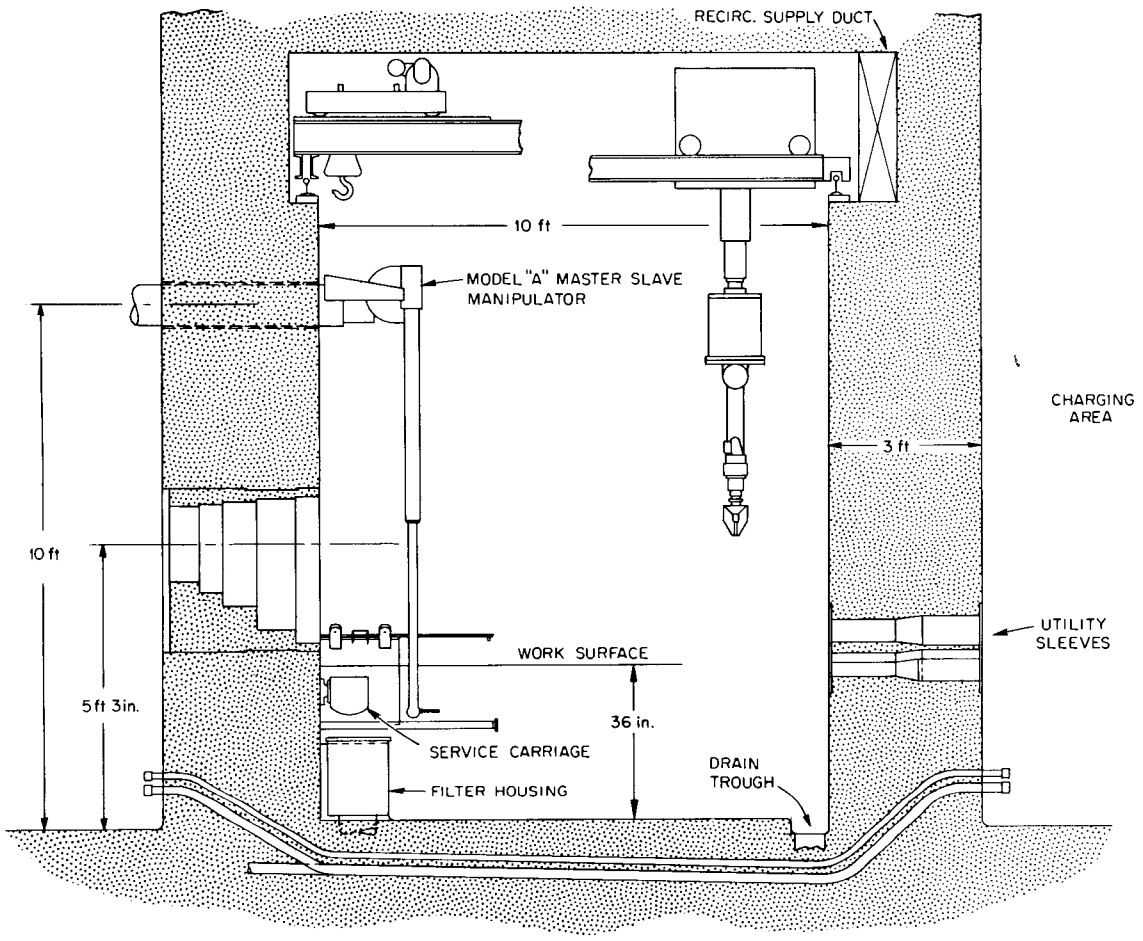

Fig. 3.9. Typical Vertical Section Through Cell.

steel sheet to provide containment of particulate matter. Special penetrations provide for the sealed entry of services, such as instrument lines, water, and gas.

Within each cell bank, heavy objects are moved by the General Mills Model 303 electromechanical manipulators and a companion 3-ton bridge crane. These motorized units are designed to be repaired remotely after remote removal through ceiling hatches into the second-floor portion of the cell complex. Also, experimental equipment to be installed, removed, or transferred to another section within the complex is handled through these hatches. Small pieces and test samples under examination are transferred within the cell complex by a trolley on tracks mounted to the wall under the windows. In the walls separating the cell banks, pass-through doors accommodate this trolley. Replaceable mercury-vapor lamps around each window provide cell illumination.

Special penetrations in the cell wall accommodate some basic experimental equipment and shielded and sealed transfer mechanisms. These penetrations include the sleeve ports for the periscopes, the stereomicroscope, and the collimator for the gamma spectrometer, as well as openings for the transfer of samples to shielded appendages for x-ray diffraction and metallographic examination. Radioactive materials enter and leave the cells through three shielded transfer stations provided at the rear face of the charging cell (No. 7). The 6 1/2-in.-diam and 14 1/2-in.-diam air locks are capable of handling objects up to 40 in. in length, while items up to 4 × 4 × 6 ft in size and weighing up to 10 tons are transferred through a shielded air-lock door system.

The supporting functions on the second floor are storage, decontamination, and maintenance of hot equipment. The areas for the first two activities are shielded with 2 ft of normal concrete, while the glove-box area for equipment maintenance is essentially unshielded.

Handling equipment located on the second-floor level includes an integrated bridge, monorail, and trolley system for transfer of objects within each area and from one area to another through the shielded doors located at either end of the decontamination area. Ports for installing master-slave manipulators are provided at each window in the decontamination area, and structural provisions have been made for installation of heavy-duty manipulation equipment in this area should it prove necessary.

The cell banks are ventilated by a system of individual recirculation units and a single exhaust system, as described in Section 3.6.

3.3 Supporting Facilities

The charging area on the first floor, bounded by the U-shaped cell structure and the curtain wall at the truck unloading area in the rear, is an air lock built to prevent the spread of contamination in the event of a mishap during charging or discharging operations. Deep dry wells are located in the floor of the charging area for interim storage of experimental samples and test components. These wells are sealed and shielded by plugs that give proper radiation protection. Both the truck unloading area and the charging area are serviced by a 10-ton bridge crane. Carriers in the 10- to 20-ton range will be transported to the charging face by a heavy-duty dolly.

The laboratory also contains photographic darkrooms, change rooms, and other supporting functions required in an integrated operation. The building is replete with emergency showers, pre-action sprinkler systems, fire-alarm systems, radiation monitors for detection of beta and gamma radiation, and associated warning devices to safeguard personnel.

All services to the experimental equipment within the cell complex are provided through sealed service ports from the charging area. The associated instruments and control panels are in the operating area and are connected to the charging area through buried conduits, which pass under the cell. By this flexible method of providing all types of services and by the versatility allowed in shifting portable equipment, any one area may be converted to new experiments without seriously interfering with adjacent operations.

3.4 Containment

The High-Radiation-Level Examination Laboratory is built to provide two complete sealed barriers to the escape of radioactive materials. The boundary of the shielded cell complex is the primary containment limit, while a secondary limit comprises essentially the outer walls of the building. These boundaries are shown on the building floor plans (Figures 3.1, 3.2, 3.3, and 3.4).

3.4.1 Primary Containment

All radioactive material of levels requiring containment and handled in Building 3525 will be in the shielded cell complex or in adequately sealed appendages. Penetrations for manipulators, instruments, and services are shielded and sealed to prevent escape of radiation and radioactive material. Samples transferred outside the cells to instruments such as the metallographs and the x-ray diffractometer are still contained in sealed extensions of the cell complex and must return to the cell. Materials sufficiently radioactive to require shielding may enter or leave the cell complex only through the three air locks between the charging cell (No. 7) and the charging area. Each of these has sealed doors at both ends, so that containment is complete at all times during the transfer. Airtight seals are provided also at all ports that penetrate the wall to accommodate supporting cell equipment such as windows and master-slave manipulators. All contaminated parts are replaced by forcing them inward into the cell as the replacement is moved forward into place; thus, complete containment is maintained continuously.

The high-level cells on the ground floor are connected through hatches to the equipment storage and maintenance cells on the second floor. The highly radioactive irradiated materials examined in the cells will never be removed through these hatches. The only items lifted through will be equipment, which is radioactive only through surface contamination. Once such equipment has been remotely decontaminated to a level not requiring shielding, it may be moved through a sealing and shielding door into the glove-maintenance area. The equipment so removed, however, is still within the primary containment zone. If for some reason it is to be removed from this zone, it is sealed in a polyethylene bag and transferred through the remote equipment maintenance air lock. New equipment to be installed in the cells follows the reverse of this path. Equipment that cannot be decontaminated sufficiently will have to be removed via the charging cell through one of the air locks into a carrier in the charging area.

If a low-level sample is to be removed from the cell, it may be transferred through a penetration from cell 13 to a glove-box area outside the equipment maintenance air lock on the second floor. This

penetration is normally sealed at the in-cell end. When in use, the penetration terminates in a glove box where the sample is bagged in polyethylene and then removed.

All gases leaving the cell complex (Section 3.6) are completely contained and, where necessary, shielded until subjected to sufficient filtration to ensure safe stack disposal. The cell air is maintained at an adequate vacuum (−2.0 in. H_2O) for all leakage to be into the cells. Since the cell air recirculation systems are completely sealed and the absolute filters in the exhaust are simultaneously replaced and removed into specially designed sealed containers without breaking the seal, the sealed basement rooms containing the blowers and filters are considered part of the secondary containment system.

Liquid cell effluents (Section 3.7) are transferred in a shielded and sealed system through a holdup tank to the adjacent underground radioactive waste storage tank farm.

Additional primary containment is provided by the storage wells in the floor of the charging area. Each well is sealed by a shielding plug and exhausted through the drain lines to the holdup tank (Section 3.7). This tank is maintained at a negative pressure by a special ventilation line exhausting through the cell exhaust system.

3.4.2 Secondary Containment

The outer shell of the building is effectively a second barrier to the spread of radioactive contamination from the building. In fact, the main part of the building is sealed from the first-floor office area so the latter can be excluded from the secondary containment zone. All outside doors and windows are normally kept closed and are gasketed to make tight seals. Air is filtered through absolute filters on the roof before it is exhausted to the atmosphere. Thus, in the event of escape of radioactivity from the cell complex, the building will contain it.

In effect, along the more probable paths for escape of radioactivity from the cell complex, there is a third barrier. Surrounding the cell complex, the operating area (including the second floor) and the charging area together form a sealed enclosure within the outer wall. To reach the outside or the office area from these areas requires passage through

the truck unloading area, the change room, the service area, or a stairwell. Since all these have gasketed doors to both the operating and outer areas, each can be converted to an air lock. An apparent exception is the doorway between the operating room and the office corridor. However, this door is kept locked to be used only under unusual conditions not coincident with hazardous or difficult operations.

The truck unloading area is a normal operating air lock. The sliding door to the charging area and the large doors that admit trucks from the outside are interlocked or alarmed so that they cannot be opened simultaneously. In the normal unloading procedure, the outside doors are closed with the truck completely within the building. The sliding door and the crane swing door, which are interlocked so they cannot be operated with the exterior door open, are then opened and the carrier is moved by the crane into the charging area. The charging area is then resealed and the truck may leave. If the truck is too big to completely enter the building, the carrier will have to be first unloaded into the truck unloading area. Radioactive materials are not transferred from the carriers to the cells until the charging area doors are closed.

During an emergency, the building ventilation system is operated in a special way to prevent release of hazardous radioactivity. The system is switched to emergency operation manually, if an operator detects hazardous conditions, or automatically, if the building instrumentation detects high radiation levels or high air activity in the operating area or failure in any part of the building ventilation system. The building supply fans are all stopped, while the charging area and operating area exhaust fans and the complete cell ventilation system continue to operate. When the internal building pressure has been brought to 0.3 in. H_2O below atmospheric, an emergency relief system automatically opens the supply system dampers to prevent a dangerous imbalance.

During normal operation, the air exhaust from the cell complex is sufficiently free of radioactivity that it is released safely through the relatively short building stack. When radioactivity is detected beyond the absolute filters in the cell exhaust or when the building ventilation system is placed in emergency operation, the cell exhaust is

diverted to the 3039 stack. The cell system exhaust is also transferred to the 3039 stack if the pressure in the cell continues to rise even after the second cell exhaust fan has been brought into operation.

The normally nonradioactive area most likely to become contaminated is the charging area. It is through this area that highly radioactive materials enter and leave the cell complex and services penetrate the cell walls. Confinement is automatic if this area should become contaminated, since it is normally isolated. Personnel doors from the charging area to the truck unloading and operating areas are gasketed and normally closed, and access is only through the special change room. The floor of the charging area is of stainless steel for ease of decontamination.

A second potential contamination zone is the remote maintenance air lock, since through it low-level activity may be removed from the cell complex. This room is normally closed off from the operating area by a sealed door, so a spill could be cleaned up without contamination of the main second-floor operating area.

Nothing radioactive should be in the operating area except bagged and sealed low-level materials from the remote maintenance area and the sample station on the second floor. The many penetrations between the cells and the operating area are so designed that replacement is made without breaking the seal by inserting a new piece from the outside as the old piece is moved into the cell. Although failure of these penetrations is highly unlikely, provisions have been made to treat the operating area as a temporary contamination zone. The main change room between the office area and the operating area is arranged for immediate conversion to a contamination zone entry point. All other doors to the area are normally locked to prevent entry and will not be opened during decontamination except to facilitate decontamination. Since gasketed doors provide access from both the first- and second-floor operating areas to the stairwells, these may serve as air locks to prevent transfer of contamination between the two floors in the event of an accident.

3.5 Radiation Monitoring Equipment

A detection and alarm system in the building provides proper warning to safeguard personnel against radiological hazards in the event of a mishap. The personnel warning system includes high-level gamma alarms, constant air monitors, and personnel contamination detectors including a hand-and-foot counter. A network of instruments provides local alarms and, in most instances, remote indications of unusual radiation conditions. A few of these instruments are connected with the ventilation control panel to actuate the controls that place the building in a state of emergency containment. Other instruments are used as process monitors to aid the control of certain operations to ensure greater safety.

All abnormal conditions in the ventilation system or in the widespread health-physics instrumentation system are indicated and alarmed at panels in the northeast corner of the operating area, near the entrance to the change room through which people may leave the building. The panels have the necessary instrumentation taps to permit a tie-in with the future plant-wide emergency control center.

The identity and location of various pieces of equipment in the monitoring system are shown in Fig. 3.10. A summary of the equipment, its functions, and its coverage is presented in Table 3.1.

3.6 Ventilation and Off-Gas Systems

The HRLEL is equipped with a radioactive off-gas system, an in-cell hood vacuum system, and separate ventilation systems for the portions of the building having different levels or probabilities of radioactive contamination. The essential characteristics of these systems are summarized in Table 3.2. The ventilation systems are schematically represented in Fig. 3.11.

Each bank of operating cells has its own air recirculation system, moving a cell volume in less than 2 min. The circulating air passes through rough and absolute filters in the cells and through recirculating blowers and a cooler in the basement. Condensate from the coolers is discharged to the radioactive hot-drain system. Air intake for the operating cells is by leakage from the lower radiation level cells on

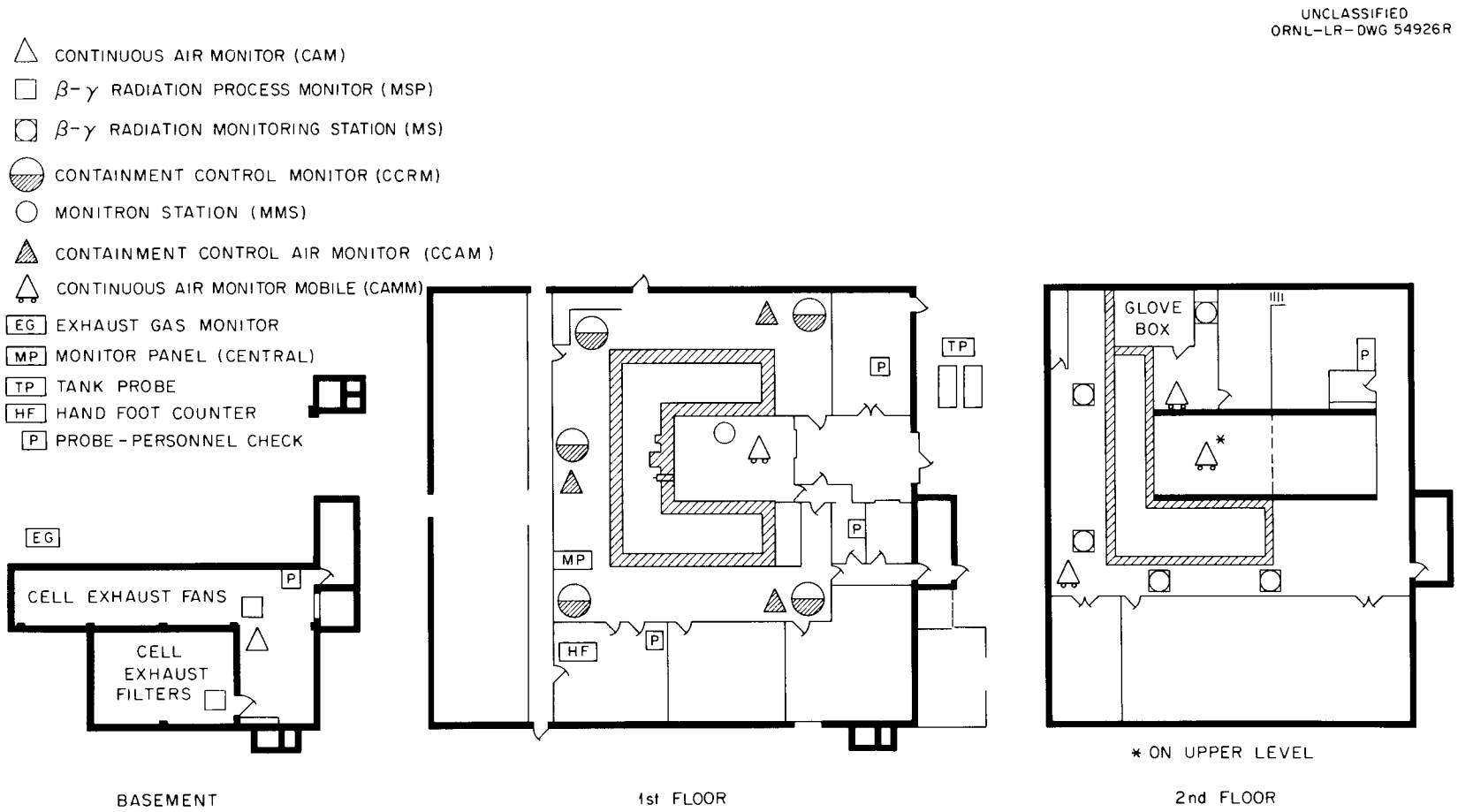

Fig. 3.10. Radiation Monitoring System, Building 3525.

Table 3.1. Radiation Monitoring System – Building 3525

Symbol	Name	Function	Instrument Failure		Intermediate Radiation Level		High Radiation Level		Containment Control	Quantity				
			Light Indicator	Audible Alarm	Light Indicator	Audible Alarm	Light Indicator	Audible Alarm		Basement	1st Floor	2nd Floor	Upper Level	Total
	CCRM	β-γ Containment Control Radiation Manitor	LP	LP	LP	LP	LP	LPB	Yes	0	5	0	0	5
	CCAM	β-γ Containment Control Air Monitor	LP	LP	LP	LP	LP	LPB	Yes	0	3	0	0	3
	MS	β-γ Radiation Monitoring Station	LP	LP	LP	LP	LP	LP	No	0	0	5	0	5
	CAMM	Continuous Air Monitor Mobile	L	L	L	L	L	L	No	0	1	2	1	4
	CAM	β-γ Continuous Air Monitor	LP	LP	LP	LP	LP	LP	No	1	0	0	0	1
	MMS	β-γ Monitor	LP	LP	LP	LP	LP	LP	No	0	1	0	0	1
	MSP	β-γ Radiation Process Monitor	LP	LP	LP	LP	LP	LP	No	2	0	0	0	2
MP	MP	Monitor Panel with Alarm Indicators and Recorders								0	1	0	0	1
EG	EGM	Exhaust Gas Monitor for Process Application	LP	P	LP	P	LP	P	Yes	1	0	0	0	1
TP	TP	β-γ Probe in Hot Waste Tank			P		P		No	0	1	0	0	1
P	PSP	Personal Survey Probe	L		L		L	L	No	1	3	1	0	5
HF	HFC	Hand and Foot Counter	L		L		L	L	No	0	1	0	0	1

L = at local detector, P = on monitor panel, B = throughout building.
All monitors which indicate at the monitor panel also record there.

Table 3.2. Properties of Off-Gas and Ventilation Systems

Primary Containment Zone

	First Floor Operating Cells	Second Floor Supporting Cells
Exhaust Flow Rate at Filters, cfm	2000	2000
Normal Exhaust Location	Building stack	Building stack
Stack dilution factor, sec/m^3	0.43×10^{-3}	0.43×10^{-3}
Decay time enroute to stack, sec	5	6
Emergency Exhaust Location	3039 stack	3039 stack
Stack dilution factor, sec/m^3	1.6×10^{-5}	1.6×10^{-5}
Decay time enroute to stack, sec	~120	~120
Leak Rate to Secondary Containment Zone at 1 in. H_2O Pressure Difference, vol/min	<0.01	

	Cell Bank A Cells 1–4	Cell Bank B Cells 5–8	Cell Bank C Cells 9–13	Equipment Storage Area	Crane Maintenance Glove Box	Remote Decontamination Area	Equipment Maintenance Glove Box
Volume, ft^3	3520	5210	5210	6980	100	4390	4195
Vacuum, in. H_2O	−1.0	−1.0	−1.0	−1.0	−1.0	−1.0	−0.5
Air Intake	(a)	(a)	(b)	Inleakage	Inleakage	Inleakage	Inleakage
Exhaust Absolute Filter System	yes	yes	yes	yes	yes	yes	yes
Filtered Recirculation Flow Rate, cfm	2000	2900	2900	1000		1000	500
Exhaust Flow Rate from Zone, cfm	600 max	600 max	600 max	<1200	<<1200	<600	600 max

Secondary Containment Zone

	First Floor Operating, Charging, and Service Areas	Second Floor Operating and Low-Level Storage Areas	Cell Fan Filter Rooms
Volume, ft^3	86,500	104,000	33,000
Minimum Enclosure Volume in Contact with Primary Containment, ft^3	14,500 (Charging Area)	3340 (Maintenance Air Lock)	33,000
Vacuum, in. H_2O	−0.3	−0.2	−0.05
Filtered Recirculation Flow Rate, cfm	none	none	none
Exhaust Flow Rate from Zone, cfm	2560	44,770	4180
Exhaust Flow Rate at Filters, cfm	2560	48,950	48,950
Intake Roughing Filter System	yes	yes	yes
Exhaust Absolute Filter System	yes	yes	yes
Exhaust Location	Roof	Roof	Roof
Exhaust Dilution Factor, sec/m^3	$\sim 2 \times 10^{-3}$	$\sim 2 \times 10^{-3}$	$\sim 2 \times 10^{-3}$
Fire Control System		Water Sprinkler System	

Radioactive Off-Gas System

Supplies: −10 in. H_2O gage vacuum to cells and −5 in. H_2O gage vacuum to low-level storage area; ~10 cfm capacity each cell; 50 cfm each low-level storage area; and 100 cfm max flow from all sources. Passes through condensate collection vessel and absolute filters, and exhausts to −30 in. H_2O gage, 10-in. stainless steel plant off-gas line to 3039 station.

In-Cell Hood Vacuum System

Supplies: −4 to −7 in. H_2O gage vacuum system to each cell, decontamination area, and low-level storage area.

Maximum Flow Rate: 100 cfm each cell bank, 100 cfm decontamination area, 200 cfm east and west low-level storage area. Exhausts through automatic control valves and blower to cell exhaust filters.

[a]From equipment storage area.
[b]From remote decontamination area.

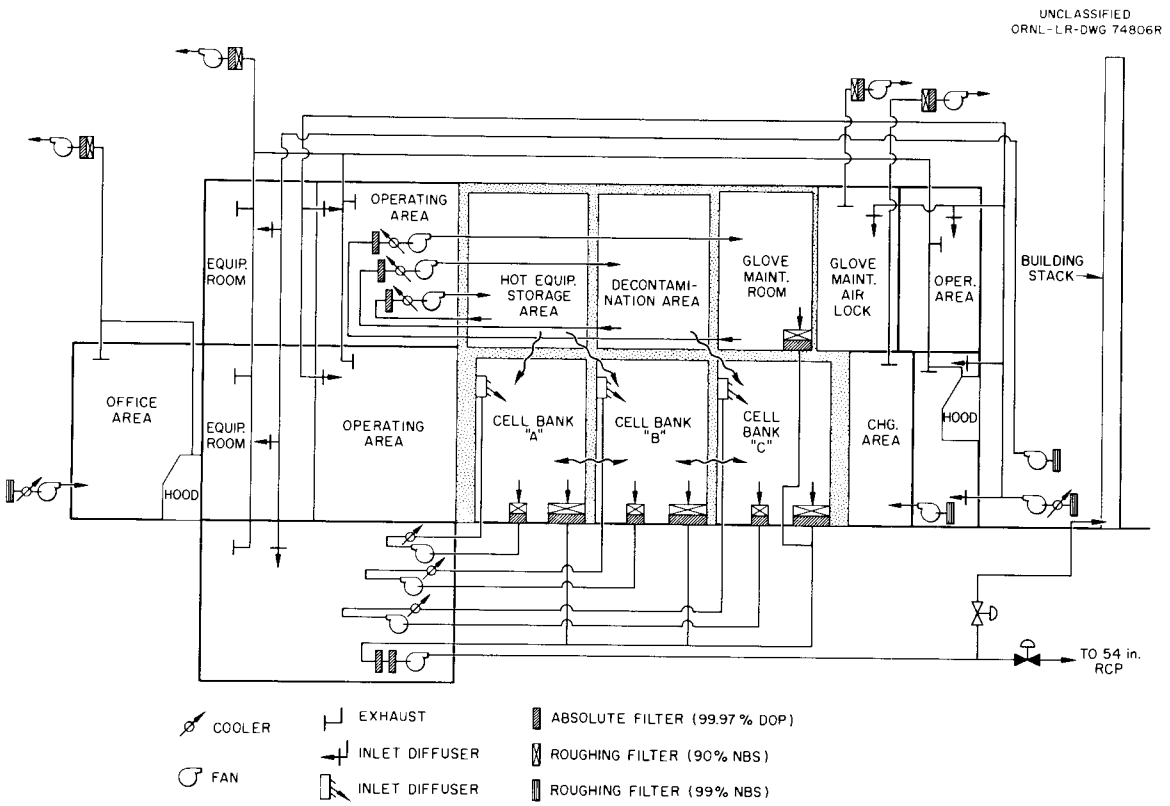

Fig. 3.11. Schematic of HRLEL Primary Ventilation Systems.

the second floor. The combined exhaust air from the three cell banks is pulled through roughing filters and absolute filters in the cells and two additional stages of absolute filters in the basement. Either of two blowers may be used, each capable of maintaining the cell pressure at well below the control point of 2.0 in. H_2O below atmospheric. The exhaust air is routed normally to the building stack, but under emergency conditions (Section 3.4) is switched to the isotope area stack, 3039. The spent in-cell filters are disposed of as solid radioactive waste (Section 3.8). Exhaust filters in the basement are discharged into special sealed boxes and replaced without breaking the seal in the exhaust line.

Dilution and deposition factors for particulate activity from the building and 3039 stacks are given in Table 3.3. These factors have been calculated for the worst combination of stack plume rise and wind speed.[2] Particles small enough to pass through the absolute filters in the exhaust system were assumed[2] to have a deposition velocity of 2 cm/sec.

Permissible rates of discharge of typical radioactivities given in Table 3.4 were calculated using the dilution and deposition factors along with permissible ground concentrations and deposits for ORNL.

The hot-equipment storage cell, the decontamination cell, and the glove-maintenance room have separate recirculation systems, with blowers, coolers, and filters in a sealed room on the upper level of the second floor. The two shielded cells are maintained at the same vacuum as the first-floor cells by controlled leakage ports. The glove-maintenance room is maintained at less vacuum (−0.5 in. H_2O) by separate exhaust through a roughing filter and an absolute filter to the cell exhaust system.

The normally nonradioactive parts of the building have ventilation systems segregated according to contamination probability. For example, the charging room, through which radioactive materials pass frequently, and the office area, which radioactive materials never enter, both have

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[2] J. P. Nichols, TRU-Proposed Rates for Operational Release of Radioactive Materials to the Atmosphere, ORNL CF-62-1-62 (Jan. 1962).

Table 3.3 Dilution and Deposition Factors for HRLEL Stack and 3039 Stack

	HRLEL Stack		3039 Stack	
	Dilution Factor[a] (sec/m^3)	Deposition Factor[b] (m^{-2})	Dilution Factor[a] (sec/m^3)	Deposition Factor[b] (m^{-2})
Maximum average[c]	4.3×10^{-4}	8.6×10^{-6}	1.6×10^{-5}	3.2×10^{-7}
Peak[d]	4.1×10^{-2}		1.6×10^{-3}	
Maximum average annual[e]	8.6×10^{-6}	2.6×10^{-7}	3.2×10^{-7}	9.6×10^{-9}

[a]The ground concentration (i.e., in air at ground level) in $curies/m^3$ resulting from a discharge rate of 1 curie/sec.

[b]The deposited concentration in $curies/m^2$ per curie discharged.

[c]The space maximum value averaged over statistical fluctuations for a period of at least several minutes of constant weather conditions.

[d]Values of short (few seconds) duration, representing maxima of statistical fluctuations.

[e]The maximum value averaged over one year's weather conditions.

Table 3.4 Permissible Release Rates for Gaseous and Particulate Radioactivities

Activity	Release Rates, curies/day	
	3039 Stack	HRLEL Stack
Kr^{85}	864	40
I^{131}	0.1	4×10^{-3}
Gross fission products	1×10^{-4}	4×10^{-6}
Alpha emitters	1×10^{-6}	4×10^{-8}

separate filtered supply and exhaust fans. The cold laboratory hood in the latter area has a separate exhaust duct. A common filtered air supply serves the operating areas and other service facilities, but separate filtered exhaust systems serve the glove-maintenance air lock and the remainder of the building. The hood in the rear laboratory discharges to the main building exhaust system through a separate duct. Under emergency conditions (Section 3.4), the supply fans are stopped to enable the exhaust fans to rapidly achieve and maintain a vacuum adequate to prevent the spread of airborne radioactivity. These fans can bring the building from atmospheric to 0.3 in. H_2O vacuum in less than 3 sec.

The radioactive off-gas system supplies 10 in. H_2O vacuum to the cells and 5 in. to the low-level storage area on the second floor. The system is capable of 10 cfm in each cell, 50 cfm at each outlet in the low-level area, and a maximum of 100 cfm from all sources. The flow passes through a condensate collection vessel and filters in an underground shielded sealed pit behind the building. The condensate drains to the radioactive hot liquid waste system (Section 3.7). The filtered gas is exhausted at approximately 30 in. H_2O vacuum through the stainless-steel laboratory off-gas line and scrubber system to the 3039 stack.

The in-cell hood vacuum system provides 4 to 7 in. H_2O vacuum to each operating cell, to the decontamination cell, and to the low-level operating area on the second floor. The maximum flow provided for is 100 cfm in each cell and 200 cfm at each of two locations in the low-level area. The system exhausts through an automatic control valve and blower into the cell exhaust system. If a hood is needed in a cell, a filter is installed with it. A scrubber is also installed when needed to remove corrosive gases from the exhaust.

3.7 Liquid Waste Disposal

Liquid wastes from the facility are routed through various systems, depending on the source of the waste. In addition to the sanitary sewers and the storm sewers, there are two operational waste systems. The normal process waste originates in the laboratories and operating areas surrounding the cells. The radioactive hot waste originates within the cell complex. The overall drain system is schematically illustrated in Fig. 3.12.

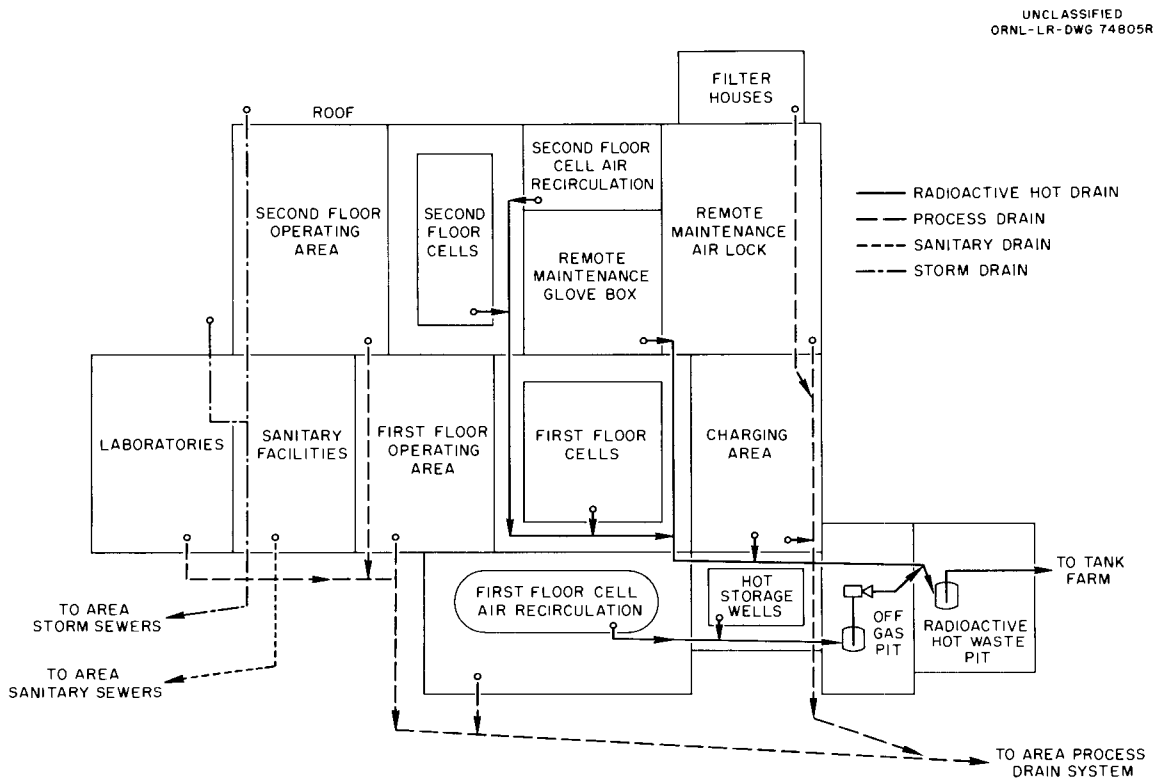

Fig. 3.12. Schematic Diagram of Building 3525 Liquid Waste Systems.

Inside the building, the process drain system is segregated into two subsystems, which join outside the building. One subsystem of process drains comes from areas that have very little probability of radioactive contamination. The other subsystem comes from floor drains and cup sinks in the charging area and the floor drain in the maintenance air lock. The latter subsystem is installed separately so that if frequent contamination occurs during operation a diversionary valve and an activity monitor to control it can be installed in the line outside the building to route the contaminated water to the radioactive hot-drain system when necessary.

The most critical liquid waste is that developed within the primary containment shell and handled by the radioactive hot-drain system. Liquid waste from the cell floor drains on the first and second floors and the condensate-collection points in the cell air recirculation systems on the upper level flows by gravity directly to the radioactive hot drain pit located outside the southeast corner of the building. There they pass through a removable basket-type strainer into a collection tank. A second hot-drain system carries waste from below grade by gravity to a transfer tank in the off-gas pit. This waste includes condensate from the cell air recirculation equipment in the basement, condensate from the radioactive off-gas system, and drainage from the storage wells under the charging area. From the transfer tank this waste is pumped by steam jet to the strainer in the main hot-liquid waste system.

The collection tank serves as a holdup and ventilation isolation point for the radioactive hot-drain system. Since the tank is not of the "ever-safe" design, administrative control procedures will prevent criticality excursions. The tank is equipped with a system for obtaining samples of its contents in sealed and shielded containers. It is also outfitted with an automatic jet ejecter, an emergency steam-jet ejecter, and a gravity overflow line. By these devices, the waste is transferred to tank W-12 in the ORNL radioactive waste tank farm. The vent from the collection tanks is connected through a filter to the cell exhaust system.

3.8 Solid Waste Disposal

Experience in performing hot-cell work has shown that the generation of solid waste as a by-product of various experimental operations presents a serious disposal problem. For example, approximately 15 gal/day of intermediate activity-level waste is handled in the operation of a seven-cell complex at Savannah River. At Hanford, the metallurgy cell complex produces from 16 to 20 ft^3 of waste per week. Most of this waste has a gamma activity measuring less than 20 r/hr at 1 ft.

Packaging of intermediate-level waste and safely transporting it to the disposal area are almost continuous operations. At the HRLEL, such waste is collected in the individual operating cells in cans 14 in. in diameter and up to 39 in. long. These cans with lids in place are transferred to the charging cell, sealed, decontaminated by ultrasonic cleaning, placed in the 14.5-in. transfer station, given a final rinse in the air lock, and moved directly into a preplaced 6-ton carrier, which provides secondary containment and 3 in. of lead shielding. Approximately four cans of intermediate-level solid waste per day pass through this station.

High-level waste and sections from experiments to be stored or transferred to other operations are handled through the 6.5-in. transfer station in cans 6 in. in diameter and up to 40 in. long. The carrier provides 7 in. of lead shielding. Approximately two cans per day pass through this station.

Both carriers can be used either horizontally or vertically. The smaller carrier has doors at both ends to increase its flexibility and permit easier movement of irradiated materials to and from the interim storage wells.

4. OPERATIONS

The general philosophy of operation, a proposed organization, and a brief description of some of the pieces of experimental equipment, their functions, and their effects on operating procedures and safety features are described below. These have been based on the Laboratory needs, the facility design, the metallurgical nature of the work, and past hot-cell operating experience at ORNL and other sites.[1,2,3]

4.1 Operating Philosophy

The main purpose of the facility is to provide technical assistance in a safe, efficient, and competent manner. Hence, the facility is run as a service function to obtain the postirradiation data needed in support of the various research and development programs at ORNL. The general direction and scope of the work performed come from the program sponsor or an affiliated representative assigned to coordinate the overall experimental effort. The responsibility for actual performance of the hot-cell work, however, rests primarily on the regular staff at the facility. When the examination involves highly specialized techniques or equipment developed by the experimenter, space is made available and the required assistance provided. In general, the program coordinator is not a member of the facility staff, but his presence is expected during the implementation of important phases of the work so that he can observe the results and alter the technical direction, if necessary. In this manner he maintains complete technical control.

Since all operations are performed by or with the assistance of the facility staff, predetermined procedures to ensure radiation safety, to protect the quality of technical data, and to minimize equipment damage

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[1] J. M. Davis and E. D. Grazzini, "Operational Experience in the Components Development Hot Cells at Atomics International," Proceedings of the Eighth Conference on Hot Laboratories and Equipment, San Francisco, California, Dec. 13–15, 1960, TID-7599, p 316.

[2] J. H. Saling et al., "Changes in the Design and Operational Management of Battelle's Hot Cell Facility," Ibid, p 324.

[3] Staff of the Metallurgy Division, Technical Function and Operation of the High Radiation Level Examination Laboratory, Bldg. 3525, ORNL CF-61-1-75, p 95 (Jan. 31, 1961).

are carefully followed. No service requests will be acted on until they have been internally reviewed for compatibility with concurrent operations from the viewpoint of radiation safety. Where the experiments involve hazards in excess of those previously approved, the appropriate ORNL Review Committee will be asked to review the proposed procedures and safety precautions and the approval of the Director of Radiation Safety will be obtained before the experiment is introduced into the facility. No changes in procedures will be permitted without the appropriate written approval.

4.2 Organization

The operating staff consists of a line operating force and a technical staff reporting to a single head. Also, various other groups (Metals and Ceramics and Analytical Chemistry Divisions) are attached to furnish special technical services in the hot cells as necessary. The lines of authority and responsibility are as clear-cut as possible in order to avoid duplication of effort, improper coverage, and split responsibility. In order to ensure a common safety authority, all functions within the facility are subject to the review and approval of the operating supervisor regardless of other technical and administrative lines of authority. The basic line organization arrangement planned is shown in Fig. 4.1. The manpower requirements for initial operation are listed in Table 4.1. It is estimated that 35 persons are required to operate the facility on a one-shift basis. In addition, seven craftsmen and one Health Physics representative are required. The facility may eventually be operated on a two- or three-shift basis.

The technical staff is composed of professional people trained in metallurgy, physical chemistry, mechanical engineering, or related fields. Their functions are to: (1) perform safety analyses, including calculations of criticality and shielding; (2) design and develop special equipment; (3) compile and report experimental data; and (4) coordinate the requirements of postirradiation examinations with preirradiation design to ensure that the needed data can be obtained in a reliable and economical manner. This staff also advises on planning, scheduling, operating procedures, and safety.

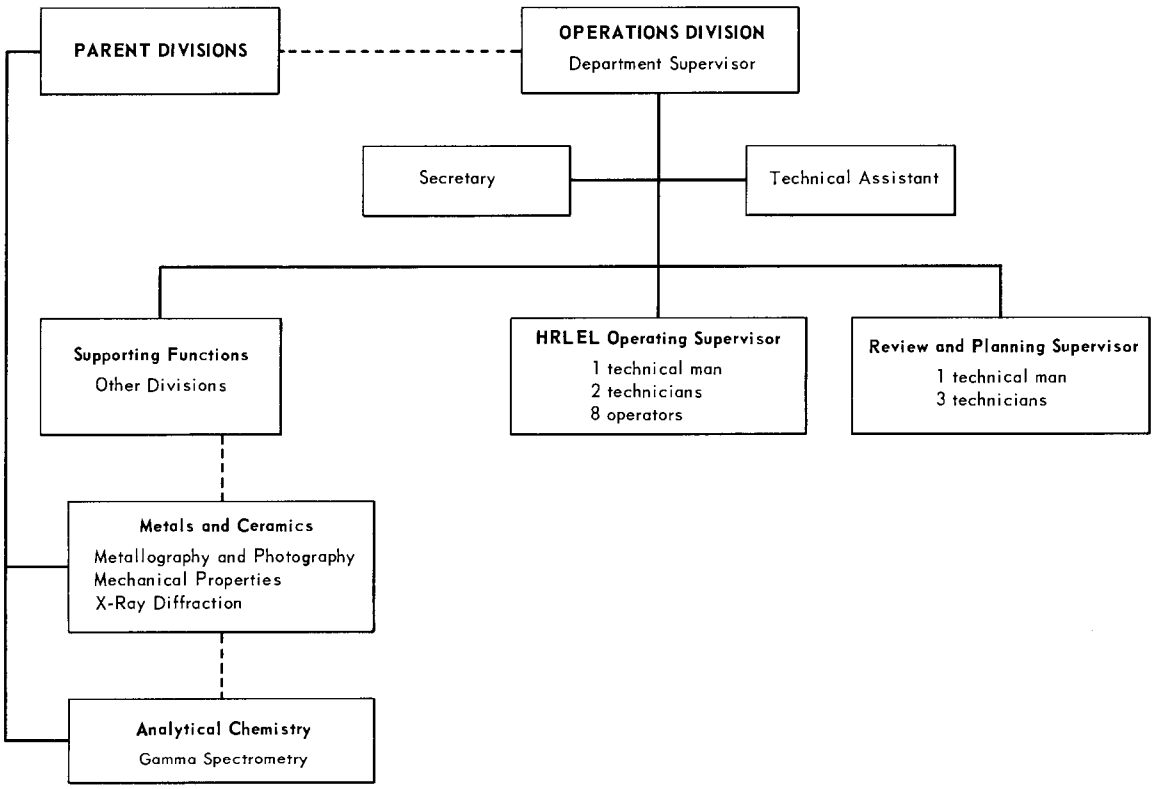

Fig. 4.1. HRLEL Operations — Proposed Organization.

Table 4.1 Estimated Manpower Requirements for Operation of Building 3525

		Professional	Non-professional
A.	Staff		
	Supervisory and Technical	2	
	Secretarial		1
B.	Operational Forces		
	Function		
	Disassembly and Cutup Charging and Discharging Fission-Gas Sampling Weighing and Density Mensuration Decontamination and Maintenance	5	13
	Metallography and Photography	3[a]	6[a]
	X-Ray Diffraction Analyses	1/2[a]	1[a]
	Mechanical Properties Determination	1/2[a]	1[a]
	Gamma Spectrometry	1/2[b]	1[b]
		11 1/2	23

C. Supporting Personnel

Function	Number
Health Physics Surveyor	1
Machinists	2
Electrician	1
Instrument Mechanic	1
Pipefitter	1
Millwrights	2

[a]Metals and Ceramics Division personnel.

[b]Analytical Chemistry Division personnel.

The operational force is composed mostly of operators with professional people for supervision. This group is responsible for all functions associated with operation of the "building" such as ventilation systems, utility systems, hot waste systems, and building cranes and other handling equipment. Also, they are responsible for remote manipulations and all hot-cell operations requiring the service of the facility, including decontamination and remote maintenance.

Various other divisions will furnish specialized technical services in the hot cells as necessary and will be responsible for furnishing the experimenter a written record of the results. In general, the Hot Cell Operations Department will not attempt to develop functions where a high degree of technical competence exists in these functions in other divisions, but will request these divisions to furnish this service in the facility. For initial operations the Metals and Ceramics Division will furnish specialized technical services in metallography, mechanical properties, x-ray diffraction, and nondestructive testing. The Analytical Chemistry Division will furnish gamma-ray spectrometry. As needed, additional professional assistance will be requested in other functions where technical competence already exists in other divisions.

Assistance in evaluating unusual problems involving potential criticality problems and other radiation hazards will be obtained from the appropriate experts in the Neutron Physics, Health Physics, and Radiation Safety groups.

4.3 Experimental Equipment

It is not appropriate here to describe in detail the many inspection techniques carried out in the cells. The important point is that many operations may be performed by moving the sample about within one sealed and shielded complex, using the equipment described in Section 3.2. Samples may be moved from charging cell to the left for fission-gas sampling and analysis, nondestructive testing, various physical observations and measurements, and chemical treatment. Transfer to the right leads to areas for mechanical testing, disassembly, and metallographic preparation and examination. Of course, specimens may be transferred past the charging cell from one side to the other as the sequence of operations requires.

A number of both nondestructive and destructive means of testing and measurement are used in the laboratory to examine, test, and evaluate a wide variety of materials, assemblies, component parts, and equipment that have been subjected to reactor irradiation. For greater flexibility and consequent better operating efficiency, the equipment is portable and in most cases can be rearranged or replaced as required. A list of most of this equipment is given elsewhere,[4] and individual reports have been or will be issued on the unique items. Only a brief summary is presented here.

Visual observation in the cells is aided by four Kollmorgen periscopes and three Bausch and Lomb zoom stereomicroscopes, all fitted for photography. A special adaptation of the Kollmorgen periscope has been developed[5] to simplify safe transfer of the instrument between stations at different cells. Wall penetrations on these instruments both shield and seal the openings. A special remote stage has been built for use with one stereomicroscope. A Questar telescope, also adaptable to photography, aids remote viewing. Closed-circuit television is also used for certain maintenance operations at locations not visible through the windows or other viewing devices.

For nondestructive ultrasonic inspection techniques, an immersion tank has been built with remotely operated positioners for transducer and specimen. Except for the transducer, the ultrasonic equipment can be located outside the cell. Eddy-current test equipment will be added when a method is perfected for transmitting the signals through the cell walls.

For gamma spectrometry of specimens within the cell complex, a special collimating penetration leads from a sample positioner in cell 13 through the wall to an attached shielded scintillation detector head outside the cell. This in turn is connected to a 256-channel analyzer with

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[4]Staff of the Metallurgy Division, Technical Function and Operation of the High Radiation Level Examination Laboratory, Bldg. 3525, ORNL CF-61-1-75, (Jan. 31, 1961).

[5]A. R. Olsen, R. E. McDonald, and J. L. Wilson, Kollmorgen Periscope Adaptations for Use in the High Radiation Level Examination Laboratory at the Oak Ridge National Laboratory, ORNL-TM-529 (May 17, 1963).

various recording devices. Burnup and activation in specimens can be determined by this apparatus. Irradiated capsules may be pierced to release radioactive gas to a shielded tank in which it can be monitored by an ion chamber and from which accurate low-level aliquots may be taken for analysis outside the cells.

A specially built, remotely operated milling machine occupies cell 5. The machine has its own cooling and lubrication systems and is electrically interlocked to prevent its operation unless both the cooling system and the lubrication system are in working order. A motorized pipe cutter has been built for cell 6 to cut tubing with minimum transfer of contamination by or to the specimen being cut. An abrasive cutoff machine, adapted for remote operation, wheel change, and maintenance, is provided in cell 4, particularly for preparation of metallographic specimens.

Equipped for remote operation, analytical balances of ordinary (200 g) and high (5 kg) capacity are available. Cathodic defilming and brushing equipment is available to remove corrosion products from metals. A remote replication method,[6] which minimizes transfer of radioactive contamination from the specimen to the replica, is set up both for large specimens and for metallographic specimens. A number of cleaning stations in the cells use ultrasonic agitation.

The remote metallographic equipment in cells 1 to 4 includes an electroplating bath, a press for mounting specimens in red bakelite, a facility for mounting specimens in epoxy resin, grinders, six vibratory polishers, an electrolytic polisher, a chemical polishing bath, a vacuum cathodic etcher, and a macrohardness tester. Located outside the cells are two metallographs, a microhardness tester, and an x-ray diffraction apparatus, all equipped with special cell-wall penetrations for transferring mounted specimens from the metallography cells and with shielding and containment to protect personnel from the radioactive specimens.

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[6]R. E. McDonald, B. W. McCollum, and G. A. Moore, "Replication of Surfaces for Hot-Cell Application," p 166 in Proceedings of the Ninth Conference on Hot Laboratories and Equipment, American Nuclear Society, Chicago, Ill. (1961).

Equipment for testing mechanical properties includes a commercially available Instron tension-compression machine built for hot-cell use. A motorized dial indicator has been developed[7] for dimensional measurements.

Experience in remote operations has shown that operator fatigue can be reduced and efficiency improved in a number of operations, if provisions are made for in-cell listening. Microphones are suitably located in the cells and connected to speakers at the operating faces.[8]

An intercommunication system between various operating stations is an invaluable aid to safe and efficient operation. This is particularly true when team members are isolated from one another by a barrier, such as in tasks requiring members to be stationed at both the front and back of the cell bank. Conduit and junction boxes for such a system are built in, and the units known to be absolutely necessary are included in the original installation.

Equipment for installation in the cells has been selected for versatility, adaptability to remote operation, minimum spread of contamination, minimum need for maintenance, and ease of removal for required maintenance. For example, although the base and table of the milling machine are mounted semipermanently in cell 5, all moving parts may be taken apart for removal from the cell. Metallographic grinders were chosen for the infrequency and ease of changing abrasive. The motorized pipe cutter is used for cutting tubing and cylindrical fuel claddings without contaminating the specimens with abrasive, damaging fuel cores, or spreading particles of radioactive sawdust.

4.4 Supporting Operations

Personnel protection during certain operations not specifically experimental in nature but required in all such facilities has been given special consideration. Experience has shown that these operations largely control the annual radiation exposure totals and the contamination problems. The procedures followed in the HRLEL for such supporting operations

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[7]R. E. McDonald *et al.*, A Remotely Operated Measuring Device, ORNL-TM-548 (May 31, 1963).

[8]R. E. McDonald and J. L. Wilson, In-Cell Sound Transmission System, ORNL-TM-565 (June 12, 1963).

are expected to reduce the probability of contamination and exposure of operating personnel to radiation. The general description of these procedures is presented here; detailed procedures will be developed with operating experience.

4.4.1 Charging

As previously pointed out, radioactive materials enter and leave the cell complex from the charging area into cell 7 through three shielded air locks. Irradiated pieces in shielded carriers are transferred from the truck unloading area to the charging area by the 10-ton crane. Doors are then closed, sealing off the charging area to prevent spread of radioactivity in the event of an accident. If the sample is to be transferred through either the 6 1/2-in. or the 14 1/2-in. air lock, the carrier is placed against a sealing gasket that surrounds the opening in the cell wall. The outer air-lock door and a revolving end plug in the carrier are then opened, the sample transferred to the air lock, and the outer door to the air lock closed. With the carrier still in place to provide shielding, the inner shielding door to the air lock is opened, the sample pulled into the cell, and the door closed completing the transfer.

Items too large for the cylindrical air locks are transferred through the central main air lock. After opening of the outer shielding door and seal door, the carrier is brought into the air lock by means of a heavy-duty dolly, which operates in the charging area on a removable section of track, which can be attached to the fixed track in the air lock when the outer seal door of the air lock is opened. With the outer doors closed, the inner seal door may be opened and the cart moved into the cell where the sample is removed from the carrier. Then, with the sample shielded from the doorway, the carrier may be removed through the air lock by reversing the steps. Electrical interlocks prevent the simultaneous opening of both seal doors. When the inner seal door is open, the external shield doors are locked preventing access even to the outer seal door. Since very few items to be examined in the HRLEL are of this size, the use of this air lock will be infrequent.

Discharging of radioactive materials from the cell has been described in Section 3.8. It involves essentially a reversal of the

operations of charging but includes additional precautionary measures. All waste and experiment residues will be sealed in cans, the activity will be monitored by an in-cell ion chamber, and the exterior of the can will be decontaminated before the material is discharged. Items too large to fit through the transfer stations will be placed in suitable sealed containers or bags and, before removal their activity will be carefully monitored in the large air lock to determine the shielding required.

4.4.2 Equipment Storage and Decontamination

In-cell examination and handling equipment to be stored or repaired is lifted through hatches in the roofs of cells 4, 5, and 9 to the second floor of the shielded complex after wiping to remove gross contamination. Pieces requiring storage for later use are given little additional cleaning before storage in the Hot Equipment Storage Cell. Pieces requiring repair are treated in the decontamination cell by steam cleaning and by washing with detergents, using ultrasonic equipment or manipulators to provide the necessary scrubbing action.

Since equipment becomes radioactive principally by surface contamination with radioactive solids, it is expected that these treatments will reduce the activity to a level permitting maintenance without shielding. Minor disassembly, when required to assure decontamination, will be done with the master-slave manipulators in the decontamination area.

4.4.3 Equipment Maintenance

Decontaminated equipment in need of repair is brought through the shield-and-seal door at the east end of the decontamination cell into the glove-maintenance area. In this sealed but relatively unshielded part of the cell complex, repairs can be made by handling ordinary tools through several available glove ports. If the equipment cannot be repaired in the glove-box area, it is bagged and sent to the Laboratory Decontamination Group for further decontamination or to the burial grounds. Special glove boxes are provided for maintenance of the bridge crane in the second-floor cell areas.

Much of the in-cell equipment is designed for maintenance without transfer to the second floor. For example, high maintenance items such as small electrical motors are so arranged that replacement units can be installed by the manipulators. Similar arrangements are provided on other components.

Equipment appended to the cells is also designed with maintenance in mind. Minor maintenance of the microhardness tester can be accomplished by removing one of two viewing windows and converting the opening to a glove port. Major maintenance requires the removal of an end-shield plate within a large plastic bag. The specimen transfer train is maintained by removal into the cell where it is repaired by established procedures.

Although both metallographs have been designed for a minimum of upkeep, adequate provisions have been made for maintenance. Because the unit is external to the operating cell, the background level of radiation is very low in the absence of a mounted specimen. Minor changes, such as replacing objective lenses, can be accomplished by converting the viewing window in the cover to a glove port. More extensive maintenance requires removal of the entire cover. In each instance, plastic bags would be used to prevent the spread of any particulate matter. The specimen transfer mechanism can be maintained by withdrawing the entire mechanism into the cell for repair or replacement.

Currently, procedures are being developed by the manipulator maintenance group of the Plant and Equipment Division for glove-box maintenance of the remote end of the Model A master-slave manipulators. Available booting is expected to keep the contamination of these units to a minimum.

4.5 Personnel and Building Monitoring and Control

The building configuration, air flow patterns, and personnel and equipment traffic patterns are such that the interior of the facility may be divided into areas having different contamination probabilities. Gasketed doors between the various rooms within an area and between areas provide still further confinement to prevent the spread of any accidental contamination. Health-physics instrumentation and change rooms are

strategically located to permit personnel to monitor themselves and equipment locally and thus control the spread of contamination.

Monitoring and control procedures similar to those used for several years in Buildings 4501 and 3025 are used in the HRLEL. Only authorized personnel are permitted in areas of the facility other than the office area. The entrance to the operating area from the change room, the only unlocked portal to the operating areas, is posted. Facility personnel are required to wear pocket meters and dosimeters as deemed necessary by the operating supervisor. Similar requirements will be imposed on all experimenters, craftsmen, and other routine visitors. Nonroutine visitor requirements will be established by the supervisor at the time of the visit. For some operations, such as charging and discharging, the involved personnel will also wear PRM's to provide additional audible protection. Unusual operations will be conducted under Health Physics surveillance. The pocket meter readings will be recorded daily and a running record of each individual's exposure will be maintained.

Routine contamination control will include daily smear tests of the charging area, the glove-maintenance room, and designated locations in the operating areas and change rooms. Results of these tests will be recorded and filed after any required action has been taken. For initial operations the control procedures will be divided into three classes as shown in Table 4.2.

More detailed procedures may be developed for specific areas, such as the charging area and glove-maintenance air lock, with operating experience.

Each member of the operating personnel will be primarily responsible for protecting his person from contamination. The office area will not be zoned, and all of the rest of the building outside of the cells will be classified as a Regulated zone as defined in Procedure 14 of the ORNL Health Physics Manual. The charging area, although a Regulated zone, will have a supervisory requirement for contamination coveralls or laboratory coats that must be probed before the person leaves the area. Shoe covers and gloves are required during all charging and discharging operations.

Table 4.2 Control Procedures for Initial Operations

Class	Smear Results (β-γ)	Action Required
1	All less than 500 disintegrations/min (50 counts/min)	None
2	If all smears are less than 1000 disintegrations/min (100 counts/min) but some are greater than 500 disintegrations/min (50 counts/min)	Continue work in areas but clean all areas greater than 500 disintegrations/min (50 counts/min)
3	If some smears are greater than 1000 disintegrations/min (100 counts/min)	Mark off contaminated area and discontinue work in these areas until they have been cleaned to Class 2 tolerance. Notify operations supervisor

Note: At least one smear from each area is to be checked for alpha contamination. If any of these counts are more than 30 disintegrations/min (10 counts/min), all other smears for that area are to be counted immediately and Class 3 action is required. In general, alpha contamination should be associated with β-γ in such a way that the control for β-γ should prevail.

Since the office area will not be zoned and contamination clothing cannot be worn in such an area, all personnel will remove such clothing in the change room. Before leaving the change room, all operating personnel and visitors must monitor themselves on the hand-and-foot counter located beside the exit door.

All shipments of radioactive material to and from the facility are required to pass a Health Physics surveillance before they are accepted or released.

All personnel will be required to attend the radiation safety training sessions and will be required to read and understand the Building Operating Procedures which are being written to detail the above procedures. These will be modified and updated as required. A copy of the current procedures will always be available in the operating supervisor's office. These practices and procedures are all reviewed by the local health physicist for compliance with the ORNL Health Physics Manual requirements. They further define the specific practices required in the HRLEL to protect personnel, equipment, and experimental data. Failure to comply with these procedures will not be tolerated.

5. HAZARDS

Hazards in the HRLEL are caused by penetrating radiation and by the possibility of contamination, criticality excursions, fires, and explosions. These hazards and the effects of possible accidents are circumvented to a large degree by the unusually tight, strong, and well-contained cell bank. Gamma radiation penetrating the 3-ft-thick barytes concrete cell wall and lead-glass windows is within acceptable limits for fuel specimens that have not undergone more than 100 to 1000 Mwd of fission exposure and have been cooled 3 to 6 months. Contamination problems have been eliminated to a large extent by providing for completely remote operation and maintenance of the cell bank. Criticality accidents are potentially serious, since the cell windows do not provide a high degree of neutron attenuation. Fires are potentially dangerous, since they may generate radioactive particles that are not easily filterable and since they tend to develop positive pressure within the cell. Fires could be initiated by mechanical friction, by electrical or radioactive heat sources, or by electrical or mechanical sparks. They could be sustained by oil, solvents, pyrophoric metals, or carbon fuels. Chemical explosions could occur because of possible reactions involving radiolytic gas, organic vapors, or sodium. Explosions might disperse radioactive aerosols and would tend to create positive pressure within the cell.

5.1 Hazardous Materials

Since the HRLEL is to be a service facility, there are at present no firm commitments as to the types of fuel elements or specimens to be examined in the cells. For this reason, a variety of fuels that appear to fit within the scope of the facility and appear to offer the worst conditions for various specific hazards were selected as being representative of the maximum inventory of radioactive material. These current concepts of the maximum quantities of various types of radioactive material and other hazardous materials to be handled within the facility are tabulated in Table 5.1.

Table 5.1. Maximum Quantities of Radioactive and Hazardous Materials in the Primary Containment Zone of the HRLEL[a]

Fuel Element or Other Source	Hazardous Material	Cell Bank A Cells 1–4	Cell Bank B Cells 5–8 or Cell Bank C Cells 9–13
Fully enriched plate type (HFIR)	Fissionable material	<350 g	10 kg U^{235}, 2 kg Pu^{239}, 2 kg U^{233}
	Total mixed fission products decayed 150 days	$<10^5$ curies	6.5×10^5 curies
	Rare gases decayed 150 days		425 curies Kr^{85}
	I^{131} decayed 150 days		3.5 curies
	Total short-lived fission products		From 10^{19} fissions
Metal–Na or NaK bond element (PRDC core 33 in. long)	Fissionable material (U-Mo alloy)	<350 g	5 kg U^{235}, 80 g Pu^{239},
	Fertile material (U-Mo alloy)	<10 kg	15 kg U^{238}
	Total mixed fission products decayed 120 days	$<10^5$ curies	1.7×10^5 curies
	Rare-gas fission products decayed 120 days	<100 curies	100 curies
	Na or NaK	<1 g	340 g
Carbon fuels (PBRE and others)	Fissionable materials	<350 g	300 g U^{235}
	Fertile materials	<10 kg	200 g Th^{232}
	Total mixed fission products decayed 120 days	$<10^5$ curies	10^5 curies
	Rare-gas fission products decayed 120 days	<30 curies	30 curies
	Carbon	<10 kg	10 kg
Oxide core clad with stainless steel, zirconium, or aluminum (EGCR)	Fissionable material	<200 g	200 g U^{235}
	Fertile material	<8.5 kg	8.5 kg U^{238}
	Total mixed fission products decayed 120 days	$<10^5$ curies	10^5 curies
	Rare-gas fission products decayed 120 days	<37 curies	37 curies
Transuranium targets (after 6-month irradiation	Pu	<10 g	<10 g
	Cm	1 g	1 g
	Cf	350 μg	350 μg
	Mixed fission products decayed 30 days	2000 curies	2000 curies
	Spontaneous fission and α-n neutrons/sec	3.5×10^9	3.5×10^9
Other hazardous materials	Radiolytic hydrogen		3×10^4 cfm
	Hydrogen gas–electrolytic, chemical, plating bath	$<3 \times 10^{-4}$ cfm	
	Organic solvents	1 kg alcohol	
	Hydraulic fluid	5 gal	25 gal
	Cutting oil		25 gal

[a]The equipment storage area and the remote decontamination area will contain less than 350 g each of fissionable material and less than 10^3 curies each of mixed fission products. The crane maintenance glove boxes and the equipment maintenance glove box will contain less than 1 g each of fissionable material and less than 1 curie each of mixed fission products. The second-floor supporting cells will contain no other hazardous materials.

An entire HFIR core was chosen as a plate-type fuel element that would contain the maximum inventory of fissile material and fission products. Possibly the worst accident that could happen with this type of fuel would be a criticality accident, which would liberate radioactive rare gases and halogens.

A PRDC fuel element was chosen as representative of a metal fuel element with a sodium or NaK bond. It is also believed that this fuel element contains representative concentrations of fission products and plutonium, typical of those that might be found in metal-fuel fines resulting from machining operations within the cell. Perhaps the worst accident with a fuel element of the PRDC type would be a sodium fire or explosion that consumes about one-half of the sodium and releases to the cell as smoke about 1% of the fission products and fuel, which might be present as fines.

An EGCR element is taken to be typical of an oxide core clad in metal tubing. Perhaps the worst accident is a criticality accident, as with the plate type. Another hazard with this type of fuel would be the dusting of ceramic fuel material during machining operations. However, this type of hazard is controlled very well in the HRLEL. During machining of this type of fuel, a local exhaust connected to the in-cell hood system will be utilized.

A graphite-base fuel element, perhaps indicative of a future generation of fuels for power reactors, that might sustain total combustion with the consequent release of all of its fission products and most of its fuel was considered. For this purpose a simulated element, based on the PBRE concept of pyrolytic-graphite-coated carbide fuels in a carbon matrix with high fuel content and burnup, was chosen. A single intact conformation rather than the individual 1 1/2-in.-diam balls of the PBRE was assumed.

Another type of source that might be handled is a transuranium target that has been irradiated for only a relatively short time in the HFIR. It would contain transuranium elements as an actinide oxide-aluminum cermet clad with aluminum, and it would emit neutrons from spontaneous fission and alpha-neutron reactions. The inventory of this type of material is limited by neutron penetration through the cell windows.

Potentially critical quantities of fissile materials in the HRLEL will be handled only in cells 5–13. Cells 1–4 will be devoted primarily to remote examination of small pieces of fuel elements and fuel specimens. The lightly shielded cells on the second floor will be primarily devoted to storage, decontamination, and maintenance of contaminated equipment.

Hydrogen gas will constitute perhaps the worst case of a potentially explosive chemical to be handled in the facility. Radiolytic hydrogen will not be generated at a rate in excess of approximately 3×10^4 cfm, a rate that might result from a HFIR core being immersed in water. Hydrogen will also be generated, but at lower rates, from etching and plating operations in small chemical hoods in cells 1–4. The nickel-plating bath will be operated with a very low current and consequent low hydrogen-production rate to prevent excessive bubble formation and porous coatings. A further reduction in porosity results from the continuous purging of the bath with nitrogen to carry the hydrogen bubbles away. This purging will further dilute the already small quantities of hydrogen released to well below the explosive concentration. The plating bath will be separately exhausted to the in-cell hood system. Periodic electrolytic polishing and etching are done in a closed-loop apparatus with even lower hydrogen evolution rates than those encountered in the plating bath. All chemical etching will be done in a separate in-cell hood continuously purged through the in-cell hood exhaust system with sufficient air to maintain a nonflammable atmosphere. Little danger is seen to accompany these etching and plating operations, since they will involve only small solid pieces of irradiated material, so that even an explosion would disperse very little, if any, radioactive material to the cell.

Some other chemical materials in the cells will constitute, primarily, a fire hazard. These are organic solvents and hydraulic and cutting oils. Organic solvents for cleaning will be handled in small quantities, principally in cells 1–4. One kilogram of alcohol is indicative of the maximum quantity of solvents from this source. A buried holdup tank of 200 gal of water-soluble cutter-coolant oil for the big milling machine is located outside the building. It is anticipated that no more than 25 gal

of oil from this source could accumulate in cells 5–13. From the various hydraulic systems, no more than 25 gal of hydraulic oil could spill into cells 5–13 and no more than 5 gal into cells 1–4.

5.2 Penetrating Radiation

During normal operation the HRLEL operating philosophy and shielding do not permit the penetrating radiation dose rate in normally occupied areas, the operating and charging areas, to exceed 0.75 mrem/hr. Hot spots of limited area, such as those opposite certain cell-wall penetrations, will be restricted to no greater than 7.5 mrem/hr. On very infrequent occasions, when it is necessary to examine large pieces of highly irradiated fuels, such as an entire HFIR core, the basic penetrating radiation dose rate in normally occupied areas will not exceed 7.5 mrem/hr. Careful control of personnel exposure will be maintained during all operations; operators will be made cognizant of unusual hazards and unit shielding will be used when it is appropriate.

The 3 ft of barytes concrete and lead-glass windows of equivalent density thickness normally will accommodate several hundred thousand curies of mixed fission products within the shielding criteria. The activity and heat production rate of fission products as a function of irradiation and decay time, as calculated by the ORNL PHOEBE code, are presented in Table 5.2 and Figs. 5.1 and 5.2. The gamma-energy groups from these same PHOEBE calculations were used in the SDC code to determine the weight of a point source of fission products required to cause a radiation dose rate of 1 mr/hr at the outside surface of the HRLEL 3-ft-thick barytes cell wall; these results are shown in Fig. 5.3.

Table 5.3 presents the results of other PHOEBE and SDC calculations that were made to determine the dose rate to be expected at the outside surface of the cell wall when the most radioactive fuel element anticipated, an entire HFIR core, is handled inside the shield. It is apparent from Table 5.3 that, if the HFIR core is allowed to decay at least five months before it is examined in the HRLEL, the dose rate will be within the established criteria. After this cooling period, the natural circulation of air inside the cell will maintain the element below the temperatures that were encountered in the reactor.

Table 5.2. Gamma Photon Release Rates per Gram of Fission Products for Various Irradiation and Decay Times

Irradiation Time, days	Gamma Energy Group	Average Group Energy, Mev	Photon Release Rate[a] for Given Decay Time, days				
			10	30	100	150	400
10	1	0.300	7.60×10^{13}	2.75×10^{13}	5.56×10^{12}	2.93×10^{12}	5.68×10^{11}
	2	0.630	1.07×10^{14}	3.88×10^{13}	1.22×10^{13}	7.30×10^{12}	9.20×10^{11}
	3	1.100	1.99×10^{13}	1.08×10^{13}	4.17×10^{12}	2.56×10^{12}	3.02×10^{11}
	4	1.550	4.98×10^{13}	1.65×10^{13}	4.63×10^{11}	1.32×10^{11}	2.13×10^{10}
	5	1.990	1.06×10^{12}	2.88×10^{11}	3.16×10^{10}	1.32×10^{10}	2.50×10^{9}
	6	2.380	3.22×10^{12}	9.68×10^{11}	6.66×10^{10}	2.68×10^{10}	4.99×10^{9}
	7	2.750	4.26×10^{11}	1.41×10^{11}	6.97×10^{9}	3.13×10^{9}	1.18×10^{9}
	8	3.250	3.24×10^{10}	2.08×10^{10}	3.55×10^{9}	1.25×10^{9}	6.63×10^{7}
	9	3.700	2.29×10^{10}	1.30×10^{10}	1.85×10^{9}	6.31×10^{8}	1.58×10^{7}
100	1	0.300	2.20×10^{13}	1.12×10^{13}	3.36×10^{12}	1.99×10^{12}	4.76×10^{11}
	2	0.630	3.36×10^{13}	1.93×10^{13}	8.06×10^{12}	4.99×10^{12}	7.18×10^{11}
	3	1.100	8.74×10^{12}	6.10×10^{12}	2.81×10^{12}	1.80×10^{12}	2.07×10^{11}
	4	1.550	1.17×10^{13}	3.83×10^{12}	1.89×10^{11}	7.72×10^{10}	1.88×10^{10}
	5	1.990	2.42×10^{11}	9.16×10^{10}	1.64×10^{10}	8.37×10^{9}	2.19×10^{9}
	6	2.380	7.56×10^{11}	2.61×10^{11}	3.36×10^{10}	1.70×10^{10}	4.36×10^{9}
	7	2.750	1.01×10^{11}	3.48×10^{10}	3.80×10^{9}	2.28×10^{9}	1.07×10^{9}
	8	3.250	1.39×10^{10}	8.49×10^{9}	1.67×10^{9}	6.82×10^{8}	4.80×10^{7}
	9	3.700	8.62×10^{9}	4.82×10^{8}	8.47×10^{8}	3.13×10^{8}	9.33×10^{6}
1000	1	0.300	2.84×10^{12}	1.68×10^{12}	7.11×10^{11}	5.01×10^{11}	1.93×10^{11}
	2	0.630	4.70×10^{12}	3.06×10^{12}	1.47×10^{12}	9.79×10^{11}	2.40×10^{11}
	3	1.100	1.33×10^{12}	9.92×10^{11}	4.97×10^{11}	3.25×10^{11}	5.06×10^{10}
	4	1.550	1.20×10^{12}	4.06×10^{11}	3.41×10^{10}	2.05×10^{10}	9.68×10^{9}
	5	1.990	2.73×10^{10}	1.18×10^{10}	3.50×10^{9}	2.42×10^{9}	1.25×10^{9}
	6	2.380	8.19×10^{10}	3.14×10^{10}	7.09×10^{9}	4.88×10^{9}	2.52×10^{9}
	7	2.750	1.11×10^{10}	4.41×10^{9}	1.13×10^{9}	8.97×10^{8}	5.06×10^{8}
	8	3.250	1.57×10^{9}	9.83×10^{8}	2.22×10^{8}	1.01×10^{8}	9.97×10^{6}
	9	3.700	9.46×10^{8}	5.40×10^{8}	1.03×10^{8}	4.04×10^{7}	1.35×10^{6}

[a]Each entry is the gamma photon release rate in the given energy group per gram of fission products (photons/sec·g) as calculated using the IBM 7090 Phoebe code.

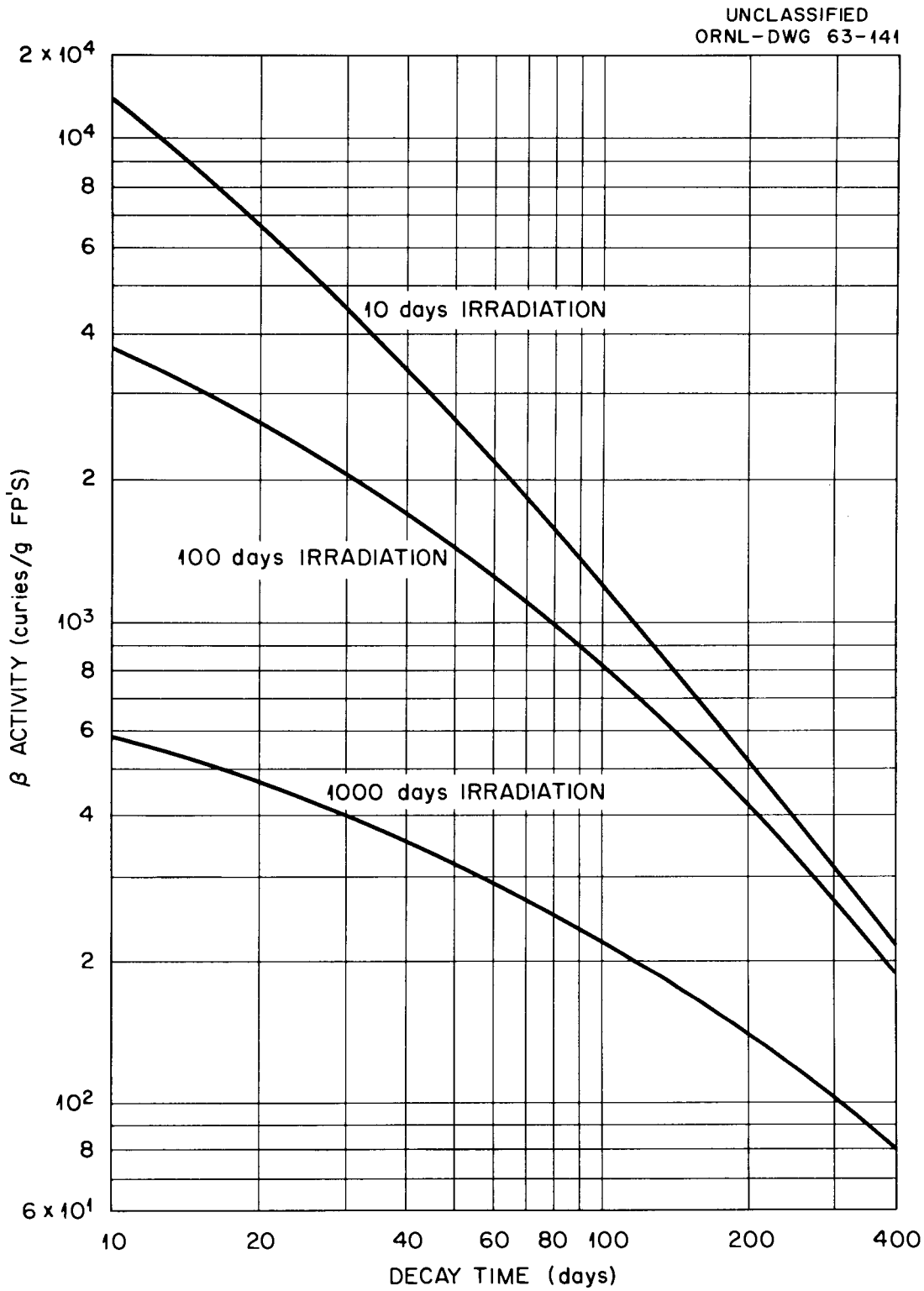

Fig. 5.1. Fission Product Beta Activity as a Function of Irradiation and Decay Time.

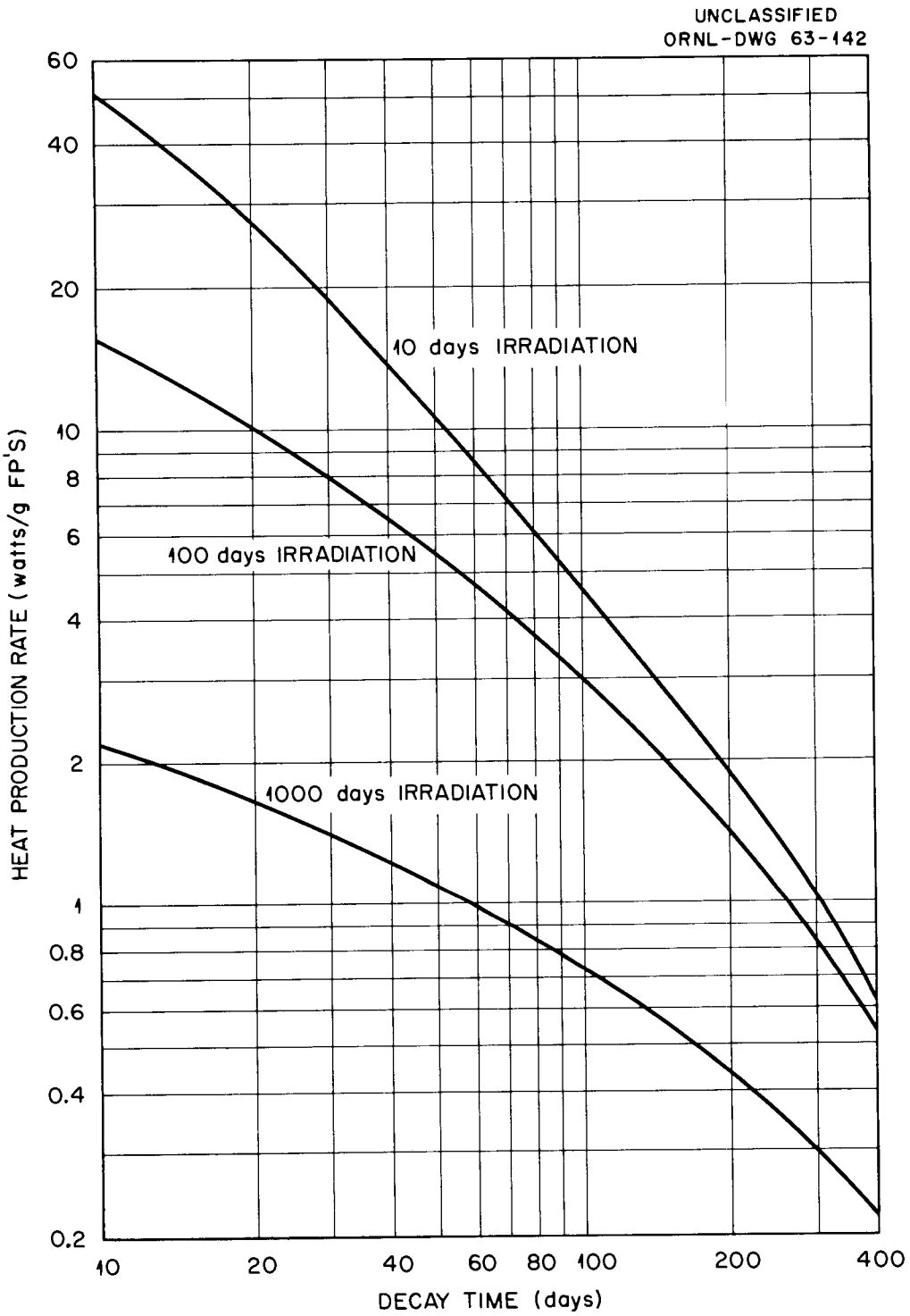

Fig. 5.2. Fission Product Heat Production Rate as a Function of Irradiation and Decay Time.

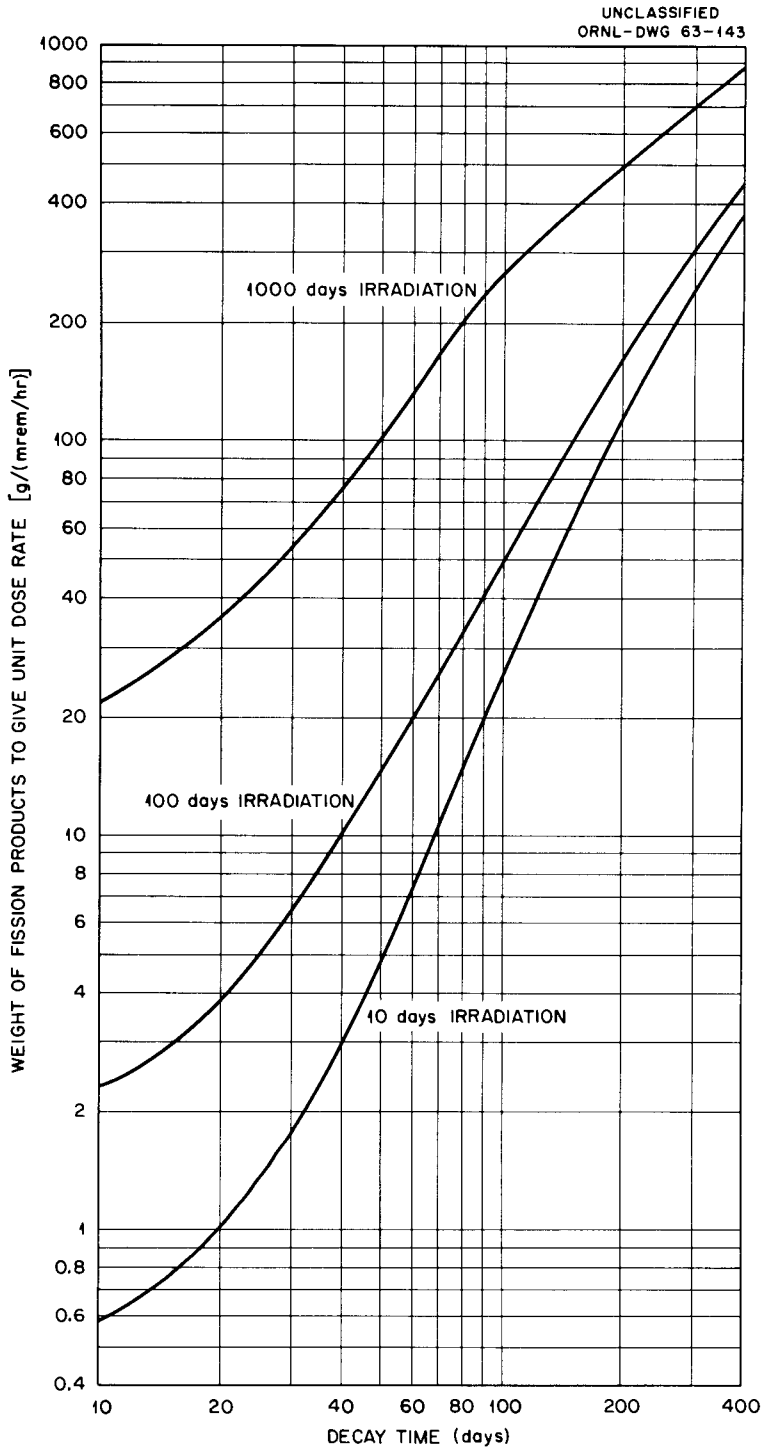

Fig. 5.3. The Effect of Irradiation and Decay Time on the Mass of a Point Source of Fission Products, Located 3 ft Inside an Operating Cell, Required to Cause a Dose Rate of 1 mrem/hr at the Outside Surface of the Cell Wall.

Table 5.3 Heat Dissipation and Radioactivity of a HFIR Core

Decay time, months	3	4	5	6
Heat dissipation rate, w	5400	3800	2900	2300
Fission-product beta activity, 10^6 curies	1.4	1.0	0.80	0.64
Dose rate,[a] mr/hr	19.5	9.8	5.9	4.0

[a]At outside surface of the 3-ft-thick shield.

The HRLEL cell wall and window do not provide a high degree of neutron attenuation. Fission-neutron attenuation kernels for 3.3 density glass and barytes concrete, as calculated by the Renupak Code, are given in Fig. 5.4. The fission-neutron attenuation factor for the HRLEL window, which consists of 32 in. of 3.3 density glass and 4 in. of oil, is $3 \times 10^{-3} \frac{\text{mrem cm}^2 \text{ sec}}{\text{hr}\cdot\text{neutron}}$. The fission-neutron attenuation factor for the 3-ft-thick barytes cell wall is $1.3 \times 10^{-4} \frac{\text{mrem cm}^2 \text{ sec}}{\text{hr}\cdot\text{neutron}}$.

The most intense neutron source that might be examined within the cell would be a 6-month-irradiated TRU-HFIR target containing 350 μg Cf^{252} and emitting 3.5×10^9 neutrons/sec. Such a source, if located 3 ft from the inside cell wall, would cause a dose rate of 25 mrem/hr and 1 mrem/hr at the outside surface of the window and wall, respectively. A unit shield of 8 in. of water between the target and the window would reduce the dose rate at the outside surface of the window to 2.5 mrem/hr.

5.3 Criticality

The probability of a criticality accident in the HRLEL will be maintained at an acceptably low level by strict administrative control, primarily batch-size limitation. Solid moderated excursions, which could generate 10^{19} to 10^{20} fissions as a single burst, will be made inconceivable since the cell shielding is not sufficient to prevent lethal doses of prompt neutron radiation to operating personnel in the event of such a burst. Criticality accidents that involve a liquid moderator (water or oil), and as a consequence are limited to 10^{17} to 10^{18} fissions/burst, cannot be considered inconceivable because of some

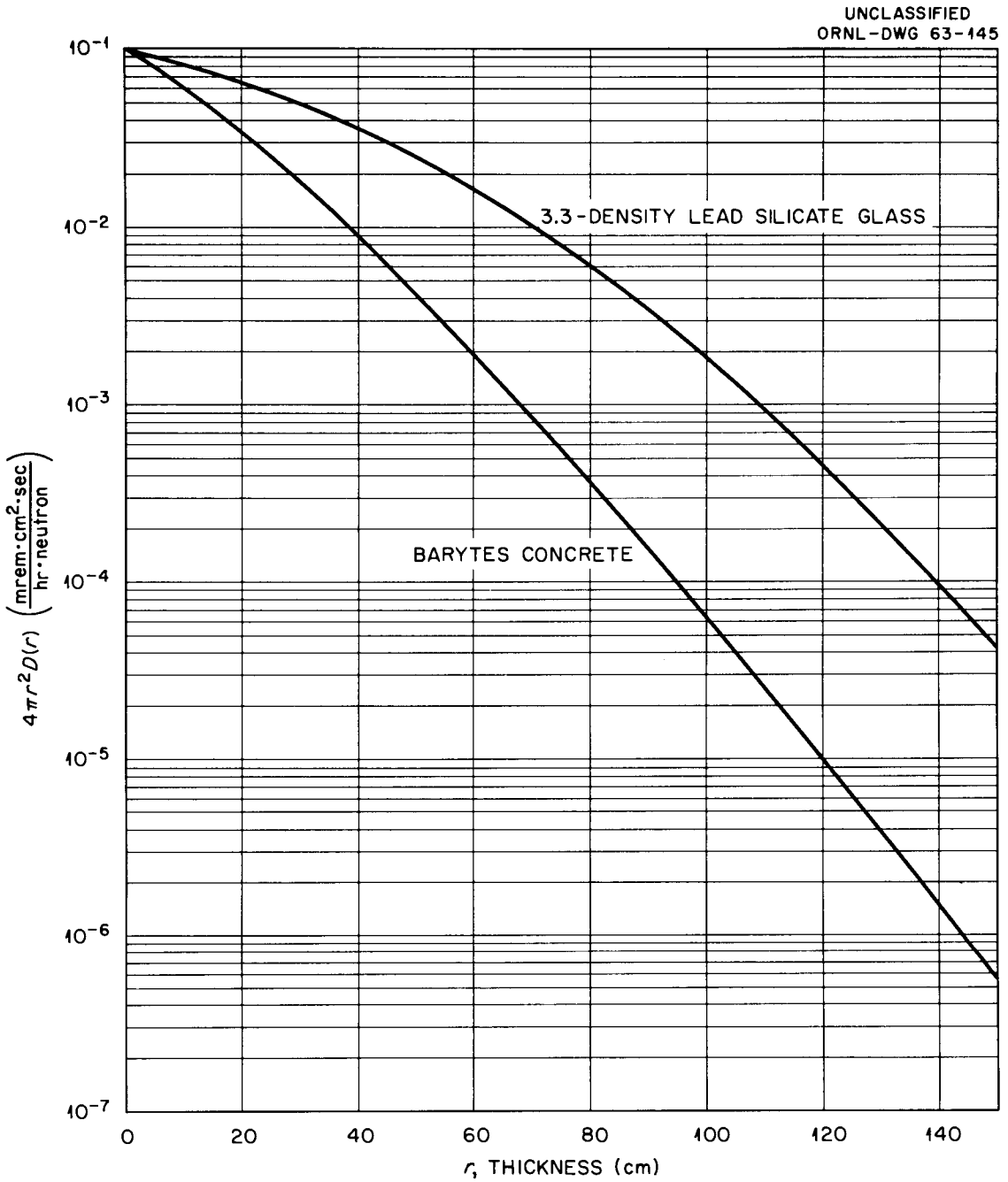

Fig. 5.4. Neutron Dose Rate from a Point Isotropic Fission Source as a Function of Penetration in 3.3-Density Glass and Barytes Concrete.

of the elements to be examined. Exposures from such a burst would not constitute lethal doses for operating personnel.

5.3.1 Types of Controls

Batch-size control is particularly suitable since, in general, it will be necessary to have only one or two entire fuel elements at a time in the cells. This, in itself, does not provide for complete safety, however, since some single elements contain more than a minimum critical mass and can be made critical by altering the spacing and the degree and type of moderation and reflection by credible mechanical operations within the cells.

It will always be possible to limit the quantity of fissile material or solid moderators and reflectors in the cells at any time so that a solid supercritical assembly is inconceivable. The mass of fissile material in any one bank of cells at any one time will be limited to 10 kg U^{235}, 2 kg Pu^{239}, or 2 kg U^{233}. Carbon and beryllium are the only solid moderators to be examined in the HRLEL cells that could cause solid critical assemblies with these limiting masses of fissile material. To guard against this contingency, the mass of carbon and beryllium in the cells will be restricted commensurate with the quantity of fissile material in the cells. When the quantity of fissile material in the cells is greater than 350 g but less than 10 kg U^{235}, 2 kg Pu^{239}, or 2 kg U^{233}, the mass of solid carbon will be maintained below 500 kg and the mass of beryllium (as metal or BeO) will be maintained below 35 kg. There will be no limit on the carbon or beryllium in the cells when the fissile material content is less than 350 g.

Fuel elements to be analyzed in the cells will be stored temporarily in their casks or in interim storage wells in the charging area. Each modification of an existing operation and each new operation with a different fuel element will be analyzed for criticality, a written summary of the analysis will be submitted to the Criticality Review Committee, and the operation will be approved by the Criticality Review Committee before the fuel element is brought into the building. Each analysis will consider nuclear interaction in transportation and storage and will contain sufficiently detailed procedures to assure the batch size and degree and

type of moderation and reflection. Once these procedures are approved by the Committee they will be transferred to written, detailed, operating procedures that are to be strictly adhered to, in a step-by-step manner, by operating personnel.

The interim storage wells in the charging area are 6 or 8 in. in diameter and 48 in. deep. They are shielded with individual cast-iron plugs and are separated one from another, edge-to-edge, by at least 12 in. of barytes concrete. Even though there is a fire-sprinkler system in the charging area, it is very unlikely that the wells could become flooded since the plugs are sealed with compressible gaskets and each well has a 1-in. drain line at the bottom. In general, a well will allow critically safe storage of essentially any single, intact fuel element. In those cases in which the storage of a single fuel element is not obviously safe or where storage of multiple fuel units is desired, storage will be as per the limits recommended in the Nuclear Safety Guide[1] or these limits as modified by the Criticality Review Committee.

5.3.2 Effects of a Criticality Accident

A criticality accident in an HRLEL cell would expose building operating personnel to prompt neutron and gamma radiation. Also, an aerosol of the radioactive material might be formed in the cell and some fraction would escape the building through the ventilation systems or through successive leaks from the cell and building.

The severity of a nuclear excursion depends on the type of critical assembly, the rapidity with which it is assembled, and the amount of excess reactivity that is available. Experience and calculations[2,3] indicate that the most powerful burst in a water- or oil-moderated assembly would be limited by gas generation and thermal expansion to approximately 10^{12} fissions/cm^3 or 10^{17} to 10^{18} total fissions in assemblies that could

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[1]A. D. Callihan *et al.*, *Nuclear Safety Guide*, TID-7016, Rev. 1 (1961).

[2]E. D. Arnold, A. T. Gresky, and J. P. Nichols, "The Evaluation of Radioactive Releases from Chemical Plants," *Seventh AEC Air Cleaning Conference Held at Brookhaven National Laboratory October 10–12, 1962*, TID-7627 (March 1962), pp 222–39; also issued as ORNL-TM-19 (Oct. 1961).

[3]H. T. Williams *et al.*, *Safety Analysis of Enriched Uranium Processing*, NYO-2980 (March 1960).

credibly occur in the HRLEL. If the supercritical assembly is not disarmed in the initial burst by rearrangement of fuel or ejection of moderator, the reaction might recur over a period of several minutes to several hours until the moderator is evaporated. It appears inconceivable that more than 10^{19} total fissions could occur, since this would liberate enough heat to evaporate approximately 30 gal of water or approximately 200 gal of oil. This is considered as a maximum credible case, since oil from the 200-gal coolant tank might be pumped into the cell to the limit and water containers with capacities greater than 30 gal are not required.

Prompt Neutron and Gamma Exposure. The prompt neutron and gamma dose from a nuclear excursion of 10^{18} fissions is calculated to be 250 rem at the operating surface of the window and 10 rem at the operating surface of the barytes concrete cell wall. This calculation assumes that the supercritical assembly is located 3 ft inside the cell and has sufficient liquid moderator in and around it that the fission energy neutrons are attenuated in the assembly by a factor of 20. These appear to be conservative assumptions. No account has been taken for the lower value of the relative biological effectiveness (RBE) that is characteristic of a single exposure to fast neutrons.

The prompt dose will increase in direct proportion to the number of fissions that occur and will decrease as the inverse square of the distance from the assembly. These effects are illustrated in Table 5.4. It is seen that personnel located within 13 ft of the cell window might be exposed to greater than 25 rem, the maximum acceptable emergency dose, before they could reasonably be expected to evacuate in response to the alarm (i.e., before 10^{18} fissions occur). In the event of no evacuation and a reaction that recurs until 10^{19} fissions occur, lethal exposures could be inflicted out to 8 ft from the cell window and maximum acceptable emergency doses out to 54 ft from the cell window.

Dispersive Effects. The explosive effects of a credible criticality accident are similar to those of the credible chemical explosions and will be discussed in greater detail in Section 5.5. In the initial and most powerful burst, taken to be 10^{18} fissions, the cell air pressure could rise very rapidly to 5.8 in. H_2O gage above atmospheric, assuming that

Table 5.4 Prompt Neutron and Gamma Dose Rate Through the HRLEL Cell Shielding Window from a Criticality Accident

Distance from Supercritical Assembly (ft)	Distance from Operating Face of Window (ft)	Dose	
		10^{18} Fissions	10^{19} Fissions
6	0	250	2500
14	8	45	450
19	13	25	250
45	39	4.5	45
60	54	2.5	25

the cell is initially operating at −2 in. H_2O gage. The blast effects of the excursion would not be sufficient to break the cell wall or window. Duration of positive pressure in the cell would be 0.7 sec. During this time, 0.5 ft^3 of cell air could escape through cracks in the cell wall to the secondary containment shell, assuming that the rate of air inleakage is 30 cfm while the cells are operating at −0.2 in. H_2O gage differential pressure. While this inleakage rate is very low, corresponding to 0.002 cell volumes per minute at 2 in. H_2O gage differential pressure, it is still believed to be very conservative in light of recent qualitative experimental measurements in the facility.

In a criticality accident considered as credible in the HRLEL, involving solid fuel pieces and a liquid moderator, it is expected that little, if any, of the nonvolatile fission products would be released from the fuel as an aerosol. As a worst case it is assumed that the accident liberates to the cell air all of the old and freshly formed halogen and rare-gas fission products from the components of a spent HFIR core. The methods used to evaluate the effects of such an accident are those reported by Arnold et al.[2] using the known yields and decay constants of fission-product species of Br, I, Xe, and Kr. A summary of the calculated effects of credible criticality accidents in the HRLEL is given in Table 5.5.

Table 5.5 Effects of Credible Criticality Accidents in the HRLEL

Type of Criticality Accident	Most Probable	Maximum Credible
Fissions per initial maximum burst	10^{17} to 10^{18}	10^{17} to 10^{18}
Total number of fissions	10^{18}	10^{19}
Peak cell air pressure, in. H_2O gage	5.8	7.8
Duration of positive pressure, sec	0.7	0.7
Cell air leakage to second containment zone, ft^3	0.5	0.5
Typical ingestion – exposure dose before evacuation, rem	0.05	0.05
Prompt neutron – gamma dose, rem	250	250
Dose rate 6 ft from cell exhaust filters, r/hr[a]	4	40
Maximum downwind personnel dose, rem		
Release from HRLEL stack	0.53	3.6
Release from 3039 stack	0.02	0.13
Maximum area contaminated, square mile[a]	0.08	0.8

[a]Predominantly short-lived activity.

NOTE: The maximum credible criticality accident is assumed to involve a water- or oil-moderated supercritical assembly of the components of a HFIR core, which has been allowed to decay for 150 days. The "old" as well as newly formed I, Br, Xe, and Kr are released to the atmosphere through the ventilation system. Personnel evacuate operating area shortly after the initial burst.

Dose to Building Personnel. A pseudo ingestion-exposure dose to operating personnel before evacuation of the secondary containment shell is calculated, assuming that the air that leaks from the cell contains fission products at the concentration that would result if they were distributed homogeneously through the volume of the cell and that this leaked air is instantly and uniformly dispersed in the secondary containment shell.[4] Decay of the short-lived "fresh" fission products with time is taken into consideration.

[4]Arnold, op. cit., Fig. 9.

It is assumed that all of the 0.5 ft^3 of gas that leaks from the cell during the initial, maximum burst leaks to the operating area. The pseudo personnel dose in the operating area would be 0.05 rem, assuming that 2 min is required to evacuate the area. The smallest enclosed volume in contact with the cell bank corresponds to the charging area, but it is expected that the pseudo personnel dose would not be greater than that in the operating area, because of the proportionately more rapid evacuation of the charging area.

The pseudo dose to building personnel would not be expected to increase if the nuclear reaction recurred over a relatively long period of time generating 10^{19} fissions, the maximum credible criticality accident, since the personnel would evacuate promptly after the initial burst; and there would be relatively little leakage of cell air after the initial burst. In any case the dose from ingestion of and exposure to volatile fission products is negligible.

Downwind Effects. The maximum ingestion-exposure dose for downwind personnel is calculated assuming that the volatile fission products are exhausted through the cell ventilation exhaust system with no deposition or filtration in the system but allowing for decay in the cell, in the ventilation system, and in the atmosphere.[5] The effects of release by successive leaks from the cell and from the building are entirely negligible.

The cell ventilation system will ordinarily be exhausted through the 3039 stack under emergency conditions (Section 3.4), but the dose from release through the HRLEL stack is calculated, since exhaust is automatically reverted to this stack on rare occasions when the 3039 duct is being used to capacity by other facilities. The maximum personnel doses from release through the 3039 stack, predominantly due to the fresh fission products rather than to the "old" volatile fission products, are 0.02 rem from 10^{18} fissions and 0.13 rem from 10^{19} fissions. The maximum personnel doses from release through the HRLEL stack are 0.53 and 3.6 rem for 10^{18} and 10^{19} fissions, respectively.

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[5] Ibid., Fig. 7.

The maximum area of deposition within a given deposition isopleth occurs for a rainout condition and is independent of the height of release. It is assumed for these calculations as in those of Guthrie and Nichols[6] that the area requiring minor decontamination from the short-lived volatile fission products (which control the deposition hazard) from a criticality accident would be that area containing greater than 6.5×10^{-7} curies/m^2 of I^{131}. The volatile fission products from the most probable type of criticality accident, 10^{18} fissions, would contaminate no more than 0.08 square mile above the allowable contamination level. This area would be contained inside a cigar-shaped isopleth extending downwind from the stack. The volatile fission products from 10^{19} fissions could contaminate 0.8 square mile. It should be emphasized that the hazardous levels of activity will persist for at most a few weeks over most of the contaminated area.

Damage to Facility. Credible criticality accidents in the HRLEL could deposit volatile fission products in the cell and cell ventilation system. Perhaps the most serious hazard from this source would be the isotopes of iodine and bromine, which might be deposited on the cell ventilation filters located in the basement. Shortly after an accident of 10^{19} fissions, the gamma dose rate 6 ft from these filters could be as high as 40 r/hr.

5.4 Fires

Fires within the HRLEL cell bank may be extremely hazardous, since they could conceivably raise the cell pressure and temperature and disperse radioactive material as smoke. Fires in the remainder of the building are not considered as a significant hazard, since the remainder of the building is protected by a water-sprinkler system and will contain relatively little dispersible radioactive material.

At the inception of design it was decided that no single type of safeguard or method of extinguishment could be effective for all the possible types of fires that might be encountered within the HRLEL cell

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[6]C. E. Guthrie and J. P. Nichols, Theoretical Possibilities and Consequences of Major Accidents in U^{233} and Pu^{239} Fuel Fabrication and Radioisotope Processing Plants, ORNL-3441 (in press).

bank. For this reason, no automatic system for dispersal of water, CO_2, or dry powder was installed. It was decided that a better method of control would be to review each planned operation within the cell bank and to provide operating procedures and protective equipment appropriate for each operation. In the following discussion no such protective equipment has been considered, so the resulting hazards represent extreme conditions.

The effects of a fire would be to disperse radioactive material as smoke within the cell and to raise the cell pressure. If the cell pressure exceeds the building pressure, a small portion of the smoke could then leak to the secondary containment zone; also, the increase in pressure would cause a larger flow rate than normal through the cell exhaust system.

The recirculation system has a very high flow rate, primarily designed to cool the cells and to catch and trap fines from machining operations. The cell air exhaust rate is normally very low, less than 100 cfm, including deliberate purging. A maximum of approximately 2000 cfm can be exhausted from the cells without allowing the cell pressure to rise. Credible fires can generate hot air at an equivalent rate greater than 2000 cfm. The characteristics of credible fires are tabulated in Table 5.6. The credible types of fires that might be sustained until they are extinguished from lack of fuel or oxygen are a fire in a carbon fuel element, a fire from a pool of about half the sodium from a PRDC fuel element, and an oil fire on the floor of a cell.

It is assumed that a carbon fuel element would totally burn at a relatively uniform rate over a period of 10 hr and release 100% of its contained fission products to the cell air. The carbon fuel, being compressed, would be expected to burn slower than charcoal in a grill. W. E. Browning[7] has burned PBRE specimens and found such a large fraction of the fission products released that the assumption of 100% release is not unduly conservative. A total of 300,000 Btu of heat would be

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[7]W. E. Browning, Jr., et al., "Release of Fission Products by In-Pile Burning of Irradiated Fueled Graphite," Nuclear Safety Program Semiann. Prog. Rept. June 30, 1963, ORNL-3483, pp 24–26.

Table 5.6 Characteristics of Credible HRLEL Fires

Type of Fire	Total Combustion of Carbon Fuel Element	Sodium Fire Involving PRDC Element and Releasing 1% of the Fuel and Fission Products as Smoke	Oil Fire on Cell Floor Pan and Milling Machine[a] Burning 1% of PRDC Element
Quantity of fuel	10 kg carbon	170 g sodium	25 gal oil
Burning rate, Btu/sec	8.35	650	250
Total heat released, Btu	300,000	39,000	1,030,000[b]
Burning time	10 hr	60 sec	1.15 hr[b]
Maximum cell air pressure[c]	−1.7 in. H_2O gage	51.5 in. H_2O gage	38.3 in. H_2O gage
Maximum cell air temperature[d]	67°F	135°F	152°F
Maximum pressure drop[e] across cell exhaust filters	0.1	6.6	5.7
Duration of positive pressure	0 sec	230 sec	900 sec
Average positive pressure	< 0	30 in. H_2O gage	20 in. H_2O gage
Activity released from fuel			
Rare gases	30 curies	1 curie	1 curie
Mixed fission products	10^5 curies	1700 curies	1700 curies
$U^{235} + U^{238} + Th^{232}$	500 g	200 g	200 g
Pu^{239}		0.8 g	0.8 g

[a]Area = 47 ft^2.

[b]Extinguished from lack of oxygen.

[c]Cell air pressure initially −2.0 in. H_2O gage.

[d]Cell air temperature initially 63°F.

[e]Assuming filters do not plug. Initial pressure drop 0.6 in. H_2O.

released. A large fraction of this heat would probably go directly into the cell air by convection and by liberation of hot gas as it is generated rather than by conduction or radiation to the cell surfaces.

J. B. Adams[8] has studied the combustion of sodium. The temperature of a pool of sodium in moist air increases at a rate of approximately 200°F/sec. When the temperature reaches approximately 1600°F, the pool blows apart. Then the small drops burn slowly, probably because of slow diffusion of air to and from the surface. A 50 mg quantity of sodium is burned in approximately 10 sec.

It is assumed (1) that a sodium fire in the HRLEL could occur when 50% of the sodium from a PRDC type fuel element is accidentally released during a machining operation, (2) that the sodium would quickly explode into small droplets, (3) that these droplets would burn at a relatively uniform rate for a period of 1 min, and (4) that 1% of the PRDC element, which might be present as machine chips, would be burned or melted so as to release its fuel and fission products to the cell air and liberate 40,000 Btu of heat.

An oil fire might occur when 25 gal of hydraulic or coolant oil is spilled on the floor of a cell during a machining operation. Such a fire would burn at a maximum rate of approximately 20,000 Btu/hr·ft^2 or approximately 900,000 Btu/hr over the 45 ft^2 area of the floor pan. The fire would extinguish itself after about 1 hr. Approximately 10^6 Btu will have been liberated when most of the oxygen in the cell air has been consumed. It is also assumed in this case that 1% of a fuel element typical of PRDC might be present as chips and would be burned, liberating its fuel and fission products to the cell air as smoke.

5.4.1 Pressure-Temperature Transient

Calculation of the pressure-temperature transient during a fire in the HRLEL cells involves the following equations:

Cell air heat balance

$$Q_c = W_c \, C_{pc}(T_c - 510) \quad , \tag{1}$$

[8]J. B. Adams, A Survey of the Hazards Involved in Processing Liquid Metal Bonded Fuels, ORNL-3147 (July 31, 1961).

where

Q_c = Heat in cell air above a reference temperature of 510°R (temperature with cell lights off), Btu.

W_c = Mass in pounds of air in the cells. This value is 1926 lb for the 25,510 ft^3 of air that is in cells 1–13 and the interconnected equipment storage and equipment decontamination area at the start of a fire.

T_c = Cell air temperature, °R.

C_{pc} = Heat capacity of cell air, Btu/lb·°F.

Wall heat balance

$$Q_w = W_w C_{pw}(T_w - 510), \tag{2}$$

where

Q_w = Heat in stainless-steel wall liners above a reference temperature of 510°R, Btu.

W_w = Mass in pounds of steel in wall and cell equipment. This weight is conservatively taken to be 11,000 lb.

C_{pw} = Heat capacity of stainless steel, Btu/lb·°F.

T_w = Wall temperature, °R.

Cell pressure

$$P_c = 4.02 \times 10^{-4} W_c T_c - 404.8 \quad , \tag{3}$$

where

P_c = Cell pressure above −2 in. H_2O gage, in. H_2O gage.

Cell air exhaust rate

The air flow rate into and out of the HRLEL cells, calculated from design specifications, is tabulated as a function of cell pressure in Table 5.7. Recent qualitative measurements have shown that these rates are conservative in that the actual leakage rate is lower and the exhaust rate for a given cell pressure is somewhat higher. The pressure drop across the cell exhaust filters is taken as 1 in. H_2O gage at 2000 cfm.

These data may be represented by the following equations with sufficient accuracy for the fire calculations:

Table 5.7 Calculated Flow-Pressure Characteristics of HRLEL Cells

Pressure in Cells (in. H_2O gage)	Air Outleakage Rate (cfm)	Cell Exhaust System Flow Rate (cfm)	Pressure Drop Across Cell Exhaust Filters (in. H_2O gage)
−2	−30	30	0.015
−1	−21	1830	0.91
0	0	2575	1.3
1	21	3140	1.6
2	30	3630	1.8
4	42	4440	2.2
10	67	6260	3.1
20	95	8460	4.2
30	116	10,200	5.1

$$\text{Air intake rate} = 0.5 - 0.25\ P_c,\ \text{cfs} \tag{4a}$$

$$\text{Exhaust rate} = R = 0.5 + 30\ P_c^{0.5}\ ,\ \text{cfs} \tag{4b}$$

<u>Heat removal rate by the recirculation system coolers</u>

$$q_{RS} = 2.8(T_c - 510),\ \text{Btu/sec}\ . \tag{5}$$

<u>Heat transfer rate from cell air to cell walls</u>

$$q_w = 0.148(T_c - T_w)^{1.25},\ \text{Btu/sec}\ , \tag{6}$$

where the area of the walls is taken to be 1400 ft^2.

<u>Rate of change of cell air weight</u>

$$\frac{dW_c}{dt} = \rho_B\ (0.5 - 0.25\ P_c) - R\rho_c\ \frac{523}{T_c} + Kq_F\ , \tag{7}$$

Table 5.8 Summary of Effects of Credible HRLEL Fires

Type of Fire	Carbon Fuel Element	Sodium PRDC Element	Oil PRDC Element
Activity released from fuel, curies			
Rare gases	30	1	1
Mixed fission products[a]	100,000	1700	1700
Pu^{239}		0.054	0.054
Mixed fission products leaked to secondary containment zone,[b] curies	0	15	13
Mixed fission products passing to cell exhaust filter, curies	830	530	250
Mixed fission products released to stack,[c] curies	8.3	5.3	2.5
Mixed fission products deposited in cell,[d] curies	99,170	1155	1437
Pseudo 2-min dose in secondary containment zone,[e] rem	0	62	51
Dose rate 6 ft from cell exhaust filters,[f] r/hr	low[g]	25	12
Maximum downwind dose,[h] rem			
HRLEL stack, filters hold	0.54	0.35	0.16
HRLEL stack, filters fail	i	35	16
3039 stack, filters hold	0.020	0.013	0.006
3039 stack, filters fail	i	1.3	0.6
Maximum contaminated area,[j] square mile			
Filters hold	0.27	0.17	0.08
Filters fail	i	20	9.3

[a]The mixed fission products control the dose and fallout hazard.

[b]During the first 2 min of the fire.

[c]Assuming filters hold.

[d]Deposited on cell walls and air recirculation system.

[e]Typical personnel dose in operating area before evacuation.

[f]These filters are exposed and located in the basement. Activity collects on them when the in-cell filters are ruptured.

[g]In-cell exhaust filter not ruptured in this case.

[h]Maximum personnel ingestion-exposure dose downwind.

[i]It does not appear credible that filters would fail.

[j]Area requiring decontamination.

where

ρ_B = Density of intake air, lb/ft^3

$\rho_c \frac{523}{T_c}$ = Density of cell air at any temperature, lb/ft^3

q_F = Fire-burning rate, Btu/sec

K = Mass in pounds of combustion gases formed per Btu of combustible material burned

t = Time after start of fire, sec.

Rate of change of cell air heat

$$\frac{dQ_c}{dt} = q_L + q_F - q_w - q_{RS} - 9.414 \frac{R}{T_c}(T_c - 510), \tag{8}$$

where

q_L = Heat from cell lights = 36.5 Btu/sec

$9.414 \frac{R}{T_c}(T_c - 510)$ = Heat removal rate due to exhaust of cell air.

At ambient conditions before a fire, the lights contribute 36.5 Btu/sec. Of this, 36.4 Btu/sec is removed in the recirculation system coolers and 0.1 Btu/sec is removed in the exhausted air. The ambient cell air temperature is 523°R (or 63°F) under these conditions.

These equations were solved simultaneously as a function of fire heat rate, q_F, by numerical integration. The cell pressure and temperature transients as a function of heat generation rate are plotted in Fig. 5.5. When addition of heat is begun, the pressure in the cell increases to a maximum value and then decreases to the initial value, −2 in. H_2O gage, when a new equilibrium air temperature is achieved. At the new level of equilibrium air temperature, heat is removed from the cell air at the same rate as that at which it is being generated. The curve for 686.5 Btu/sec, which is representative of the sodium fire plus the cell lights, was not carried to equilibrium conditions but was terminated after 1 min, thereafter leaving only the heat generation rate of the cell lights.

Pertinent characteristics of the pressure and temperature in the three types of credible HRLEL fires are summarized in Table 5.8. In the

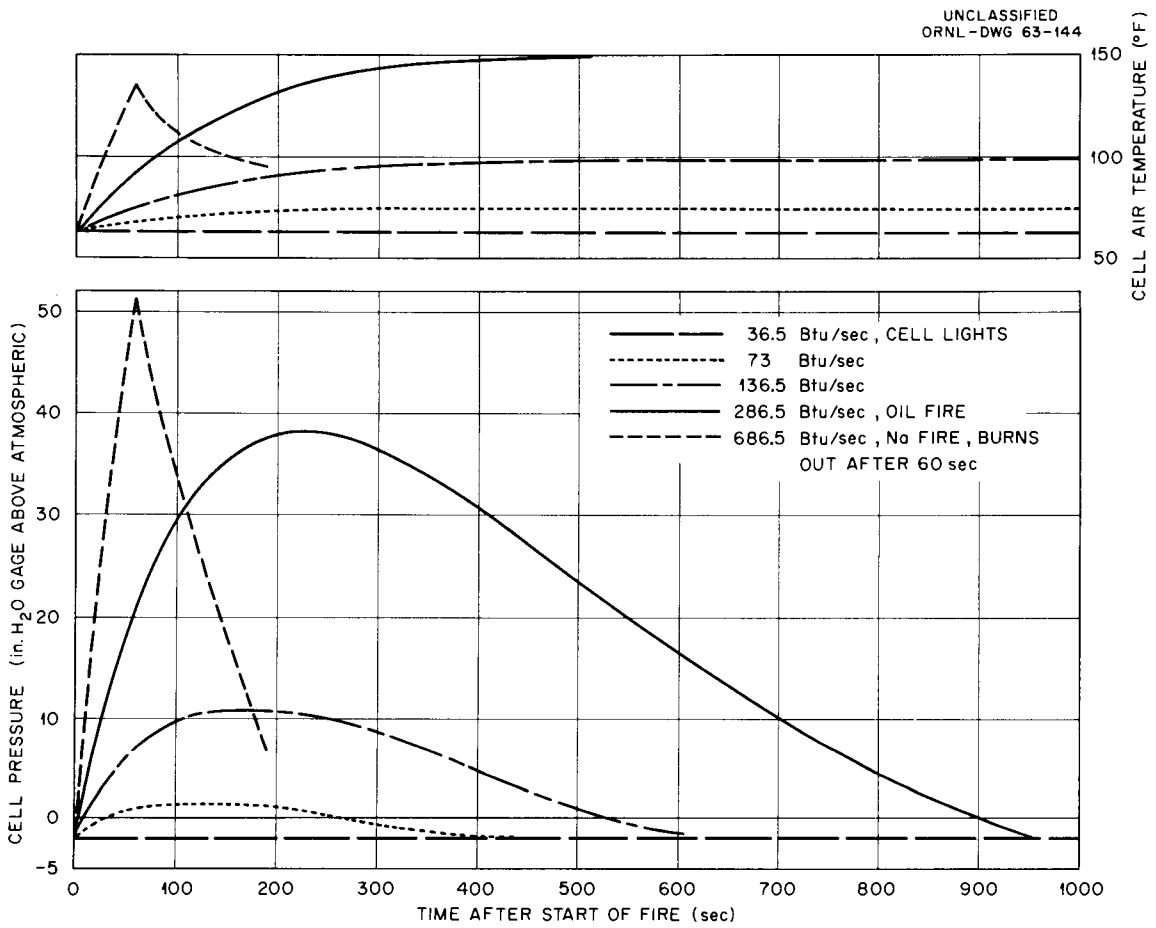

Fig. 5.5. Pressure and Temperature Transients in a HRLEL Cell as a Function of Heat Generation Rate.

carbon fuel element fire the cell pressure does not rise above atmospheric, the cell temperature rises only 4°F; and the pressure drop across the cell exhaust filters rises to 0.1 in. H_2O gage. In the sodium fire the maximum cell-air pressure and temperature are 51.5 in. H_2O gage and 135°F, respectively. The maximum pressure drop across the final cell exhaust filters is 6.6 in. H_2O gage, which might rupture them, especially if they were not in a "clean" condition before the fire. The maximum cell pressure and temperature during the oil fire are 38.3 in. H_2O gage and 152°F, respectively. This fire also might create sufficient pressure drop to rupture the exhaust filters. It is seen that the assumed oil fire would reach equilibrium after about 16 min. The fire might continue to burn for an additional 45 to 50 min until lack of oxygen extinguishes it.

5.4.2 Dispersive Effects

The dispersive effects of the credible HRLEL fires are tabulated in Table 5.8. The total inventory, 30 curies of rare gases and 100,000 curies of mixed long-cooled fission products, could be released to the cell air in the sustained carbon fuel element fire. One curie of rare gases, 1700 curies of mixed fission products, and 0.7 g of Pu^{239} could be released as smoke in the sodium and oil fires.

Part of the smoke would be deposited on the cell recirculation system filters and part would escape to the exhaust system, depending on the relative flow rates during the fire. It is calculated that the fraction of total smoke released to the exhaust system would be 0.0083, 0.146, and 0.31 for the carbon, oil, and sodium fires, respectively.

It is assumed that the cell exhaust filters remove 99% of the smoke that passes to them. Silverman[9] had originally reported the efficiency of AEC absolute filters to be 87% for 0.5 to 0.1 μ particles typical of smoke. More recently, Cheever[10] at Argonne measured an efficiency of 99.5% for one absolute filter or two in series.

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[9]Leslie Silverman, Harvard Air Cleaning Laboratory, personal communication to J. P. Nichols, Oak Ridge National Laboratory, Feb. 24, 1960.

[10]C. L. Cheever, "Recent Air Cleaning Developments at Argonne National Laboratory," Seventh AEC Air Cleaning Conference Held at Brookhaven National Laboratory October 10-12, 1962, TID-7627 (March 1962), p 310.

The maximum permissible concentration in air for a 40-hr/week exposure to the 120-day-cooled mixed fission products was calculated to be 6.6×10^{-9} $\mu c/cm^3$, determined primarily by the 3% of the activity that is Sr^{90}. The allowable level of surface contamination is taken to be 1.7×10^{-6} curies/m^2, which corresponds to 1 mr/hr of beta radiation above ground, or 1000 dis/min of Sr^{90} per 100 cm^2.

The maximum permissible concentration in air for a 40-hr/week exposure for Pu^{239} is 2×10^{-12} $\mu c/cm^3$. The allowable level of deposition was taken to be 1.0×10^{-9} curies/m^2, corresponding to approximately 20 dis/min per 100 cm^2. These values are not of particular significance since the mixed fission products determine the dose and fallout hazards.

The pseudo ingestion-exposure dose to personnel before evacuation of the operating area would be 0, 62, and 51 rem, respectively, for the carbon, sodium, and oil fires. It was assumed that, if the activity level is indeed high in the operating area, personnel would don respirators or fresh-air apparatus and return to extinguish the fire.

The dose rate 6 ft from the final cell exhaust filters in the basement of the HRLEL would be low after a carbon fire, since the unruptured in-cell absolute filters would retain most of the suspended radioactivity. The dose rates 6 ft from the cell exhaust filters after the sodium and oil fires would be 25 and 12 rem/hr, respectively. These dose rates are low enough to allow filter replacement.

The most probable maximum downwind personnel doses that would occur if the smoke were exhausted from the 3039 stack and the cell exhaust filters were not ruptured are 0.02, 0.013, and 0.006 rem for the carbon, sodium, and oil fires, respectively. The doses would be 1.3 and 0.6 rem for the sodium and oil fires, respectively, if the filters were ruptured.

In the essentially incredible event that the 3039 duct is being used to capacity during the fire, the maximum downwind dose would be 0.54, 0.35, and 0.16 rem for the carbon, sodium, and oil fires, respectively, if the filters are not ruptured. The dose would be 35 and 16 rem for the sodium and oil fires, respectively, if the filters are ruptured and the release is from the HRLEL stack.

The maximum area contaminated by the release would occur during a rainout condition and would be independent of the release height. If

the filters hold, 0.27, 0.17, and 0.08 square mile would be contaminated above the permissible level by the carbon, sodium, and oil fires, respectively. If the filters fail, the contaminated areas would be 20 and 9.3 square miles for the sodium and oil fires, respectively.

5.5 Explosions

The properties of maximum credible explosions in the HRLEL, an explosion of approximately 10 ft^3 of a 30% H_2-air mixture, a nuclear burst of 10^{18} fissions, and an explosion from 170 g of sodium reacting with water, are related to the properties of a 3-lb TNT explosion in Table 5.9. The air pressure transient in a cell bank (B or C) sustaining such an explosion is shown in Fig. 5.6. Each of the credible explosions would generate about 100 ft^3 of hot gases, and the resulting shock waves would be less energetic than those of 3 lb TNT.[11] The cell bank, windows, and doors are sufficiently strong to withstand a 3-lb TNT blast without breaching the primary containment.

The effects of the credible explosions are summarized in Table 5.10. It is assumed that the credible explosions would release fission products and plutonium equivalent to 1% of a PRDC type fuel element. The other assumptions are the same as those used in evaluation of the credible fires. It is not considered likely that the final exhaust filters would be ruptured in an explosion, since neither the blast nor the air flow pressure is in excess of the filter-bursting pressure, approximately 6 in. H_2O gage. The shock wave is sufficiently attenuated by dissipation along the tortuous path through the ventilation system.

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[11] C. E. Guthrie and J. P. Nichols, Theoretical Possibilities and Consequences of Major Accidents in U^{233} and Pu^{239} Fuel Fabrication and Radioisotope Processing Plants, ORNL-3441 (in press).

Table 5.9 Properties of Credible Explosions in HRLEL

Source of Explosion	Total Energy Release (Btu)	Volume of Hot Gas and Steam at STP (ft^3)	Shock Wave Pressure lb/ft^2		Shock Wave Energy $ft\text{-}lb/ft^2$	
			at 15 ft	at 5 ft	at 15 ft	at 5 ft
3 lb TNT[a]	5400	~ 100	800	20,000	230	2100
10 ft^3 of a 30% H_2-air mixture[a]	860	90	< 800	< 20,000	<230	< 2100
10^{18} Fissions burst[a]	30,000	< 100	< 800	< 20,000	<230	< 2100
170 g Na/H_2O (Hydrogen-air explosion)	1800	~ 100	< 800	< 20,000	<230	< 2100

[a]C. E. Guthrie and J. P. Nichols, Theoretical Possibilities and Consequences of Major Accidents in U^{233} and Pu^{239} Fuel Fabrication and Radioisotope Processing Plants, ORNL-3441 (in press).

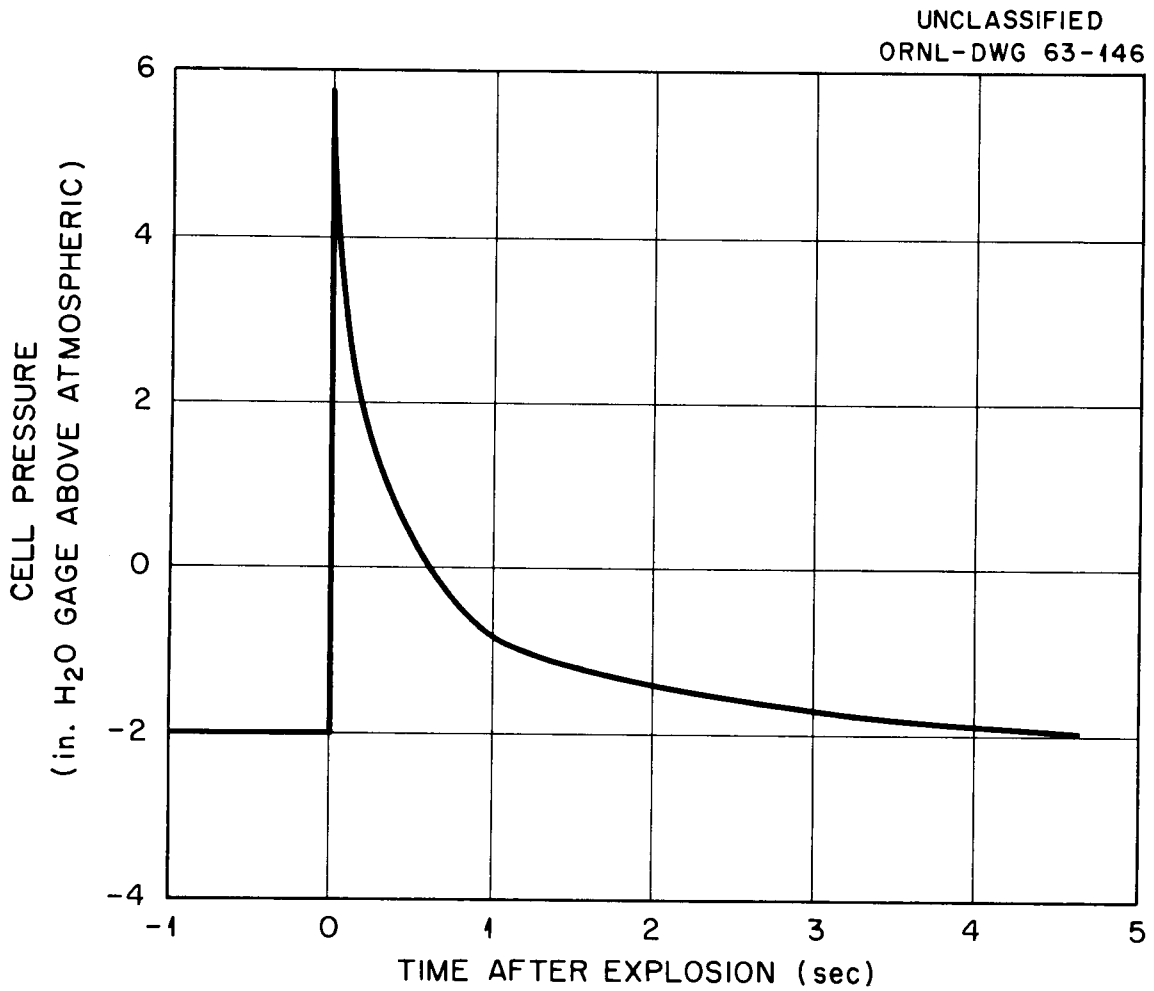

Fig. 5.6. Pressure Transient in a HRLEL Cell After the Maximum Credible Explosion.

Table 5.10 Effects of Credible Chemical Explosion in HRLEL[a]

Effect	Magnitude
Peak cell air pressure, in.H_2O gage	7.8
Duration of positive pressure, sec	0.7
Cell air leakage to secondary containment zone, ft^3	0.5
Activity released from fuel, curies	
Rare gases	1
Mixed fission products (controlling)	1700
Pu^{239}	0.054
Mixed fission products leaked to secondary containment zone, curies	0.03
Mixed fission products passing to final cell exhaust filters, curies	6.5
Mixed fission products released to stack, curies	0.065
Mixed fission products deposited in cell, curies	1693
Pseudo 2-min dose in secondary containment zone, rem	0.25
Dose rate 6 ft from final cell exhaust filters, rem	0.03
Maximum downwind dose, rem	
HRLEL stack, filters intact	0.0042
HRLEL stack, filters ruptured	0.42
3039 stack, intact	0.00016
3039 stack, ruptured	0.016
Maximum contaminated area, square mile	
Filters intact	0.002
Filters ruptured	0.21

[a]It is assumed that in a chemical explosion 1% of a PRDC fuel element burns and releases its activity to the cell as smoke.

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