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Seismic Mitigation for Equipment at Army Medical Centers

Methods Illustrated With Examples from Madigan Army Medical Center

by
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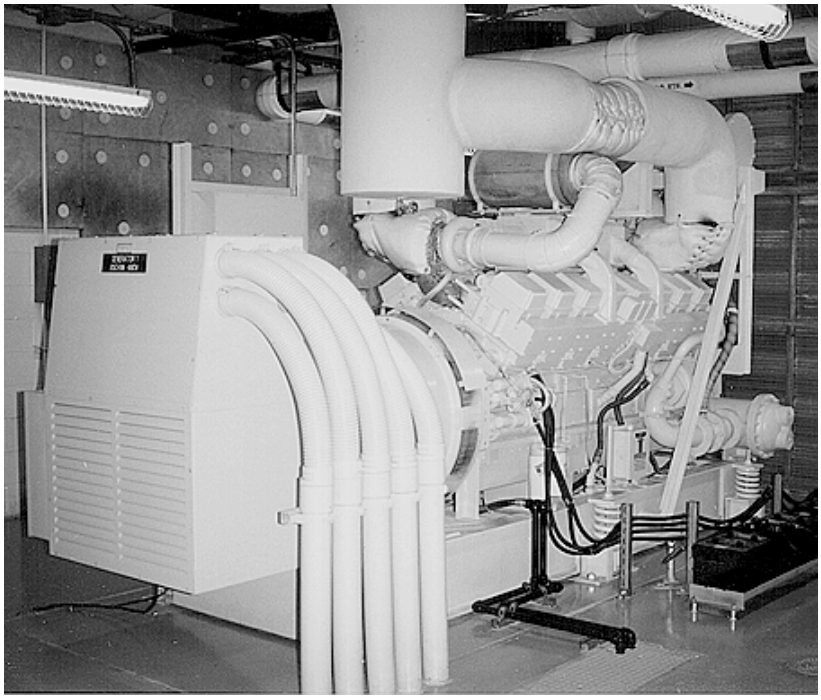

Medical centers may be the most critical facilities in the response and recovery phase immediately after a damaging earthquake. This report presents observations and makes recommendations for the protection of equipment, many of which support essential functions. These observations are based on a walk-down inspection of Madigan Army Medical Center conducted in December 1996. Protecting critical equipment include, ensuring an adequate load path, providing adequate anchorage, and accomodating differential movement. Observations and recommendations are presented based on effective equipment protection seen at MAMC, anchorage problems seen at MAMC, and load path concerns for well anchored equipment. Lastly several references are listed with highlights on their significance to medical facilities.

Foreword

This study was conducted for Madigan Army Medical Center (MAMC) under Military Interdepartmental Purchase Request (MIPR) 96CERL0004, “Center of Technical Expertise Support; USACERL,” dated 30 September 1996. Additional funding was provided by Headquarters, U.S. Army Corps of Engineers (HQUSACE) under Project 4A162784AT41, "Military Facilities Engineering Technology"; Work Unit CA7, "Seismic Protection of Equipment." The MAMC Technical Monitors were John Williamson and Charles Cole, Facilities Management Division, Fort Lewis, WA. The HQUSACE Technical Monitor was Charles Gutberlet, CEMP-ET.

The work was performed by the Engineering Division (FL-E) of the Facilities Technology Laboratory (FL), U.S. Army Construction Engineering Research Laboratories (USACERL). The USACERL Principal Investigator was James Wilcoski. Dale L. Herron is Acting Chief, CECER-FL-E, and Larry M. Windingland is Acting Operations Chief, CECER-FL. The USACERL technical editor was Gordon L. Cohen, Technical Information Team.

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COL James A. Walter is Commander of USACERL and Dr. Michael J. O’Connor is Director.

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1 Introduction

Background

Medical centers are perhaps the most critical facilities in the response and recovery phase immediately after a damaging earthquake. Immediately following such a disaster, large numbers of crush and burn victims (the latter primarily due to fires caused by natural gas line rupture and ignition) can be expected. These victims will need immediate medical care and can most effectively be treated at a medical facility in the immediate area. If the facilities to provide this care are damaged (structural and nonstructural including critical equipment), these victims must be transported to other operational facilities. Transporting victims to more remote facilities will require greater time, especially when one considers the expected damage to transportation systems and the heavy demand for their use. If there is a significant loss to both medical and transportation systems, evacuating people to remote sites will greatly delay treatment. Loss of medical facilities also presents the challenge of relocating existing patients, which is especially difficult for intensive care patients. Therefore, great care should be taken to ensure that medical facilities remain operational after damaging earthquakes. This includes structural and non-structural components needed to protect both life-safety and essential functions.

Personnel from the U.S. Army Construction Engineering Research Laboratories (USACERL) conducted a walk-down inspection of Madigan Army Medical Center (MAMC) in December 1996. MAMC is located at Fort Lewis, WA, south of Tacoma. This center is quite new, having opened in March 1992, and care has clearly been taken on many of the systems to provide earthquake resistance. Most older medical centers would have many more problems to address, particularly in the areas of nonexistent or inadequate anchorage and a lack of flexible connections. Figure 1[1] shows the east side of the Nursing Tower at MAMC. To the West and connected to this tower is the ancillary building (not seen in the figure), which contains most of the critical equipment. To the north

[1] All figures are presented immediately after the chapter in which they are first referred to.

is the clinic building, which contains limited operationally essential functions; therefore relatively little attention was given to the contents of this building.

Objective

The objective of this report is to present simple methods for reducing the seismic vulnerability of equipment at Army medical centers.

Approach

The seismic mitigation methods presented here are illustrated with examples from MAMC. Concerns about particular well anchored critical medical equipment are presented. The observations and recommendations in this report are based on the walk-down inspection of MAMC. Although this new facility may be better prepared to withstand earthquakes than older facilities, the observations made here on what was done right — and the suggested improvements — can be applied to older facilities that may have taken little action on seismic mitigation for equipment.

Observations on equipment interactions and interdependencies are provided. An example from MAMC is the Medical Digital Imaging Control Center (MDICC). This system supports all the x-ray image digital conversion, processing, reading and storage, and is assumed to be essential based on its function and concerns expressed by medical staff at MAMC.[2] This system is made up of several components, such as equipment for converting the x-ray film to digital images, an optical disk system, a minicomputer, a data storage unit, a distribution network box and image reading monitors. The continued operation of each component is required for the entire system to work. Additionally, many of these components are in a computer room served by an air conditioning (A/C) unit, a fire detection and suppression system, and emergency power provided by the medical center generators. The entire MDICC system could be lost, if for example, the A/C unit fails due to the loss of commercial power and failure of the emergency generators due to interruption of fuel supply. Other examples of this type of system interdependency concern are noted in the report.

[2] Jon R. Carter, Medical Physicist at Madigan Army Medical Center, HSHJ-R.

Much of the medical equipment inspected was well anchored, but there were notable exceptions. Other concerns beyond equipment anchorage are noted. Equipment seismic vulnerability observations and recommendations are presented in Chapters 2 through 4. Related reference materials of interest to medical facility managers are listed in Chapter 5.

Scope

This report provides only general recommendations to familiarize facility managers with technical issues. Detailed engineering guidance may be needed to evaluate the adequacy of existing systems, and design guidance may be needed to actually upgrade vulnerable equipment systems.

Several observations are made on the adequacy of various equipment components, but comments on equipment interdependency are limited to issues that could be identified during the brief walk-down inspection. A thorough understanding of each system's operations is needed to identify these interdependencies at any given medical facility. A walk-down inspection that includes the evaluation of system interdependencies may be needed to set priorities for more detailed investigation and to establish the necessary degree of seismic resistance for each equipment component.

Mode of Technology Transfer

Walk-down inspections of specific medical facilities can be provided to develop site-specific reports similar in scope to the recommendations developed for MAMC. The findings from this report and other similar inspections may be used to develop an Engineering Technical Letter that contains detailed guidance on how to implement the concepts presented here.

Figure 1. East side of the Nursing Tower at MAMC.

2 Effective Equipment Protection Measures Observed at MAMC

In general, mechanical and electrical equipment at MAMC was well anchored and appeared to be well constructed to resist seismic loading. MAMC has a very good practice of running the entire medical center on the emergency generators for 3 hours each month. This practice will help to ensure that this system is functional if commercial power is lost due to an earthquake. The uninterruptible power supply (UPS) supporting the Medical Digital Imaging Control Center (MDICC) is also tested each month in conjunction with the generator tests. This UPS battery system provides power immediately after power loss until the generator system comes on-line.

This chapter introduces many issues related to protecting critical equipment and illustrates them using good examples seen at MAMC. In general, these issues include ensuring an adequate load path, providing adequate anchorage, and accommodating differential movement.

Adequate Load Path and Anchorage

Adequate load path is provided by ensuring that the equipment frame and various subcomponents have sufficient strength to carry earthquake-induced inertia forces and gravity loads from the subcomponents through the frame and down to the point of anchorage. This will be dependent on the materials used, weight distribution, and configuration of the equipment. For equipment that is fairly simple mechanically and can be easily seen, this can often be determined by engineering judgment. Other more complex equipment, especially with heavy and brittle components, may require shake table testing or detailed analysis.

Figure 2 is a schematic diagram of an equipment cabinet anchored to the floor with anchors at the exterior of the cabinet. Similarly, Figure 3 shows a detail for the Figure 2 cabinet with the anchors at the cabinet interior. The interior anchorage is preferred as it looks better and does not present a tripping hazard. Existing cabinets not designed for anchorage may need exterior fasteners if cabinet contents prevent the use of interior anchors. Figure 4 is a schematic

diagram of equipment supported with a narrow flexible base, which requires bracing to a wall or other well supported equipment.

Figure 5 shows electrical substation switch gear cabinets. The heavy cabinet panels and frames provide adequate load path. These cabinets are well anchored at the cabinet interiors (Figure 6) and are also braced by bolting to each other. Figure 7 shows the primary switch gear. These switch the power from commercial to generator power if commercial power is lost. These heavy cabinets are effectively anchored to the floor by welding the frames to a plate that is cast into a reinforced concrete floor pad (Figure 8). Figure 9 shows the station batteries that provide UPS for the switch gear. The batteries are supported on heavy-moment frames and are well anchored to the floor. (However, Chapter 3 of this report describes a problem with the foam spacers restraining the batteries.) Figure 10 shows a distribution network box for the MDICC system. This is essentially a communications rack and it is well anchored to the computer floor, as seen in Figure 11. Most of the large medical equipment was well anchored. For example, Figure 12 shows a Varian Accelerator in a rotated position and Figure 13 shows its anchorage to the floor, through the cabinet shown at the rear portion of Figure 12.

Adequate Anchorage and Accommodating Differential Movement

Figure 14 is a schematic diagram of seismic protection for a water heater. MAMC itself does not have such water heaters, but other medical centers may. This diagram is included here to illustrate several unique anchorage and flexible connection recommendations. Unsecured water heaters often fail in earthquakes and may cause water damage to critical electronic equipment located on floors below. This is an example of interaction between equipment in which secondary damage to the electronic equipment is more serious than the direct loss of the water heater itself. Figure 14 illustrates several issues of importance to equipment at medical centers. The plumber's tape and spacer boards are needed at both the top and bottom of the water tank to anchor it effectively to the wall. The anchorage at the top prevents overturning of the tank, while the bottom anchorage prevents it from "walking out." The flexible hoses for gas and water pipes accommodate differential movement between the tank and rest of the pipe system, thereby reducing loads on pipe connections and preventing their failure.

Figure 15 shows the CO_2 fire suppression system for the switch gear. Similar to the water heater example, this equipment is well anchored to the wall. These tanks have a single anchor just above their center of gravity, preventing both

overturning and walk-out. The flexible hoses will also accommodate differential movement. Figure 16 shows an emergency generator that appears well constructed to resist seismic loading. The generator is well anchored using vibration isolators in conjunction with seismic restraints, sometimes called "snubbers" (Figure 17). The vibration isolators protect the building from generator operation vibration by mechanical isolation at the generator supports. These systems tend to be very flexible, and seismically induced floor motions can be greatly amplified. Excessive deflections that could exceed the capacity of the isolators are prevented with seismic restraints. The seismic restraints shown in Figure 17 will effectively limit deflections at the isolators and cushion against impact in all three directions. Flexible connections seen at the top of the generator are for a radiator, fan and exhaust system for cooling the generator. These connections will accommodate the large differential movements caused by the isolated generator.

Overhead Supported Equipment

Figure 18 is a schematic diagram of ceiling-suspended equipment. Figure 18a is an example of mechanical equipment supported on a trapeze configuration using threaded rods. A seismic retrofit (Figure 18b) requires the addition of a brace and the replacement of the rods with heavier (less slender) members that will not buckle when lateral seismic motions together with the brace place the vertical members in compression. The SMACNA *Seismic Restraint Manual: Guidelines for Mechanical Systems* (see list of related references in Chapter 5) gives detailed design guidance for suspended ducts and pipe systems. Pages 4.11 – 4.13 and 9.12 of this document shows how an existing tie rod support system can be upgraded with channels or angle members such that the rod remains in place for carrying the gravity load and the additional members carry vertical compressive and lateral seismically induced loads.

Figure 19 shows overhead suspended pipes in a mechanical room. These appear to be well suspended with tie rods and braced with cables. The cables carry tension only, so they must extend to the ceiling structure in all four directions (e.g., north, south, east, and west) in order to carry the seismically induced loads in both lateral directions. Overhead anchored equipment is supported through the ceiling by the interstitial floors. Figure 20 shows an overhead anchored telescopic arm supporting an x-ray head (collimator). The supporting rails appear to be well anchored to the overhead interstitial floor. Figure 21 is a view looking down at an interstitial floor showing a frame that distributes the load from overhead anchored equipment below to the interstitial floor. Based on the site visit it could not be determined what this frame is supporting, but it

appears well constructed to serve its purpose of preventing punching shear through the interstitial floor.

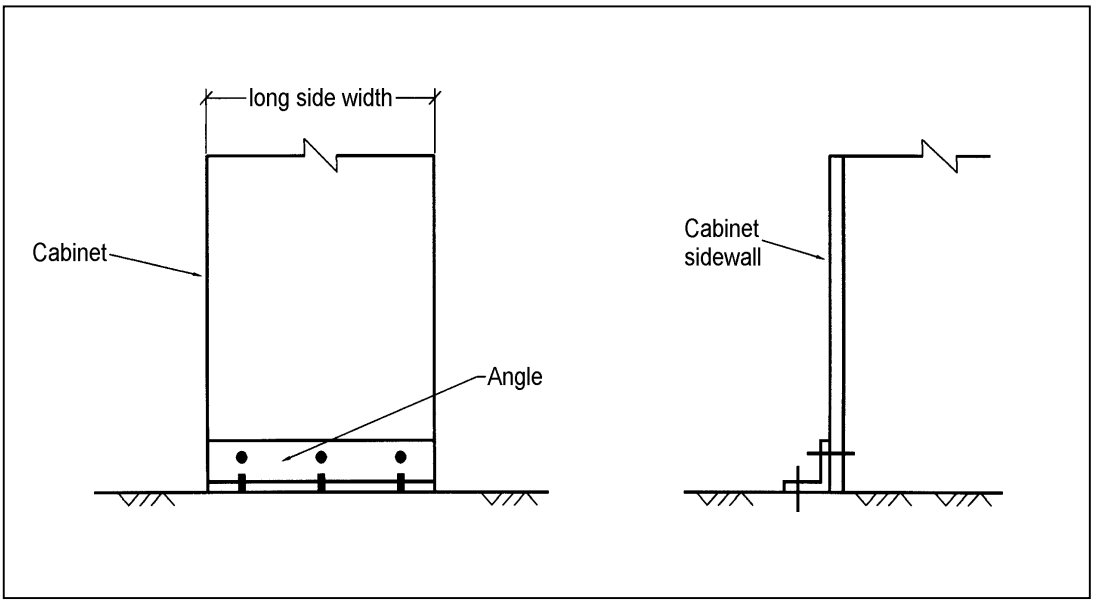

Figure 2. Equipment floor anchorage, exterior of cabinet.

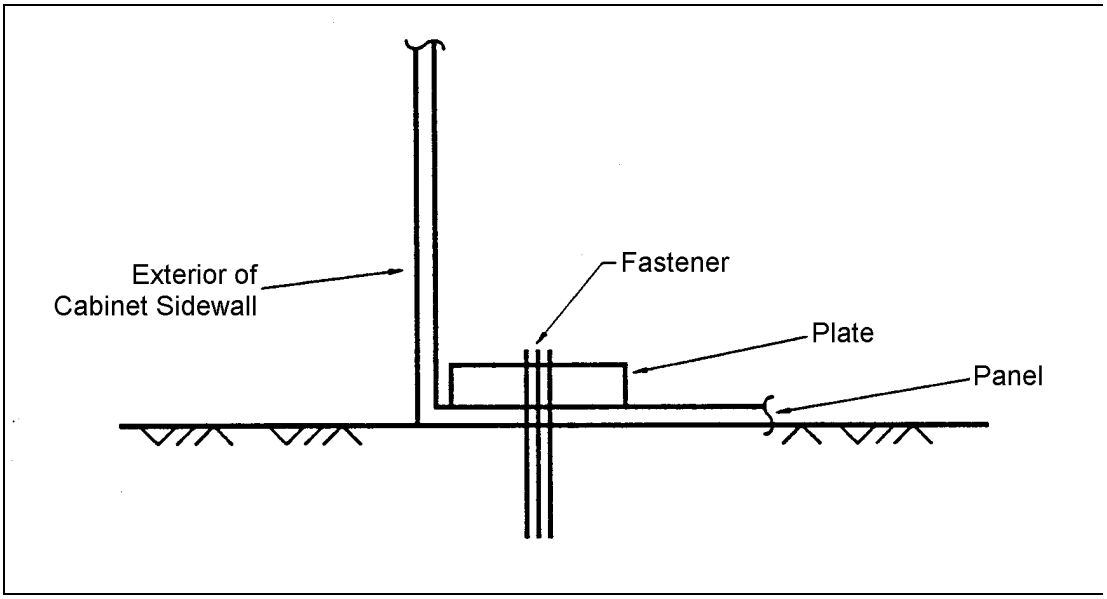

Figure 3. Equipment floor anchorage, interior of cabinet.

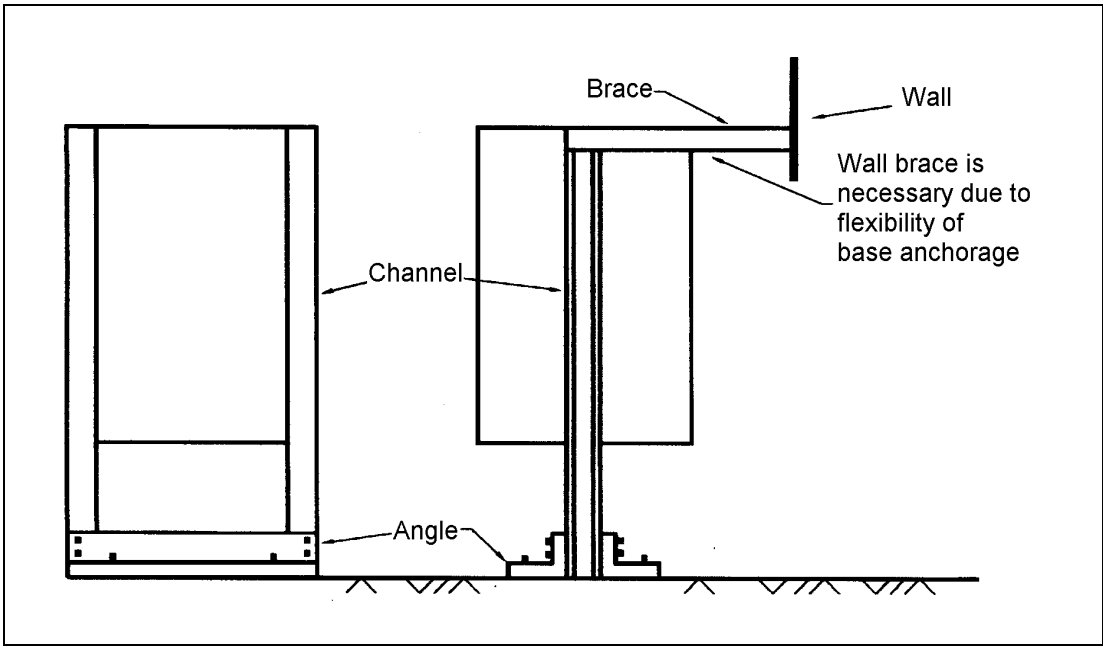

Figure 4. Equipment with flexible base anchorage and wall bracing.

Figure 5. Electrical substation switch gear cabinets.

Figure 6. Anchorage for switch gear cabinets.

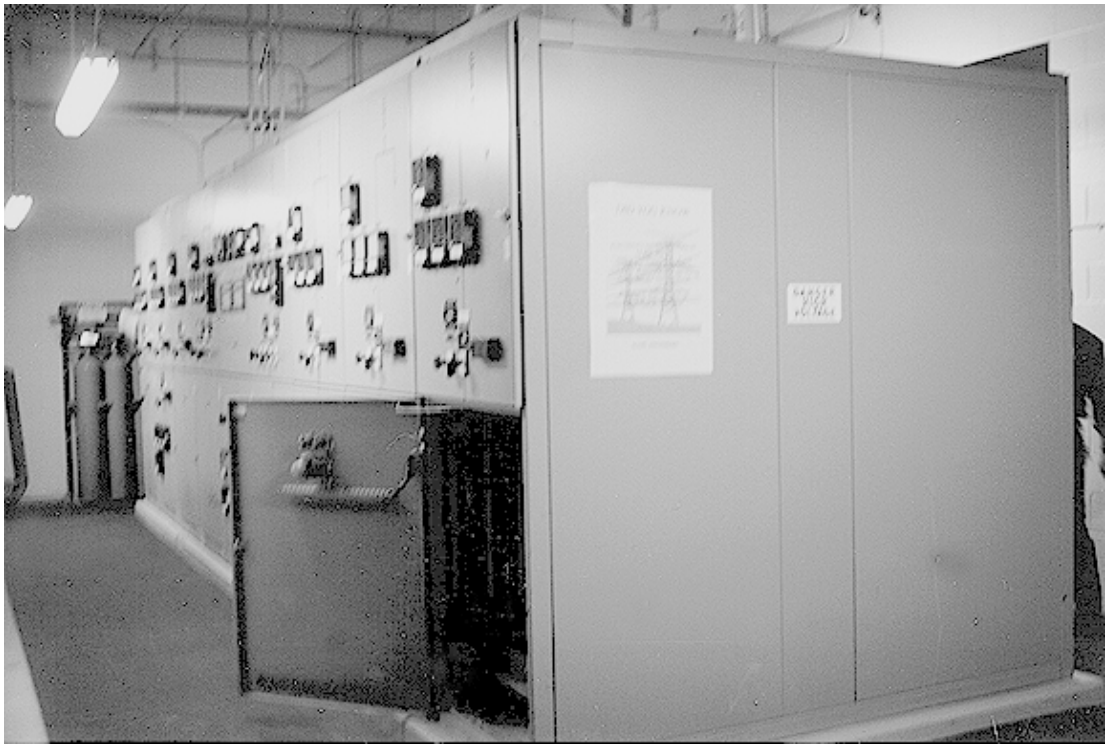

Figure 7. Primary switch gear cabinets.

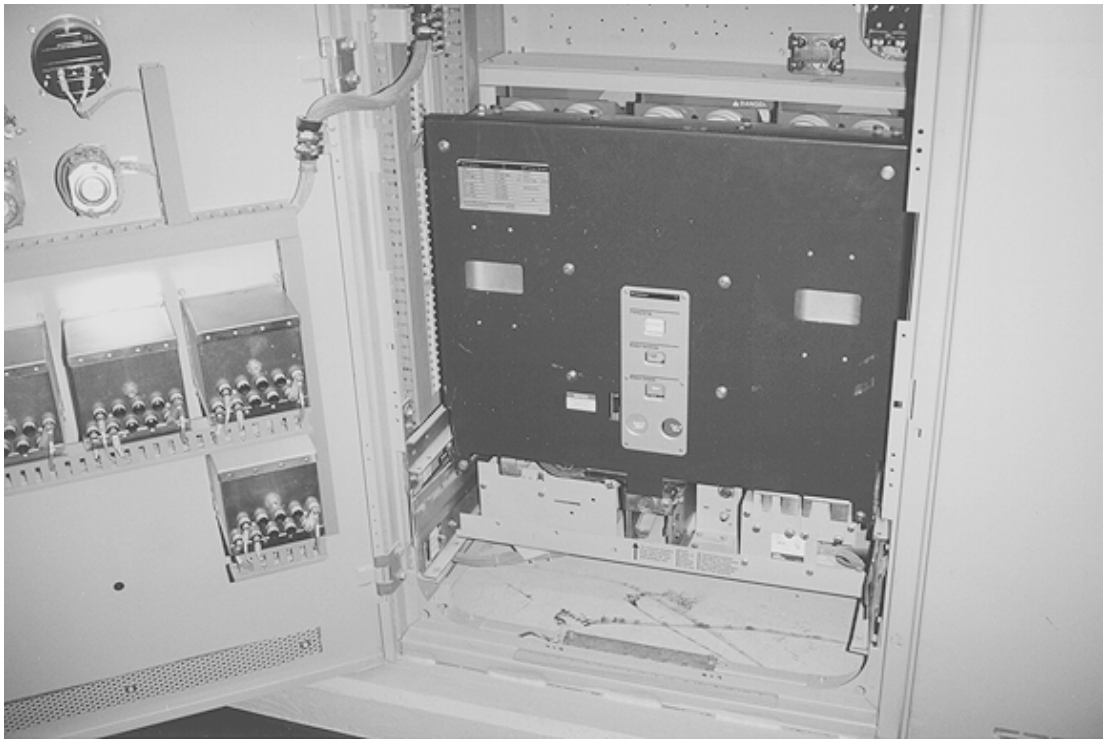

Figure 8. Anchorage for primary switch gear cabinets.

Figure 9. Station batteries that provide UPS for switch gear.

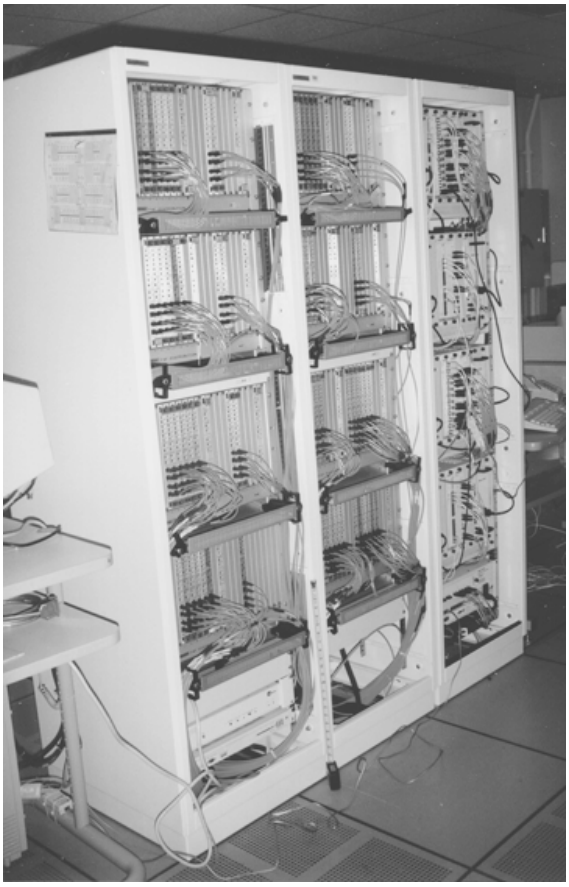

Figure 10. Distribution network box for the MDICC system.

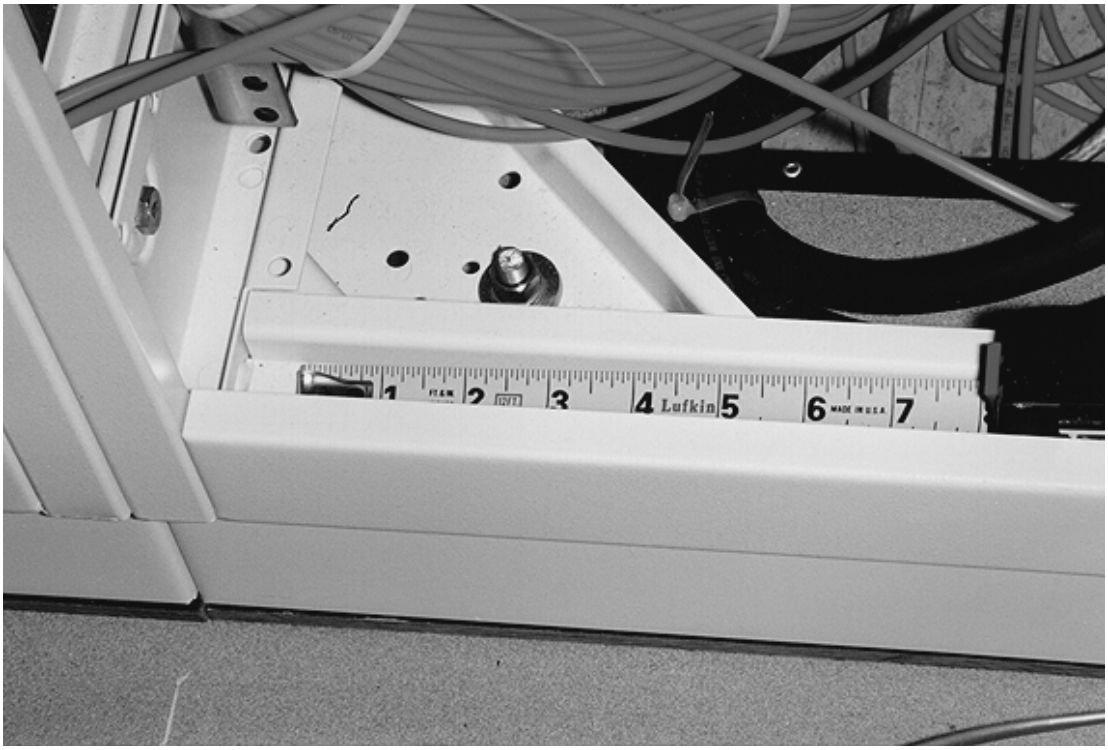

Figure 11. Anchorage for distribution network box

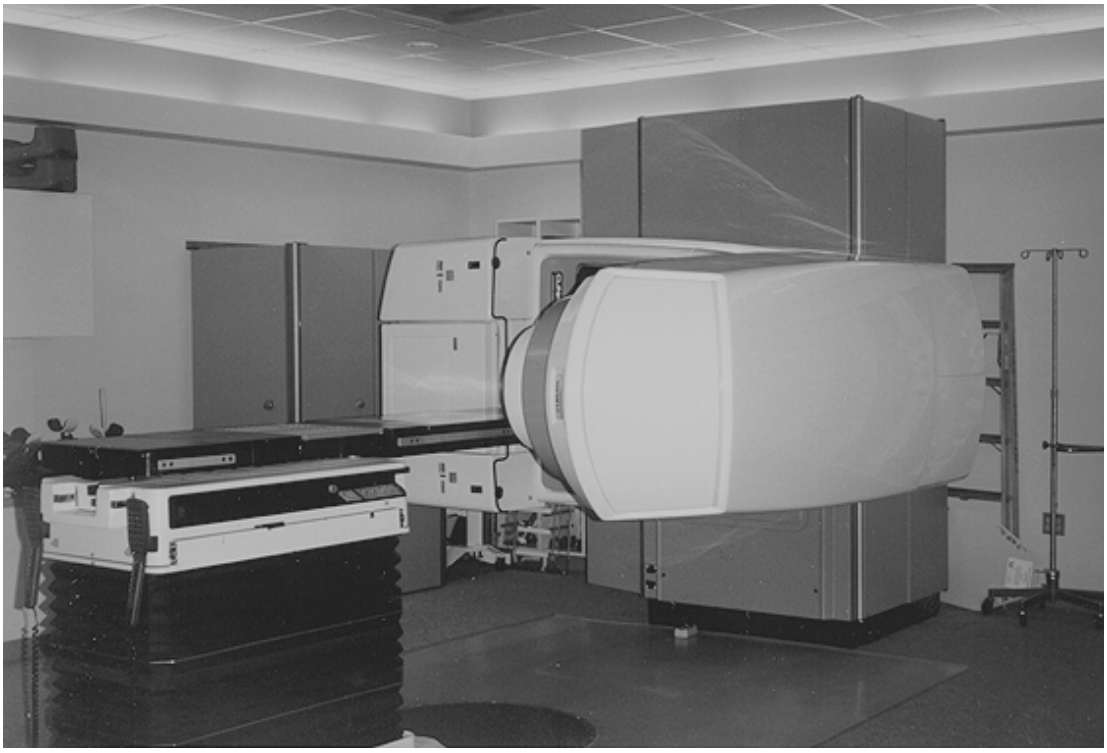

Figure 12. Varian-CLINAC 2100C Radiotherapy Accelerator in a rotated position.

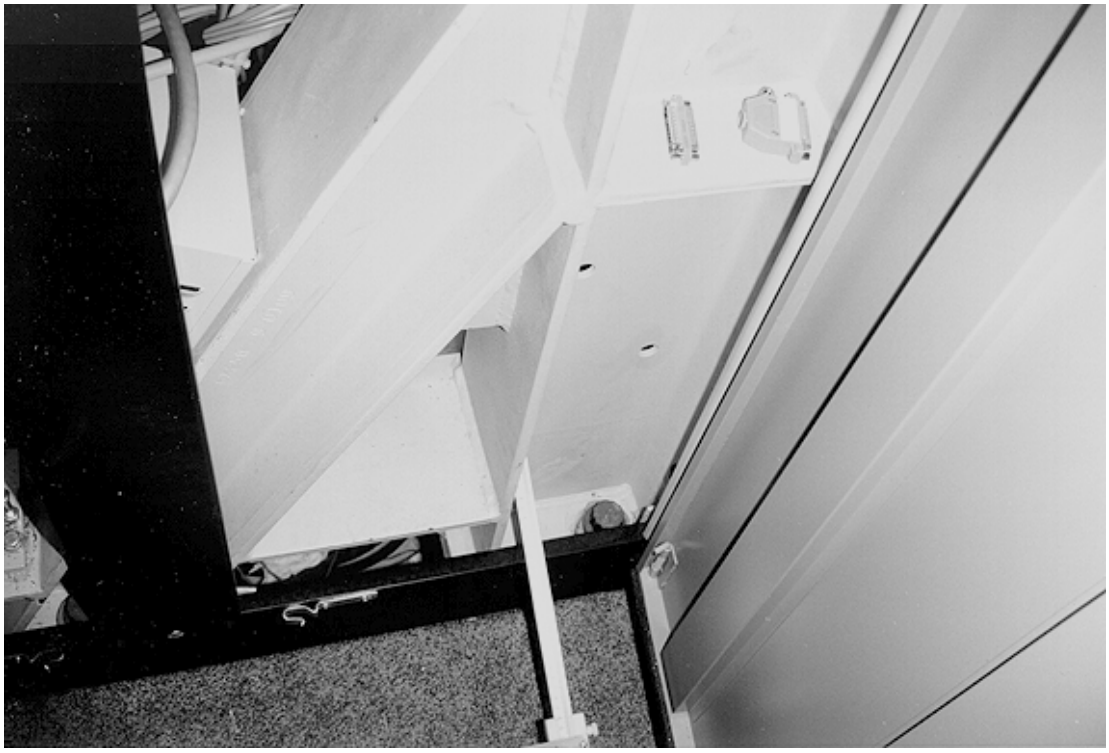

Figure 13. Anchorage for the Varian accelerator.

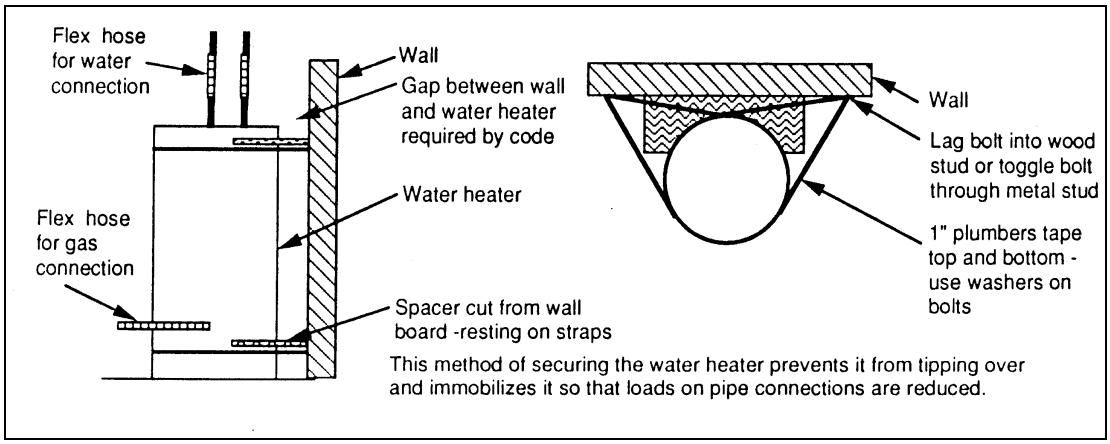

Figure 14. Seismic protection for a water heater.

Figure 15. CO_2 fire suppression system for the switch gear.

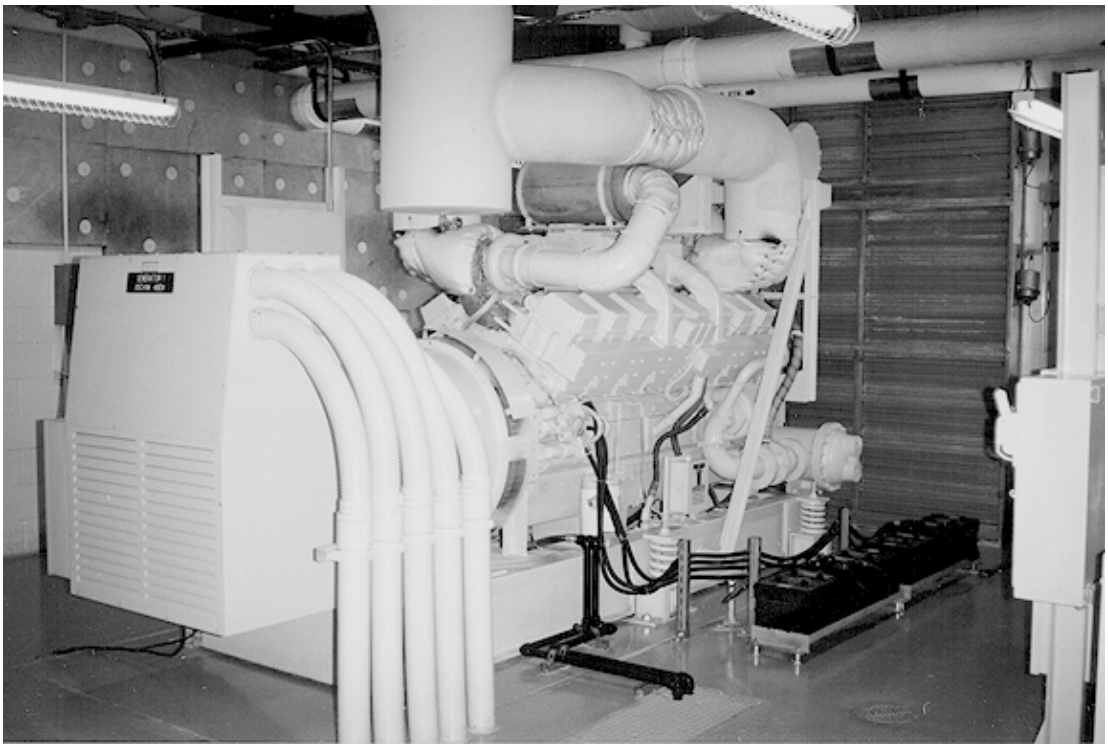

Figure 16. Emergency generator.

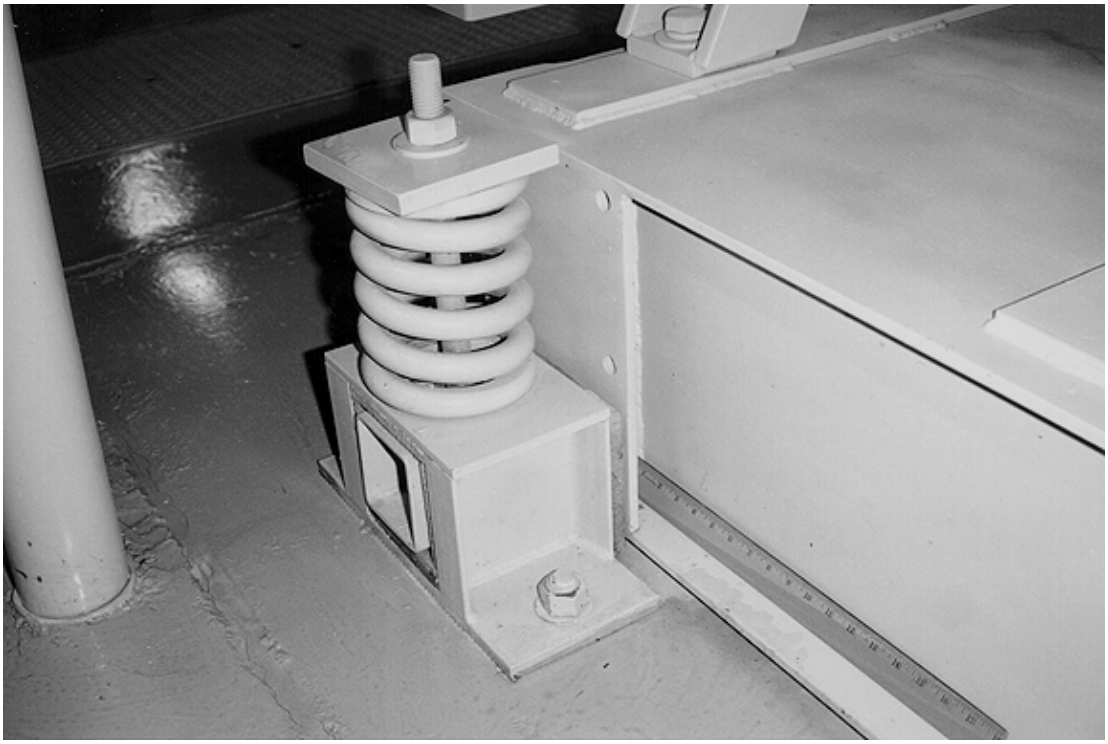

Figure 17. Emergency generator anchorage with vibration isolator and seismic restraint.

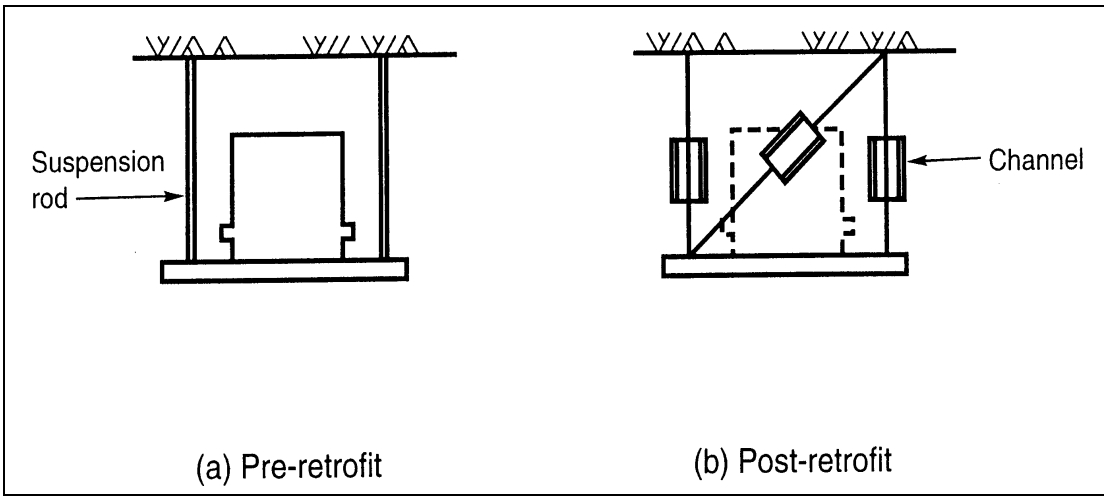

Figure 18. Ceiling-suspended equipment.

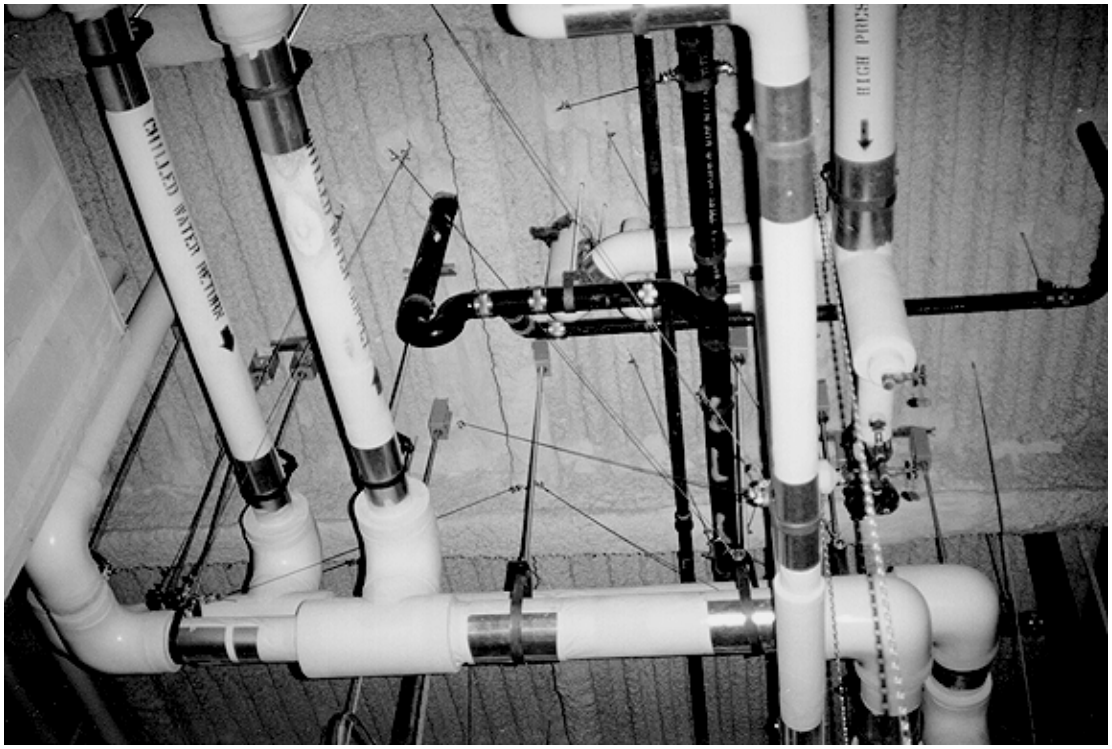

Figure 19. Overhead suspended pipes in a mechanical room.

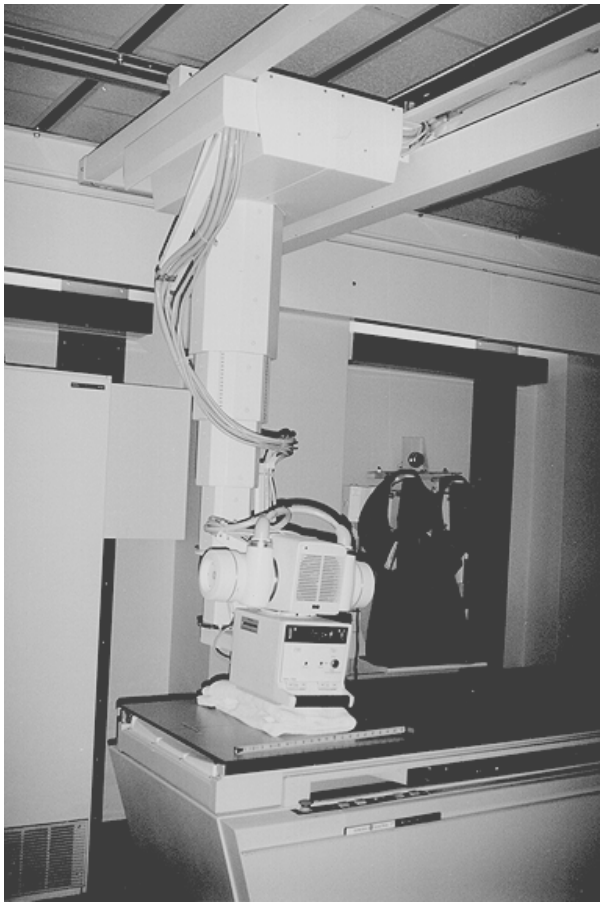

Figure 20. Overhead anchored telescopic arm supporting an x-ray head.

Figure 21. Interstitial floor showing frame that distributes loads for overhead-anchored equipment.

3 Anchorage Problems Observed at MAMC

As could be expected at any large, complex facility, numerous problems related to the seismic resistance of equipment were identified. This chapter presents anchorage-related problems, and recommendations for correcting them. Many of these problems can be eliminated by following the principles presented in Chapter 2 and illustrated by the good examples already in place at MAMC.

Emergency Room Communications Center

Figure 22 shows what may be the most urgent problem found at MAMC. Communications equipment at the emergency room communications center was resting loosely on a folding table, which in turn rests loosely on the floor. Figure 23 shows the edge of this equipment, which demonstrates how tall it is relative to its depth. According to the operators of this equipment, the supplier sent the wrong support cabinet. Apparently this unit was temporarily set loosely on the table, but the correct cabinet was never obtained or installed. In even a moderate earthquake the table would slide on the floor and the equipment would topple. The correct cabinet should be ordered as soon as possible. The communications equipment should be anchored to the cabinet and cabinet should be anchored to the floor. If this cannot be done immediately, the equipment should temporarily be anchored to a more stable counter. In this same room security monitors and fire detection units were well anchored, but the back of their cabinets were open. These cabinets should be closed to prevent the monitors from falling out backwards during an earthquake.

Medical Digital Imaging Control Center

Figure 24 shows equipment that is part of the MDICC system. This particular equipment uses a laser to convert x-ray film plate images to digital records. Figure 25 is a close-up of a wheel and leg at one corner, showing that it is not anchored to the floor. The leg shown could easily be modified to anchor it to the floor.

Figure 26 shows a Kodak Optical Disk System (6800-ADL). This unit stores and moves optical platters containing x-ray image data into read stations. This unit

rests loosely on the computer floor (Figure 27) and is of critical importance to medical staff at MAMC. The supporting computer floor tiles are loosely supported on a stringer system frame. Computer floors supported on stringer system frames apparently perform well in earthquakes. Other computer floors are supported on a stringer-less system where a post supports and should be fastened to each corner of the floor tiles. These posts must be braced to resist lateral seismic motions. Often the fasteners are left out, and in earthquakes loose tiles near equipment could shift off their posts, and drop to the floor below. This in turn would allow equipment to shift and drop into the fallen tile area on one side, and then fall over. All critical equipment should either be bolted to the floor below the tile using a tie-rod or, for lighter equipment, bolted to individual floor tiles. Figure 28 shows a mainframe computer, supported on a computer floor that was tested on the USACERL Triaxial Earthquake and Shock Simulator (TESS). This was the standard field installation for seismic design where the tiles were fastened to the computer floor posts, the posts were braced, and the computer was fastened to the floor below using a tie-rod that penetrated the computer floor surface. This configuration performed well in seismic qualification tests.[3]

The right side of Figure 29 shows the mini-computer central processing unit (CPU), a Digital VAX 4000-505A. This critical computer supports the entire MDICC system but it is unanchored, as seen in Figure 30.

Magnetic Resonance Imaging (MRI) Supporting Computers

Figure 31 shows the computers (GE SIGNA) that control MAMC's MRI system. These computers are not anchored. The smaller computer shown in Figure 32, which records MRI results, is anchored to the computer floor rather than to the floor below. All of these machines are vulnerable for the reasons described above. The MRI equipment anchorage should be upgraded in the same manner described above for the MDICC system.

[3] The TESS has been used for a variety of equipment qualification tests.

Miscellaneous Pharmacy Items

The outpatient pharmacy, which also serves the inpatient nursing tower, contains many tall narrow cabinets that are not anchored. Figure 33 shows a pharmacy freezer that is quite tall, has a small footprint, and is unanchored. (It should be noted that the kitchen also has many tall, narrow unanchored coolers and freezers similar to this.) These should either be braced (see Figures 4 and 14) or anchored to the floor. Figures 34 and 35 show tall, narrow shelves. These shelves can be simply braced by bolting them to a wall or to each other in a T or L configuration (in plan). The two shelves shown in Figure 34 could be braced by simply bolting them to each other near their tops and bottoms. (They will form a T configuration in plan if left in the positions shown in this figure.) Tall shelves such as those shown in Figures 34 and 35 could also be braced to the ceiling structural system. Shelves that are at least seven feet tall configured in parallel rows can be braced to each other perpendicular to the row and across the tops. Figure 36 shows small storage bins in the pharmacy. These bins have a small lip at the front. Storage bins like these should have a higher retainer edge to keep contents in the bins. The same retainer edge should be used for horizontal shelves throughout MAMC. It is recognized that such a retainer edge would make shelves slightly less accessible, but this is a relatively small cost to protect important medical assets. This approach is used in other types of facilities in active seismic regions, such as libraries in California which often have wires in front of books to hold them in place during an earthquake. Lightweight contents can also be held on shelves with cabinet doors with latches.

Miscellaneous Logistics Area Items

The logistics area provides shipping and receiving services plus some storage. Figure 37 shows tall narrow storage racks that are unanchored (Figure 38). The storage rack leg shown in Figure 38 has bolt holes for anchoring the unit to the floor. These should be fastened to the floor, or they may also be braced by bolting to each other, to a wall or to the ceiling structural system. If bolted to each other, they should be fastened near their tops and bottoms to form a T or L configuration, as described above for the pharmacy shelves. Shelf bracing must be designed so as to avoid long unsupported lengths of shelving. Figure 39 shows 55-gallon barrels stacked loosely. In an earthquake, these could easily topple and injure workers, damage property, or rupture. These barrels should remain stable if they are simply unstacked.

Miscellaneous Laboratory Equipment

Figure 40 shows an unanchored milling machine that is fairly tall and has a narrow footprint. The bolt holes shown in Figure 41 demonstrate that this machine can easily be bolted to the floor. Figure 42 is a low-melting alloy dispenser, providing molten lead for casting radiation shielding blocks. This unit weighs over 100 lb (45 kg), and is resting loosely on the countertop. It should be anchored to the countertop or braced back to the wall. Figure 43 shows typical laboratory equipment — both the cabinet and its contents should be anchored. Also note the file cabinet on the right side of this figure — it is unanchored and may easily topple, blocking escape from the door next to it.

Office Equipment

Many offices throughout MAMC have unanchored personal computer CPUs and monitors, as shown in Figure 44. These can easily be anchored to their desks with Velcro strips or double-sided foam tape. The foam material assures that the tape will conform to slight irregularities in the surfaces. Double-coated acrylic foam tape Number 4950, manufactured by the 3M company, has a holding power of about 80 pounds per square inch (0.5 megapascals), so a small patch at each corner would provide an effective restraint. Figure 45 shows typical office file cabinets that are unanchored and may easily topple, blocking escape through the doorway. The drawers on these cabinets have no latches, so several drawers may roll open at the same time, making the cabinets even more susceptible to falling over. Standard file cabinets with latches should be used, and the cabinets should be anchored or braced to the wall or each other as described earlier for shelving units.

Friction Clips

Friction clips, which are often used to support or brace cable trays and various other equipment, should be avoided. Figure 46 shows a Unistrut frame supporting an air-handling unit control panel in a mechanical room. The brace at the bottom of this frame uses friction clips to connect the diagonal members. These clips may work loose after several cycles of seismically induced motions. Such connections should be made with standard fasteners rather than these clips.

Equipment on Wheels

Many examples of equipment on wheels were observed. If the wheels are not locked the equipment will roll around until it strikes other equipment, and may then fall over. If the wheelbase is wide enough the unit may not topple, but the impact may damage either the equipment on wheels or whatever it hits, such as gas lines in intensive care units. It is recommended that the wheels on all such equipment be kept locked. Even with the wheels locked this equipment may fall over if the wheelbase is not wide enough relative to the height of the equipment center of gravity. If such equipment cannot be anchored, it can only be protected by increasing the wheelbase or lowering the center of gravity. Equipment on rollers was seen in the emergency room communications center, intensive care unit (ICU) rooms, ICU nursery, delivery rooms, operating rooms, and in the area near gamma ray cameras. Figure 47 shows a nursery bed on wheels in the ICU nursery. Figure 48 shows a monitor on wheels with a very narrow wheelbase. Figure 49 shows other equipment with a narrow wheelbase near the ICU nursery.

Restrainer Spacer Pads Missing from Batteries

Figure 9 (see Chapter 2) showed the station batteries that comprise the UPS for the switch gear. The frames are well anchored, but Figure 50 shows that the batteries are not snugly supported in the frames. The same foam spacers used between the batteries are needed on the sides of the batteries and at the ends of the racks. The spacers must be sized to provide a snug fit.

Hot Water Tank and Pipe Wall Penetrations

On the left-hand edge of Figure 51 a large hot water tank can be seen. A 4 in. (10 cm) pipe (approximate) connected near the top of this tank couples it to a much smaller tank near the right edge of Figure 51. The pipe is primarily horizontal near the top of photograph in Figure 51. This coupling pipe may cause a problem by not allowing differential movement because it will be very rigid along its axis. In an earthquake the larger tank will oscillate at its own natural frequency, with relatively large displacements near its top. The connecting pipe will then drive the top of the second tank, in the direction of the pipe's axis, with the same motion as the top of the first tank. However, this motion will have a different frequency, phase, and amplitude than the natural motion of the smaller tank. It is important to determine whether the supports for the smaller tank can handle the displacements and forces placed upon them,

and whether the pipe connections can withstand the forces placed upon them. Determining the answer to this seismically induced forced vibration problem would require further study. However, this example does demonstrate the potential problems created by the elimination of differential movement when equipment is coupled together.

Figure 52 shows a wall penetration with heavy conduit. This penetration rigidly ties the conduit to the concrete masonry unit (CMU) wall. The pipes are quite long axially, without elbows and will therefore be quite stiff. Consequently, this wall will be forced to pick up the full seismic loads in the direction of the pipes which is out-of-plane to the wall. The wall is relatively weak in the out-of-plane direction. This configuration represents a poor construction detail. The wall penetration holes could have been made much larger to isolate the pipes from the wall; the gap could have been filled with some soft, resilient fire-retardant material to preserve the fire break. This loading on the wall also could have been avoided if elbows were provided in the conduit near the wall, and the pipe supports could have been braced up to the floor structure above. As it is, adding braces alone to the conduit support will do little to reduce these loads in the wall because of the axial rigidity of the conduit.

Automated Storage Racks

The outpatient pharmacy is supplied by the automated storage racks shown in Figure 53. These movable racks provide 10 days of supply storage. The racks are supported with a structural floor and frame designed to carry 1000 lb (453kg) per 2 x 2 ft (in plan) and 7 ft tall (0.6 x 0.6 x 2.1 m) unit. According to MAMC personnel responsible for this area, the actual weight per unit rarely exceeds 200 lb (90 kg). The logistics area has similar storage racks; their contents appear somewhat heavier, but still well within frame capacity. These frames are approximately 60 ft deep (front to back) and move clockwise along a horizontal track in such a way that racks on the right move toward the front while racks on the left move toward the rear. Therefore, one frame supports about 120 linear feet of 2 x 2 x 7 ft storage units. The pharmacy is equipped with five of these frames. The frames are well anchored to the floor and they appear to be well braced to carry seismically induced lateral loads. The storage units appear to be well supported, with all vertical loads carried along a track at the tops of the frames. The bottoms of these units are restrained by a roller from swinging in against a support bar on the frame, but they are free to swing out — particularly away from the track ends. The racks of one frame are separated from the racks of the parallel frame by only 6 in. Figure 54 shows the bottoms of the racks of two such frames, with the 6 in. separation seen in the

center of the photo. In the center of this photo a box has been laid to span across between the two frames. In an earthquake, these frames will be free to swing out at their bottoms, striking the adjacent racks. Immediately after an earthquake begins the racks should be shut down so this impacting will not bind the racks to each other. However, rack contents such as the box shown in Figure 54 will probably fall out of the racks, or to an adjacent rack, or get wedged between the racks, preventing the operation of the racks temporarily. This debris would need to be cleared away by manually removing rack units, climbing into the racks and removing the obstruction. It may require several hours to clear away the debris but should not cause a long-term problem. If someone attempts to operate the racks before removing this debris, the racks could be forced out of position and bind to each other. If this happened, the rack units or frames could twist, resulting in the need for time-consuming repairs. Therefore, after an earthquake, the racks should be inspected and debris removed to prevent longer-term problems. Figure 54 shows that the base of each rack section slopes in toward the center of the frame, which would help to retain most contents during an earthquake. The actual loss of rack contents should be minimal.

Figure 22. Equipment at emergency room communications center resting loosely on a table.

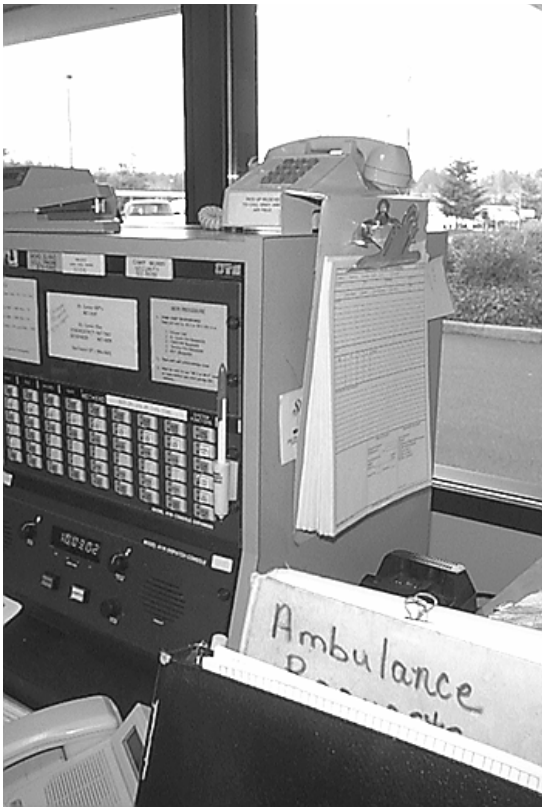

Figure 23. Side view of communications center equipment.

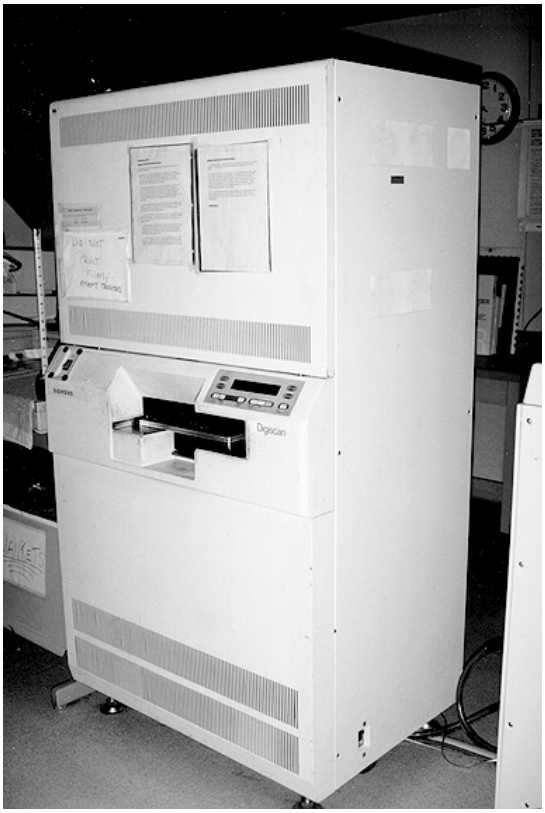

Figure 24. Digiscan (Fuji 7000) supporting the Medical Digital Imaging Control Center system.

Figure 25. Close-up showing lack of anchorage for the Digiscan equipment.

Figure 26. Kodak Optical Disk System (6800-ADL).

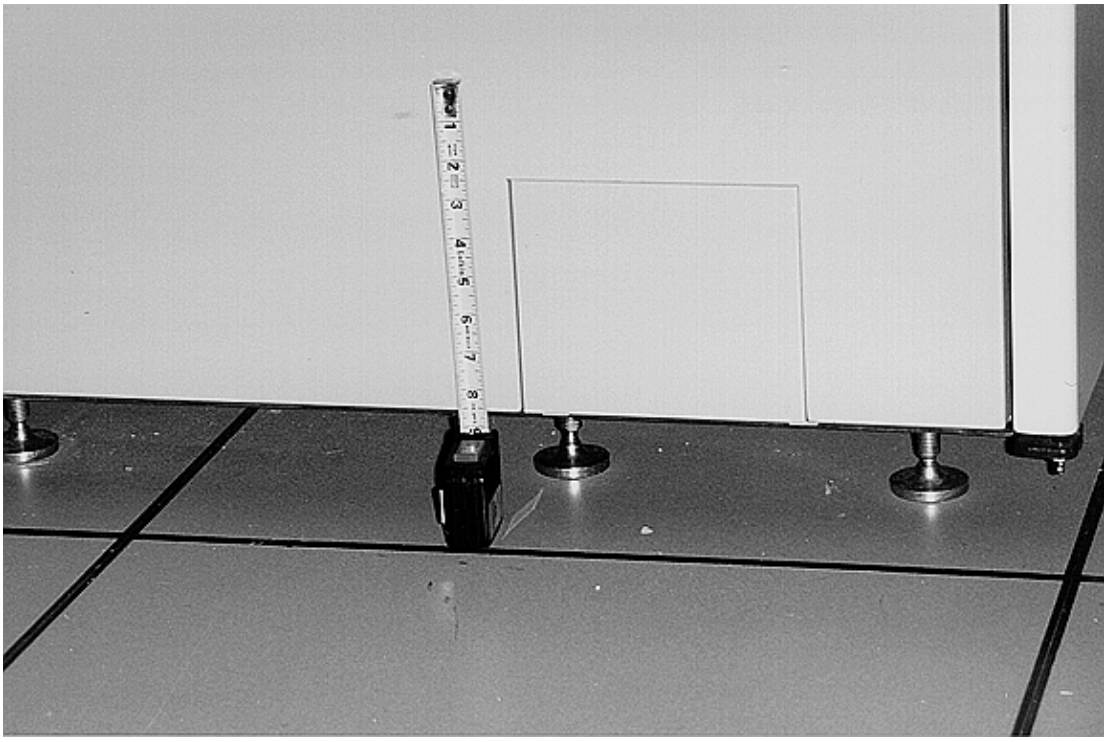

Figure 27. Close-up showing lack of anchorage for the optical disk system.

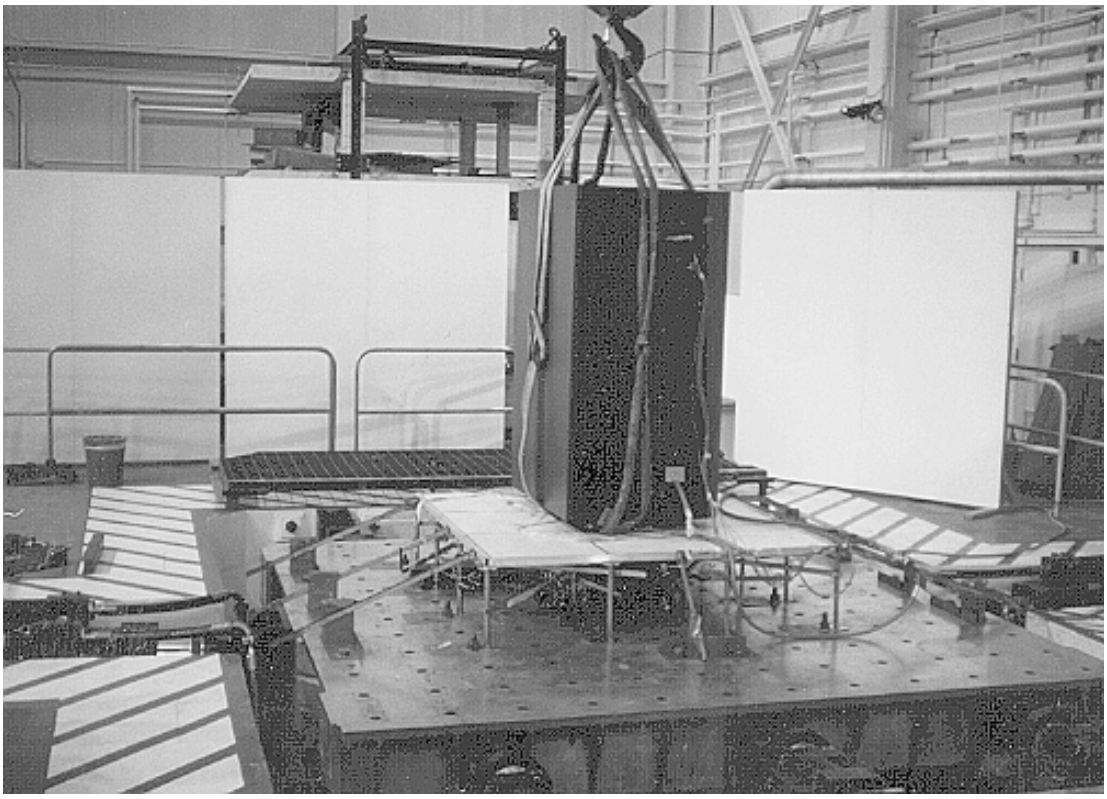

Figure 28. Mainframe computer on a computer floor tested on the USACERL TESS.

Figure 29. Digital-VAX mini-computer CPU supporting the MDICC.

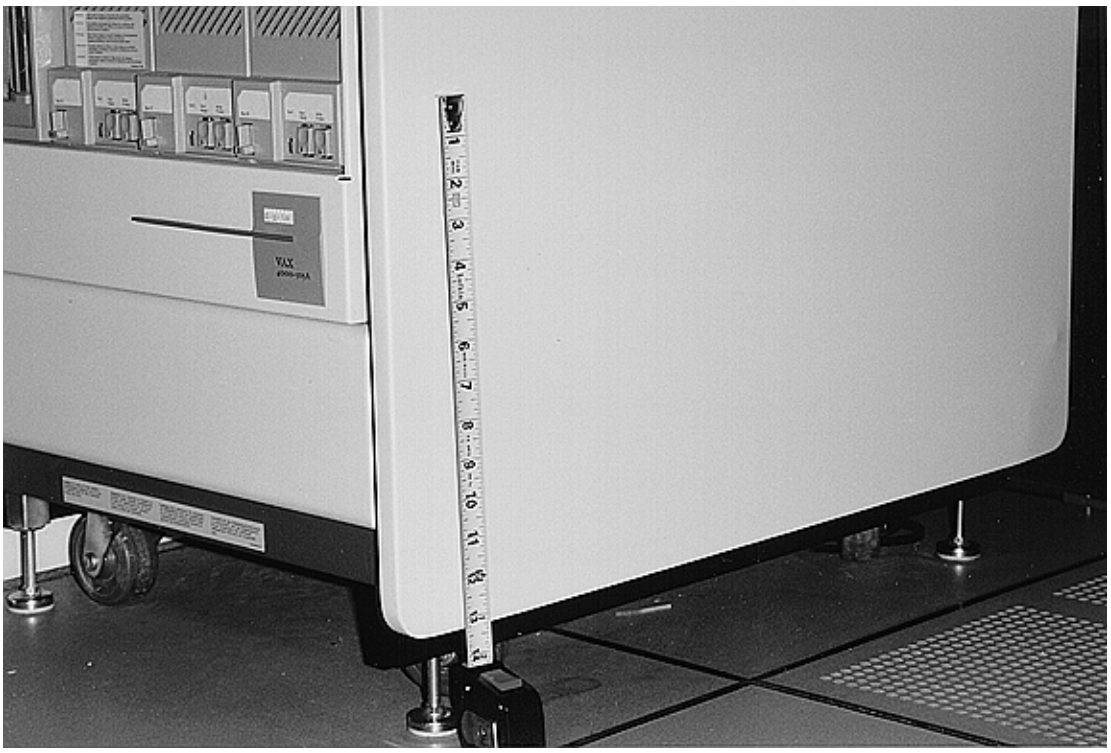

Figure 30. Close-up showing a lack of anchorage for the mini-computer.

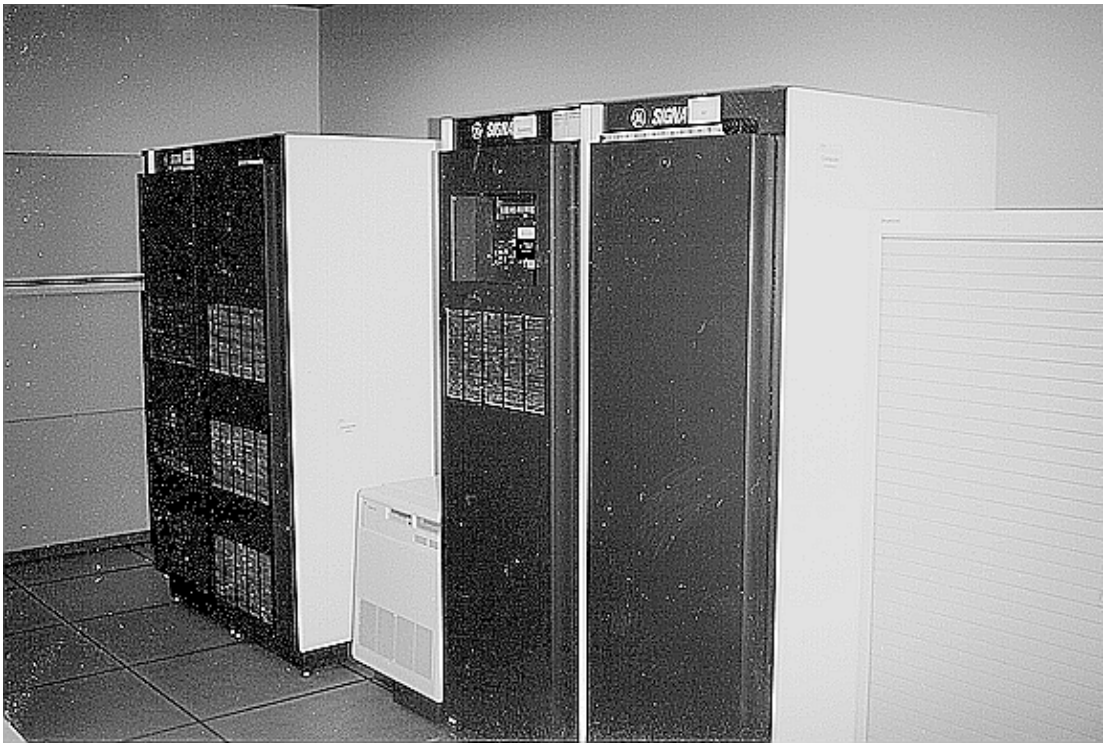

Figure 31. General Electric (GE) computers that control the MRI system.

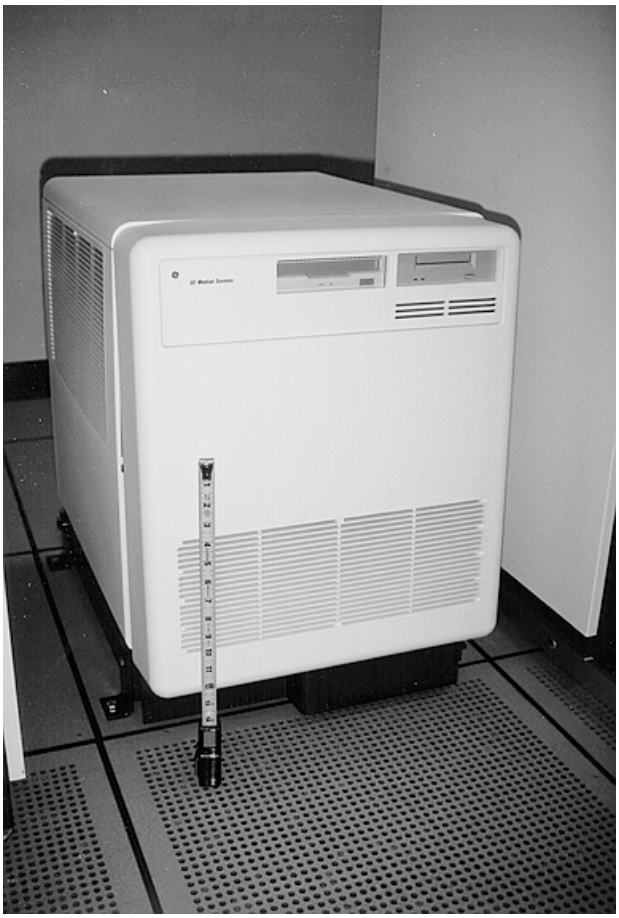

Figure 32. Computer that records MRI results, anchored to a single computer floor tile.

Figure 33. Tall unanchored pharmacy freezer with a narrow footprint.

Figure 34. Unanchored tall narrow shelves that may be secured in their present configuration.

Figure 35. Unanchored tall narrow shelves.

Figure 36. Small storage bins in the pharmacy.

Figure 37. Tall, narrow storage racks in the logistics area.

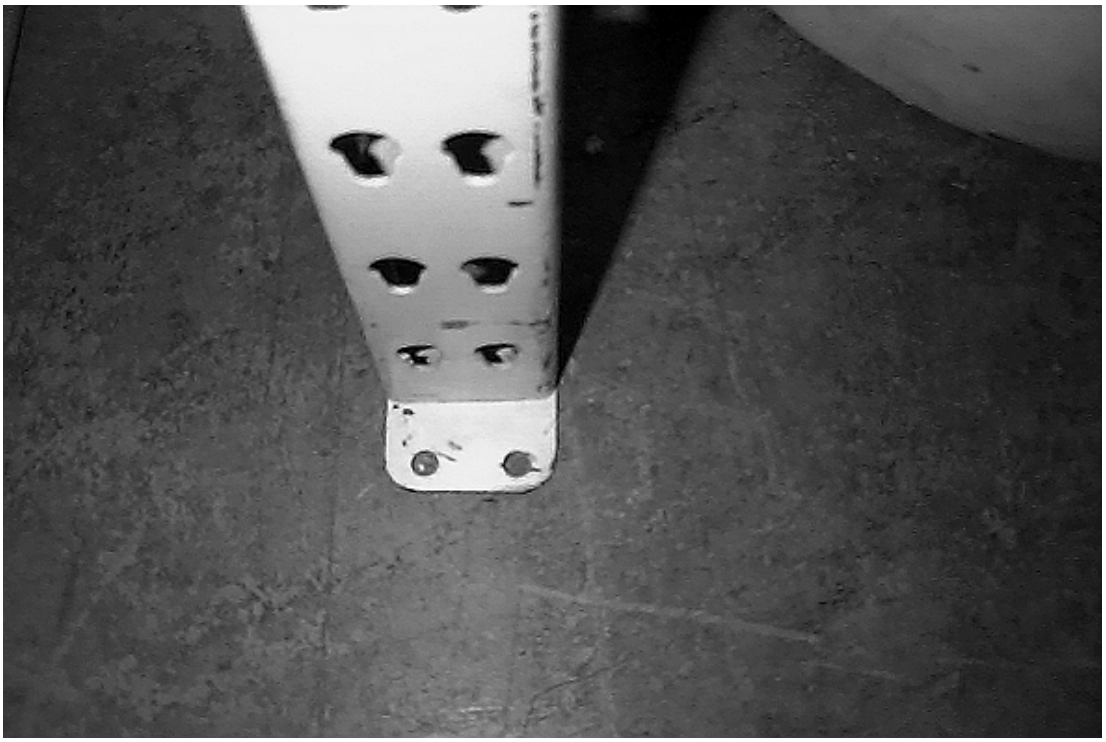

Figure 38. Close-up of logistics area storage racks showing lack of anchorage.

Figure 39. Loosely stacked barrels.

Figure 40. Tall, narrow milling machine.

Figure 41. Close-up of milling machine legs showing bolt holes for anchorage.

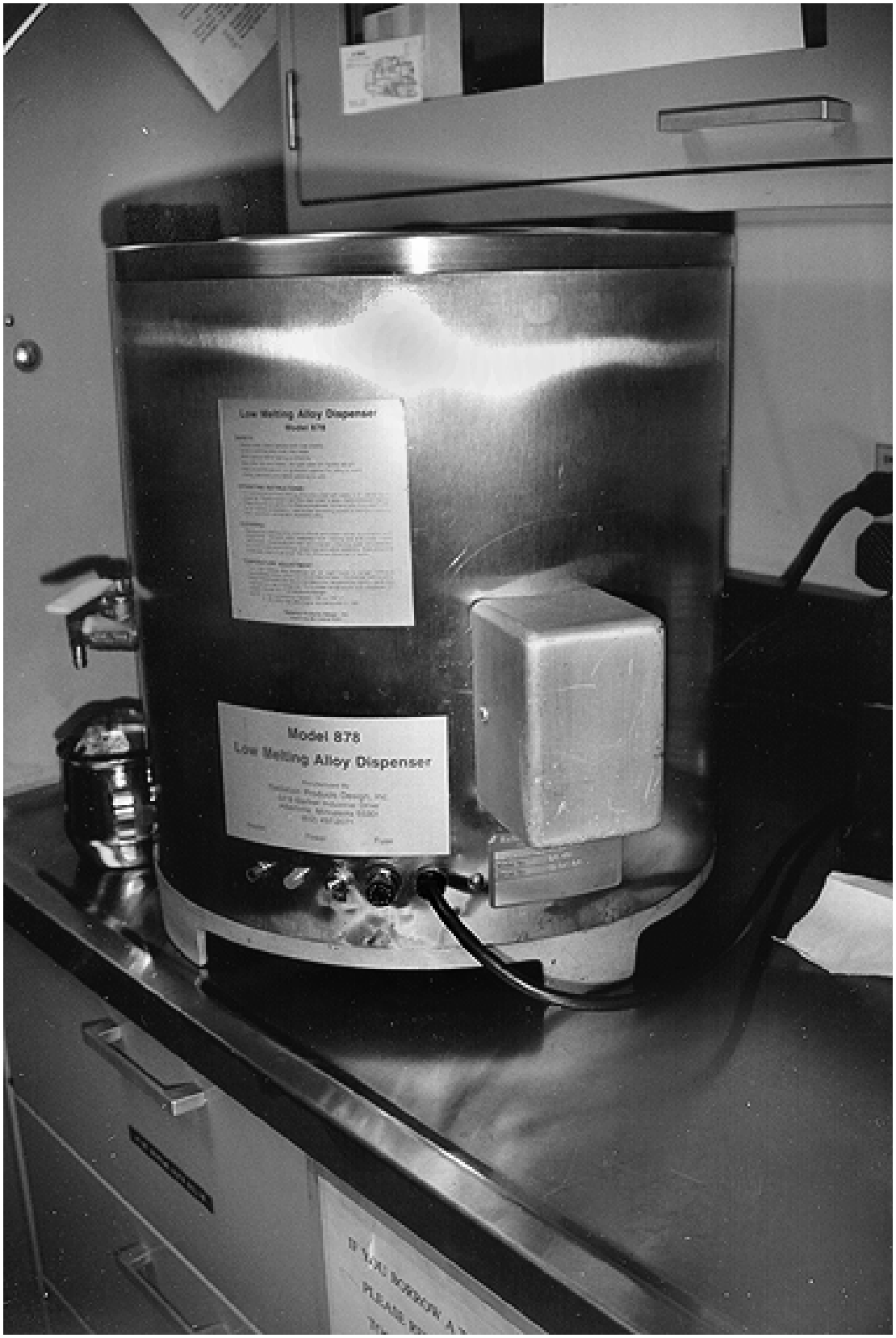

Figure 42. Low-melting alloy dispenser, shown resting loosely on countertop.

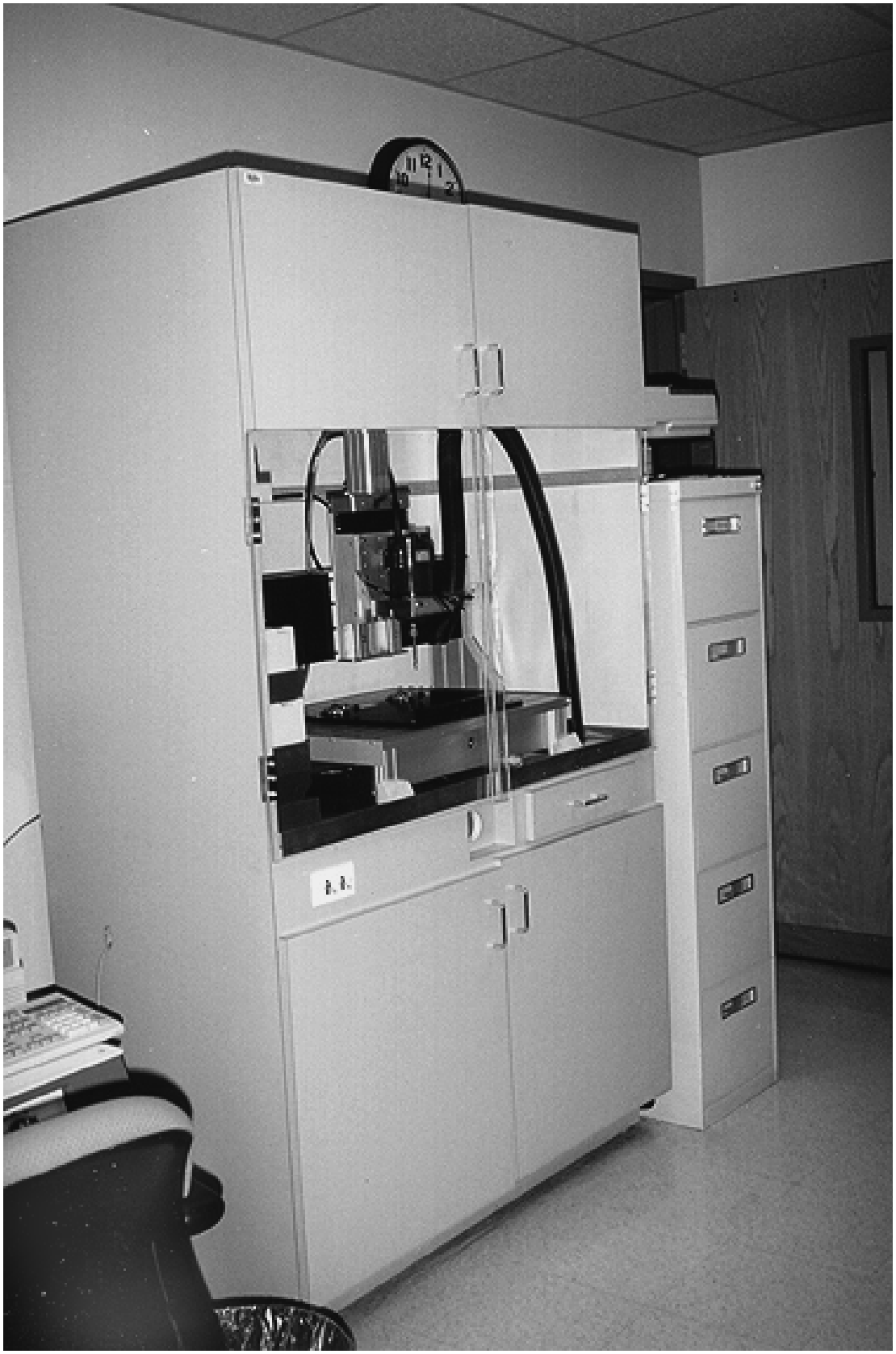

Figure 43. Unanchored typical laboratory equipment.

Figure 44. Unanchored desktop computer CPU and monitor.

Figure 45. Typical office file cabinet.

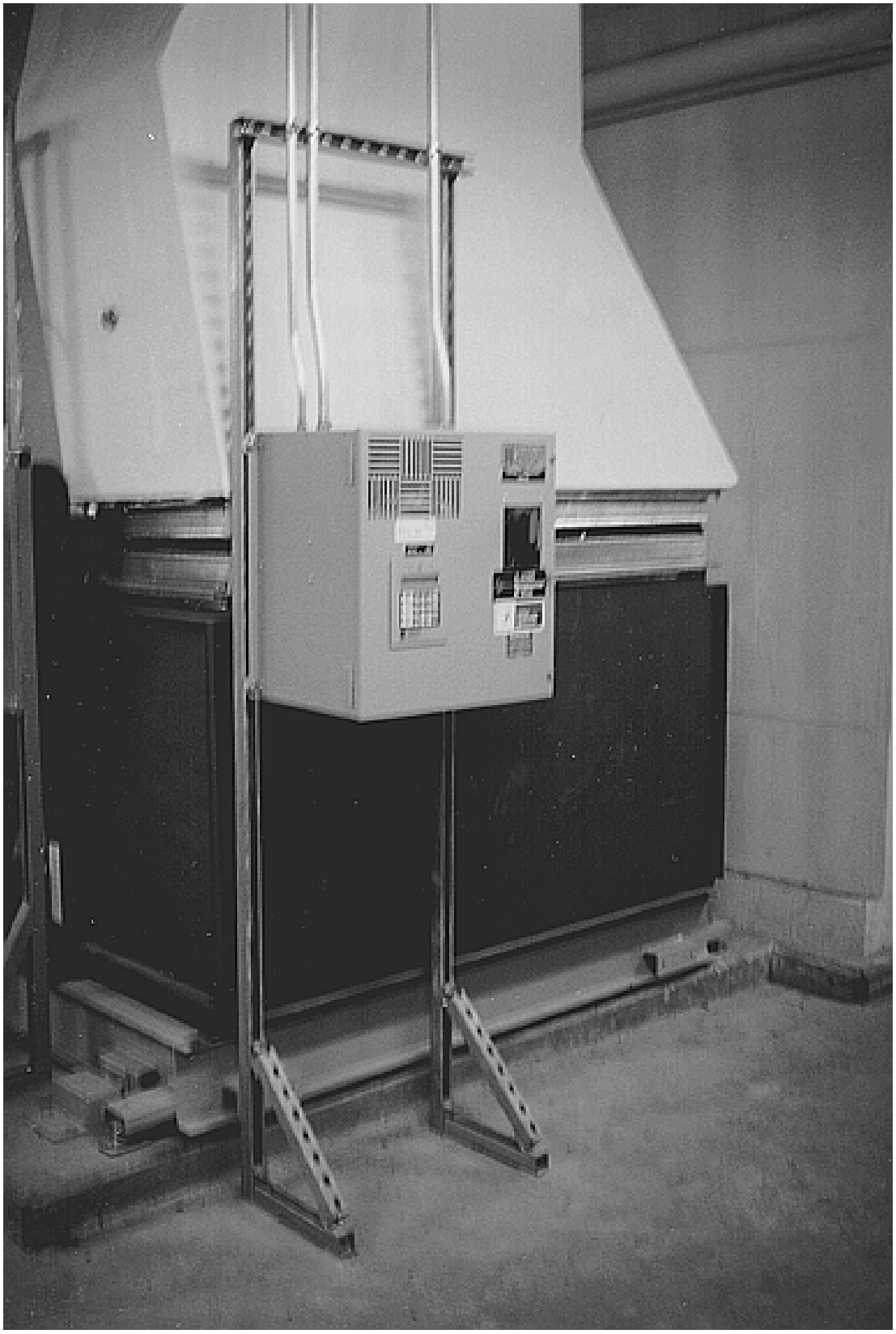

Figure 46. Unistrut frame with friction clips supporting air handling unit control panel.

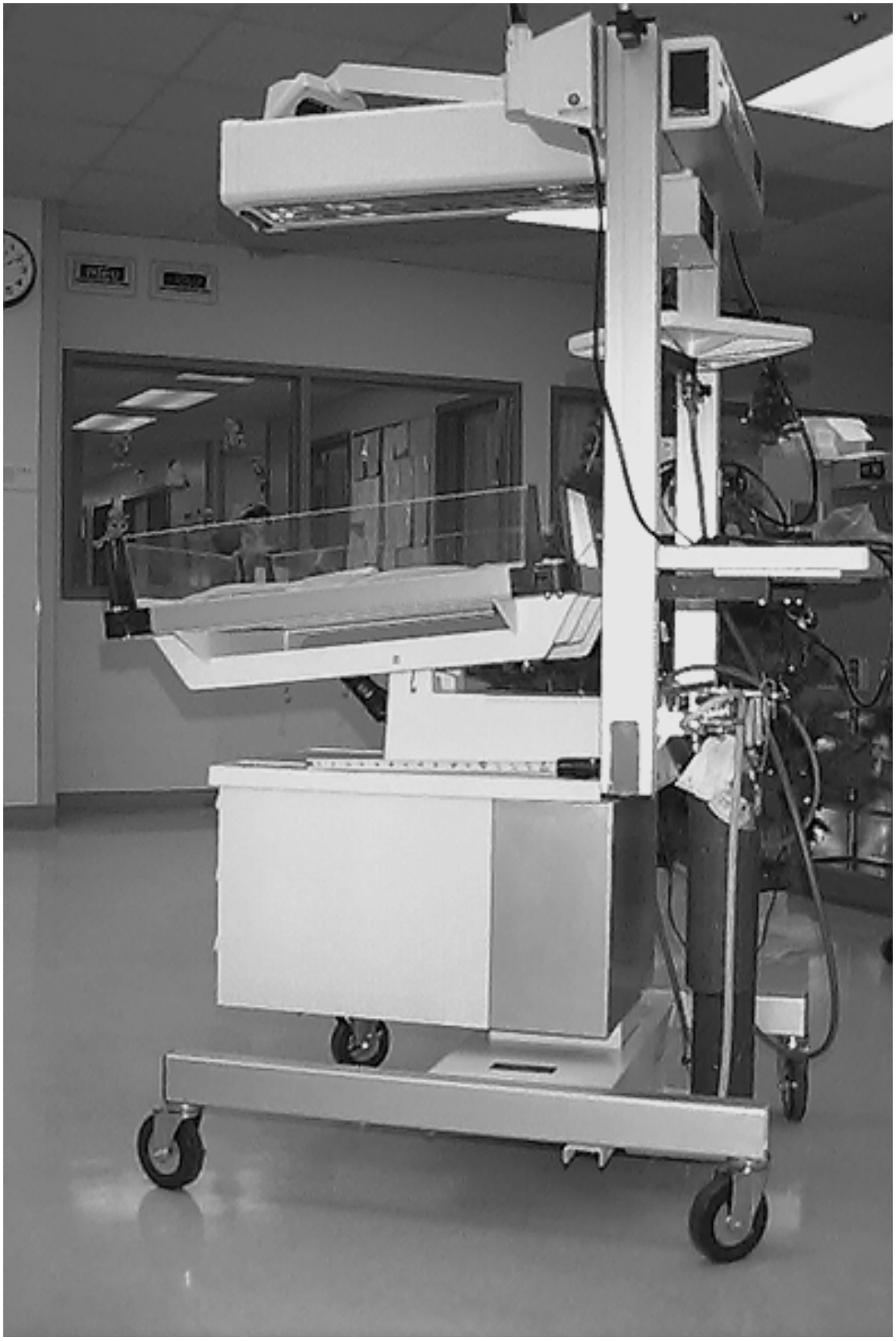

Figure 47. Nursery bed on wheels in the ICU nursery.

Figure 48. Monitor on wheels with a very narrow wheelbase.

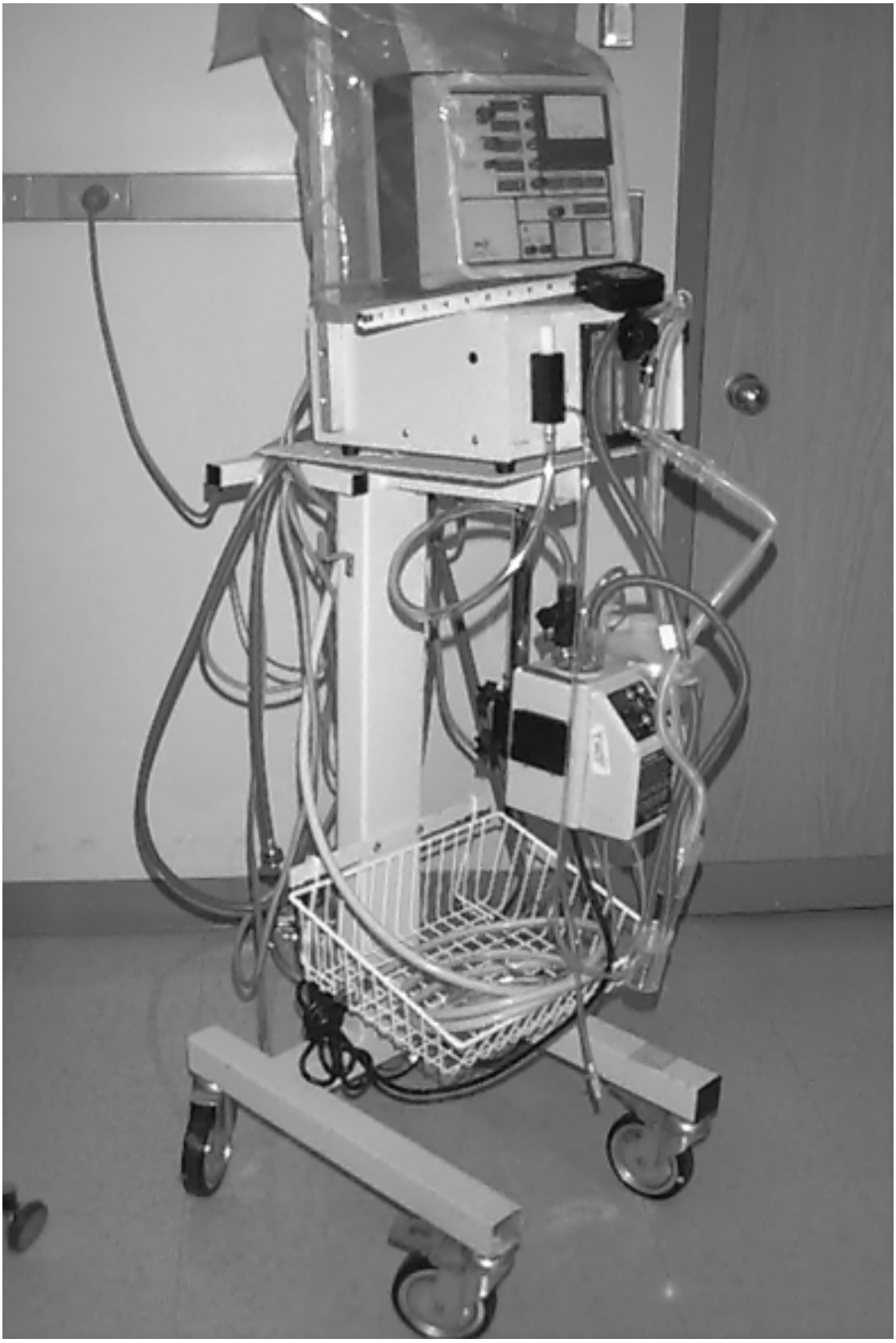

Figure 49. Other equipment on wheels with a narrow wheelbase.

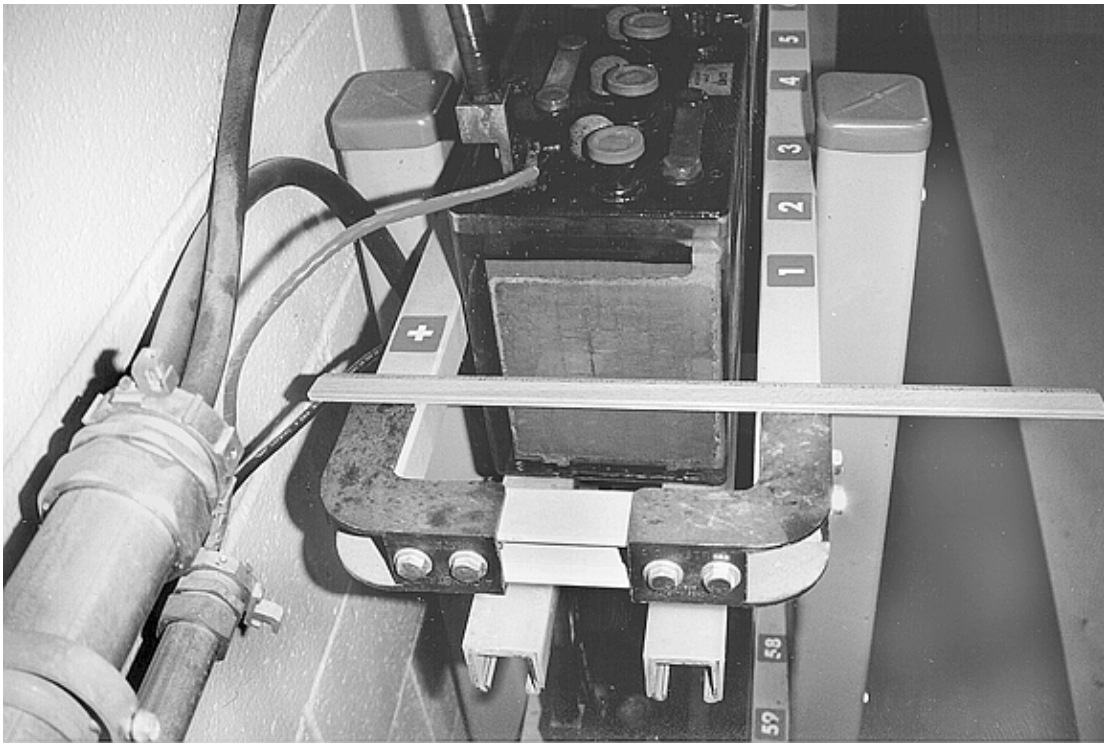

Figure 50. Close-up of station batteries showing lack of foam spacers.

Figure 51. Large hot water tank coupled to smaller tank, restraining differential motion.

Figure 52. Heavy conduit penetrating CMU wall, loading wall out-of-plane.

Figure 53. Front view of automated storage racks in the outpatient pharmacy.

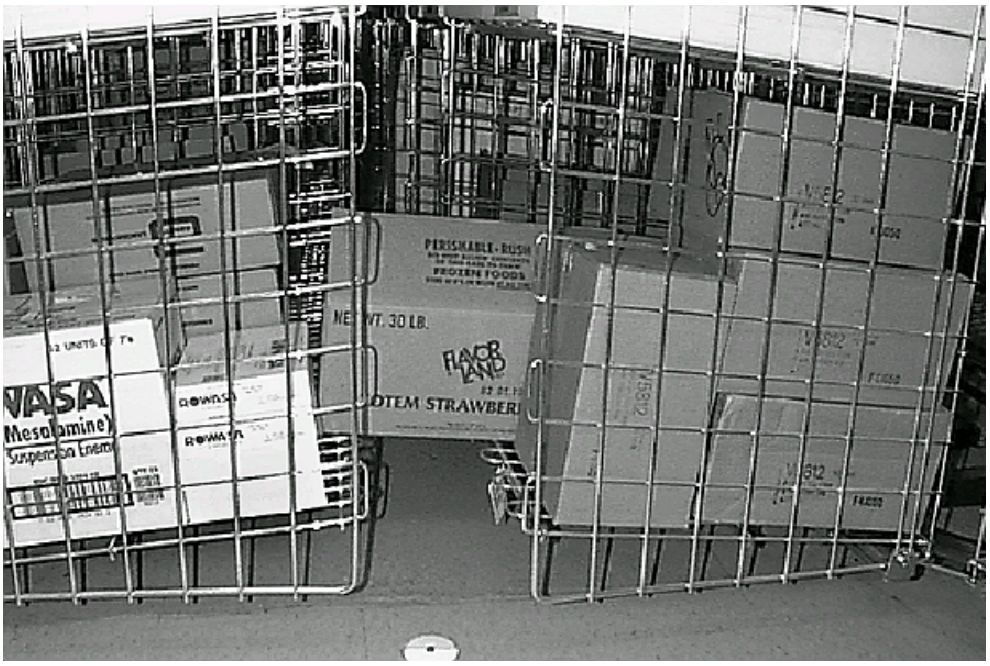

Figure 54. Close-up showing narrow gap between racks at bottom of automated storage racks.

4 Load Path Concerns for Well Anchored Equipment

Critical medical equipment was visually inspected at MAMC. The extent of this inspection was limited because equipment covers prevented the inspection of interior components. Evaluating the seismic resistance of well anchored equipment often requires shake table testing or detailed analysis when equipment material properties and construction are not well understood. Equipment is sometimes shipped with internal isolation. This is when a particular internal component is protected against shipping vibration damage by inserting protective isolation devices or pads. After the equipment is installed the isolation is removed, for the equipment to be operational. Equipment shipped with such isolation may also be vulnerable to seismic motions, and evaluation efforts could focus on these. USACERL will begin to investigate medical equipment seismic resistance by contacting equipment manufacturers and equipment procurement personnel to determine what equipment may have been seismically qualified and according to what standards. There appears to be a lack of guidance available for equipment manufacturers and procurement personnel on how to provide seismic resistance for equipment. Military Handbook 1191, *DOD Medical Military Construction Program Facilities Design and Construction Criteria*, simply references Army Technical Manual (TM) 5-809-10. In particular, Army TM 5-809-10-1, *Seismic Design Guidelines for Essential Buildings*, provides only equipment anchorage guidance, but requires certification of essential mechanical and electrical equipment based on experimental or approved analysis.[4] No guidance is provided on what experimental or analytical work is needed to constitute certification. USACERL plans to work with equipment manufacturers, equipment procurement personnel and appropriate technical committees[5] on the establishment of standards for the ensuring the seismic resistance of critical equipment. This

[4] Army TM 5-809-10-1, Seismic Design Guidelines for Essential Buildings, section 6-6, Mechanical and electrical elements, February 1986.

[5] An example is the Office of Statewide Health Planning and Development (OSHPD), which has responsibility for non-Federal medical facilities in the State of California.

chapter presents observations and some concerns about specific critical equipment at MAMC.

CT Scanner

Figure 55 shows a General Electric (GE) computed tomography (CT) scanner. According to medical staff at MAMC, the x-ray tube and detector array rotate in the circular ring shown in Figure 55. These can easily move out of alignment during a seismic event — particularly while spinning. The CT scanner may be the most vulnerable medical equipment at MAMC and, as noted previously, is of particular concern to medical staff.

X-Ray

Figure 20 (see Chapter 2) showed a GE standard x-ray (collimator) supported by a telescopic arm. X-ray equipment is critical for treating crush victims, so the continued operation of this and other related equipment should be ensured.

Gamma Cameras

Gamma ray cameras of various types, all manufactured by Siemens, were seen at MAMC. These include the single-head Orbiter, a single-square-head Diacam, and a triple-head Prism 3000 gamma camera. The triple-head camera is shown in Figure 56. Each head in this camera contains 60 glass tubes in rows, costing $3000 per tube. USACERL inspected the Sepulveda Veterans Administration (VA) Medical Center, which is located about 20 miles (32 km), Northwest of downtown Los Angeles, CA, shortly after the 1994 Northridge Earthquake. Figure 57 shows a single-head gamma camera that was damaged in the Northridge event. The camera was well anchored to the floor, but the mechanism at the base of the cantilever arm supporting the head was damaged.

Medical Digital Imaging Control Center

The MDICC is a critical system and contains several equipment components that could be vulnerable to earthquake motions. The Digiscan (Fuji 7000) computed radiography machine shown in Figure 24 (Chapter 3) contains an arm that manipulates x-ray film plates as a laser converts them to digital records. This system could be vulnerable to seismic motions even if well anchored. The

Kodak Optical Disk System (6800-ADL) shown in Figure 26 (Chapter 3) has components for manipulating optical platters containing x-ray image data; like the Digiscan device, it could be vulnerable even if well anchored.

Linear Accelerators

Figure 12 (Chapter 2) shows the Varian-CLINAC 2100C Radiotherapy Accelerator. This 18MV unit is the largest linear accelerator at MAMC. These accelerators appeared to be well constructed, but their seismic hardness is not known. Transformers are needed to step up power to the high voltages required by the accelerator, and these contain potentially vulnerable porcelain insulators. Figure 58 shows the transformer for the smaller Varian-TEM XIMATRON CX accelerator.

Overhead Examination Lights

Overhead examination lights such as the one seen in Figure 59 are located throughout MAMC. These are well anchored to the roof above, but the supporting arm appears questionable, especially when fully extended. These may have been seismically qualified, but further investigation is needed to verify that.

Figure 55. General Electric CT Scanner, potentially the most vulnerable equipment at MAMC.

Figure 56. Triple-head Prism 3000 Gamma Camera.

Figure 57. Single-head gamma camera damaged in the 1994 Northridge earthquake.

Figure 58. High-voltage power transformer for the Varian-TEM XIMATRON CX accelerator.

Figure 59. Overhead examination light, typical of those located throughout MAMC.

5 Related References of Interest

The following references are particularly significant for medical facilities:

National Earthquake Hazards Reduction Program (NEHRP) Recommended Provisions for Seismic Regulations for New Buildings; Part 1 – Provisions, FEMA 222A; and Part 2 – Commentary, Federal Emergency Management Agency (FEMA) 223A (May 1995). This is intended to serve as a source document for code writing bodies.

Non-Structural Earthquake Hazard Mitigation for Hospitals and Other Health Care Facilities, FEMA SM 370 (1989). This document provides guidance for emergency planning and suggestions for reducing nonstructural losses, with an emphasis on medical facilities. It is written for a nontechnical audience.

The Northridge Earthquake: A Report to the Hospital Building Safety Board on the Performance of Hospitals California Office of Statewide Health Planning and Development (OSHPD), Facilities Development Division (June 1995). This report provides a general overview of the structural and nonstructural performance of non-Federal medical facilities affected by the 1994 Northridge earthquake.

Northridge Earthquake Study of Seismic Design Factors for Hospital Non-Structural Components, URS Consultants for the California Office of Statewide Health Planning and Development (OSHPD), Contract Number 94-5124 (not dated). This report focuses on the building response of the Olive View Medical Center, located in Sylmar, CA. Using actual recorded motions, this study evaluates the building response during the Northridge event as it pertains to damage sustained by the hospital's nonstructural elements. The report also comments on the adequacy of current code provisions for seismic design. Particular emphasis was placed on the evaluation of equipment anchorage, rather than the seismic resistance of the equipment itself.

Observations on Hospital Performance in the Great Hanshin-Awaji (Kobe) Earthquake of 17 January 1995, California OSHPD (not dated). This report provides a general overview of the damage caused by and lessons learned from the 1995 Kobe earthquake. A comparison is made between practices in Japan and California. Of particular interest was the damage to diagnostic and

laboratory equipment that limited emergency care capabilities. These included Imaging (MRI), x-ray equipment, CT scanners, communication equipment, and blood analyzers.

Reducing the Risks of Nonstructural Earthquake Damage: A Practical Guide, FEMA 74 (September 1994). Written for a nontechnical audience, this document explains the sources of nonstructural earthquake damage and presents methods of reducing this damage. Chapter 4 provides numerous photographs of earthquake damage and schematic upgrade guidance; many details on equipment anchorage are included. The checklists in Appendix B provide a useful guide for walk-down inspections.

Seismic Considerations – Health Care Facilities, FEMA 150 (Revised May 1990). This document provides various general considerations with an emphasis on the NEHRP Recommend Provisions documents noted above.

Seismic Restraint Manual: Guidelines for Mechanical Systems, Sheet Metal and Air Conditioning Contractors National Association (SMACNA) First Edition, 1991. This document provides step-by-step guidance for seismic bracing for ducts, pipes and conduit. Connections to various structural members such as wood, concrete, steel, and steel joists are also shown.

Seismic Vulnerability of Equipment in Critical Facilities: Life-Safety and Operational Consequences, K. Porter, G.S. Johnson, M.M. Zadeh, C.R. Scawthorn, and S.J. Eder, EQE International, National Center for Earthquake Engineering Research Technical Report NCEER-93-0022 (November 1993). Section 3.5 of this report focuses on a specific hospital in the San Francisco area and presents various issues, with emphasis on utilities.

6 Summary

Critical functions at medical centers must continue to operate after an earthquake to provide immediate care for disaster victims. Protecting equipment at medical facilities in the immediate area of the earthquake is essential to maintaining these functions. Observations and recommendations were developed based on a walk-down inspection of MAMC but the general issues identified are pertinent to any medical center. Concerns are raised about the seismic resistance of specific well anchored equipment and the lack of technical guidance on ensuring the resistance of these. The principles, guidance, and concerns provided for this facility can also benefit other similar facilities.

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