NEW TECHNIQUES IN SHIELDING

The advent of Nuclear Magnetic Resonance (NMR) imaging technology has created a new and unique set of shielding requirements. Equipment manufacturers require a non-magnetic shielding system that exceeds 90 dB of attenuation to the magnetic fields and 100 dB attenuation to the electric fields over a frequency range from 1 MHz to 100 MHz. Hospitals desire a shielding system that provides flush, waterproof floors, high ceilings, and conventionally finished interior walls and ceiling. Since most NMR systems are installed in existing buildings, hospitals also require a shielding system that can adapt to unusual site requirements.

When developing new NMR shielding systems, there are three basic considerations. These decisions involve the type of material to be used, the thickness of the material, and the construction design.

While a variety of materials were potentially capable of meeting the shielding requirements, the magnetic considerations reduced the final choices to copper, stainless steel and aluminum. Aluminum was eliminated because of concern about the problems that could be encountered with long term oxidation and the resulting leakage. The lower mechanical strength and the difficulty of joining aluminum was another negative factor. Stainless steel was eliminated because of cost and joining considerations. After extensive evaluation, copper was chosen for the new NMR shielding system because it could be easily soldered or mechanically joined. It offers low contact resistance and good long term oxidation resistance. An all-copper structure also eliminated the problem of corrosion caused by the galvanic action between dissimilar metals.

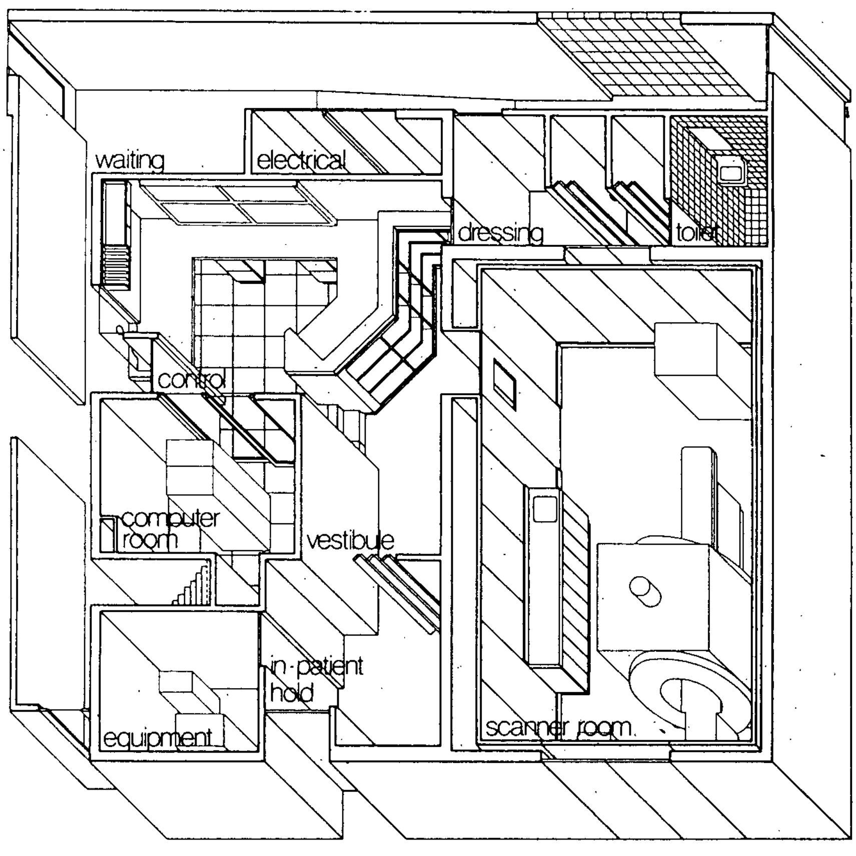

Figure 1. NMR Imaging, Facility, Huntington Medical Research Institutes, Pasadena, CA.

Experience with in-place single shields has shown the difficulty of controlling RF integrity or maintaining NMR shielding standards. While double-shield modular and welded enclosures offer adequate attenuation, high-cost magnetic considerations and the difficulty of finishing the interior are undesirable factors.

See LMI on back cover.

This design was used at the Huntington Medical Center in Pasadena, California (See Figure 1). In the rough construction stage, a conventional concrete floor was poured. The floor was then covered with copper and the seams were soldered. The soldering operation was easily accomplished since gravity was an aid rather than a hindrance. A second layer of concrete was then poured over the copper. The outside edges of the copper sheet were turned upward and protrude through the top layer of concrete around the perimeter of the room. The copper floor sheets were then finished into a perimeter mounting rail as shown in Figure 2. This allowed the use of prefabricated wall panels which reduced costly on-site construction time and permitted the use of proven joining techniques.

This type of floor construction has a number of advantages. First, the floor can easily handle the weight load of even the largest magnet and still assure total shielding of the underside of the room. The mechanical seams in floors made from modular panels can be adversely affected when heavy equipment or large nitrogen or helium dewars are rolled across the floor surface or placed over a mechanical seam. Secondly, the floor of the NMR room and the threshold must be flush with the floor in the rest of the building. This eases the movement of patient gurneys, equipment, and nitrogen dewars in the area. Lastly, this design provides a flat, waterproof surface that can be finished with tile, terrazzo, or any other type of floor covering.

In most locations, the shielded floor design is used over existing floors in parent rooms. In these cases, the copper sheets are bonded to the parent room floor and all seams are soldered. Two layers of ¼″ plywood are cross-lapped and bonded over the shield and finished with vinyl asbestos tile. The floor and threshold have only a ¾″ elevation rise. This design has no mechanical seams and is totally impervious to water.

Another option open to the room designer is to specify cable trenches or conduits in the floor. These cable paths can be placed in the concrete either above or below the copper shield. The use of trenches allows easy access to the wiring of the equipment and keeps the floor area clear of cables. If the cable trench is installed above the shield, the floor and trench covers can be finished in the same manner as the rest of the floor. The special floor design can also be used in conjunction with single- or double-shield modular panels to shield computer rooms. A raised computer floor grid can be installed over the floor to provide cooling air for computers and peripherals.

The walls and ceilings of the Huntington NMR room are modular panels made with a thin copper shield. Panels interlock on all adjoining surfaces in a manner that provides a high performance mechanical seal on every seam. The panels have an integral wood frame. This makes each panel lightweight and structurally rigid which permits high, self-supporting walls and long ceiling spans. The wall and ceiling panels weigh less than 1 ½# per square foot as opposed to 4#/ft.^{2} for metal clad ¾″ plywood panels. This simplifies the supporting structure for the shield and reduces construction cost.

The integral wood frame inside each shield panel facilitates conventional interior finishing and allows electrical conduits to be recessed inside the walls as shown in Figure 3. The walls can then be covered with drywall, paneling, or acoustical panels. Aluminum grid acoustical ceilings and exposed or recessed non-ferrous incandescent lights can be suspended from the ceiling frames. The panel design allows local electricians and carpenters to finish the room without major risk of affecting the shield integrity.

Some hospitals prefer to use fluorescent lights in place of incandescent lamps, since they offer more light with less heat. Unfortunately, fluorescent lights emit electromagnetic noise which can degrade an NMR image and interfere with sensitive measurements. Also, NMR requires a uniform magnetic field. Since the ballast of a fluorescent lamp contains a significant mass of magnetic material, it can adversely affect the magnetic field uniformity on some NMR systems. For these reasons, use of fluorescent lighting in shielded enclosures used for NMR is not recommended.

As with all high performance shielding systems, NMR rooms should be tested twice during construction. The first test should

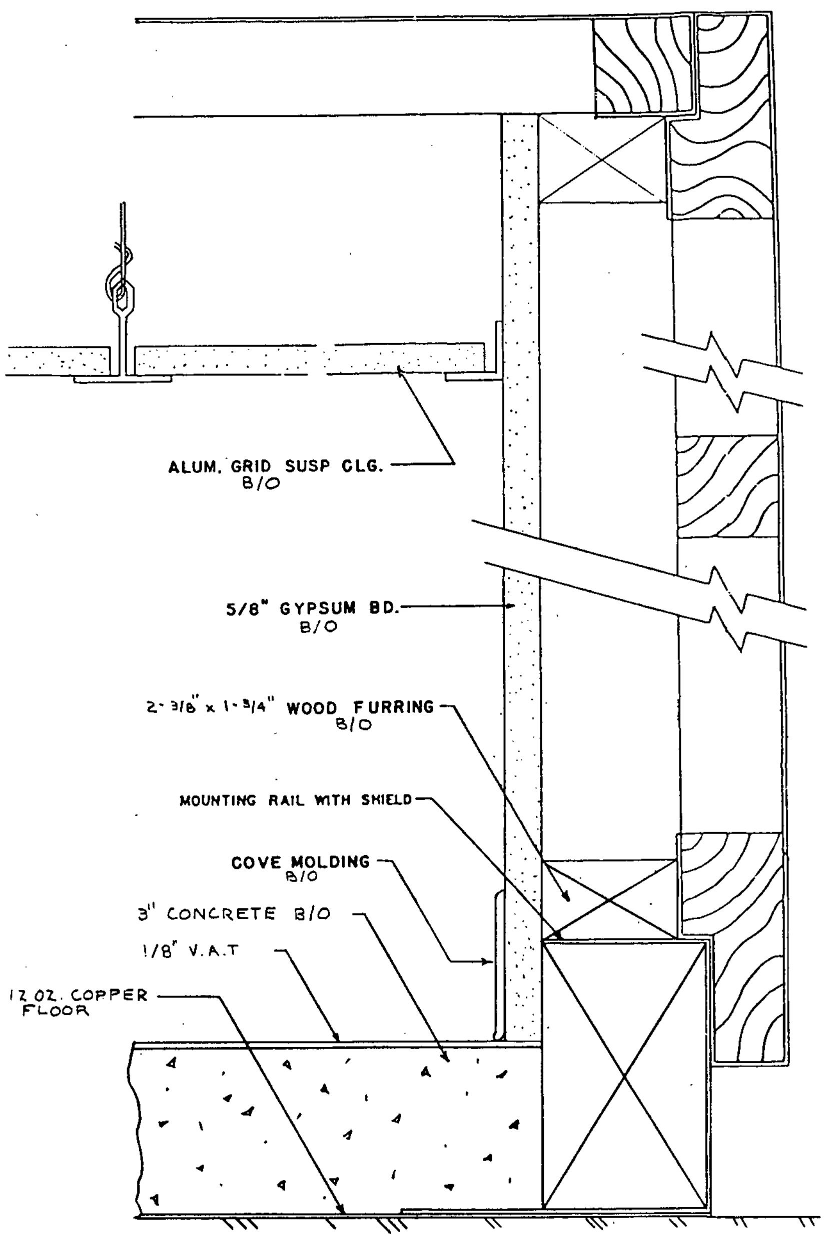

Figure 2. Finishing copper floor sheets into a perimeter mounting rail.

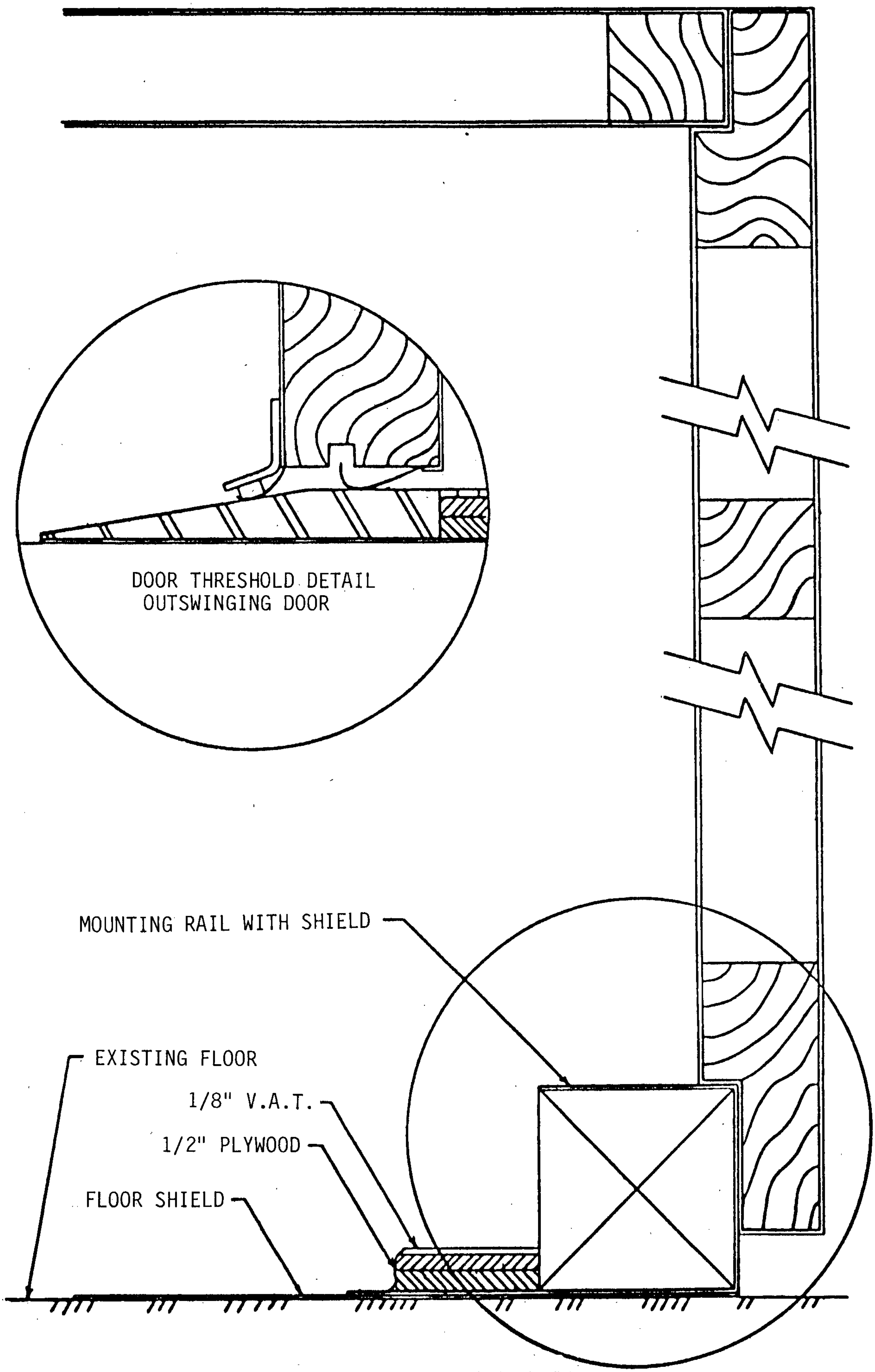

Figure 3. NMR wall construction with interior finishes.

be conducted when the shielding is completed and a second test should be run after the interior finish is applied. All testing should be done in accordance with MIL-STD-285. The first test verifies the integrity of the shield prior to room finishing. The second test simply verifies that the shield was not damaged during finishing.

The importance of shield integrity and single point grounding cannot be over emphasized. A shield with even a minor discontinuity is analogous to a pail with a hole in the bottom. Since even small discontinuities can have a major affect on shield performance, there must be very careful attention to seam integrity. Areas that require special treatment include floor drains, vents for helium and nitrogen boil-off, ventilation ducts, signal lines, and view windows. All water pipes, drains, and ducts must be interrupted close to the exterior shield with non-conductive links to prevent them from acting as antennas and conducting unwanted RF into the shielded area.

The door is the most difficult area to seal and certainly the most critical component in the system. Because of the requirement for a flush threshold, many designs have been forced to sacrifice one of the seals at the door bottom. The subject door design uses a brass threshold in conjunction with two separate, totally independent wiping contact surfaces.

Engineers have designed and built special brass waveguide floor drains that have been used at the AMC Cancer Research Center in Denver, the Albert Einstein Hospital in Philadelphia, and at the Planta Sotano NMR Center in Barcelona, Spain. These facilities also utilized custom waveguide feed-throughs with non-conductive links in water and gas lines. Special non-ferrous honeycomb waveguide air vents insure the integrity of ventilating ducts and air returns.

The subject of view windows and their effect on the integrity of a shield has been an area of considerable confusion. The two most common techniques for shielding view windows are to use glass coated with vaporized metal or metal screen. Unfortunately, vaporized metal performance varies with the amount of metal deposited on the glass. To date, manufacturers of metalized glass windows have not been able to develop an acceptable combination of transparency and shielding effectiveness. The upper limit for vaporized metal windows with suitable transparency is less than 60 dB at 100 MHz. Single screen windows can achieve 70 dB of shielding effectiveness at 100 MHz, however, this requires a mesh with less than 40% open area. Some fine wire monel view windows offer up to 70 dB at 100 MHz with 90% open area. Unfortunately, monel screen windows are smaller than those required for most NMR applications. The most effective window currently available uses two layers of screen which provides over 100 dB of shielding effectiveness at 100 MHz and with over 70% open area.

Just as a chain is only as strong as its weakest link, a shield is only as effective as its weakest component. Experience has shown that a properly designed single shield system can be built economically and still provide superior shielding. Single shield NMR installations, computer rooms, and security rooms can now achieve over 100 dB of attenuation while providing the amenities of flush floors and conventional finishing.

To illustrate the process of acquiring and installing an NMR unit, the case of Skokie Valley Hospital may hold some valuable insights.

Skokie Valley is a 370-bed community hospital located in Skokie, Illinois, a northern suburb of Chicago. The hospital's chief radiologist, has been following NMR imaging technology for more than three years. Last May he learned that Elscint, Inc., a diagnostic equipment manufacturer based in Haifa, Israel, was ready to sell its first NMR unit.

This was an important sale for Elscint, because Chicago was to be the location of the annual meeting of the Radiological Society of North America in only five months.

Terms of the sale were completed by mid-June, with the understanding that the installation would be complete by November 13, the first day of the RSNA Convention.

An intensive round of meetings were held with Elscint to layout a construction and installation timetable. It was decided that a 3,300 sq. ft. satellite addition to this new building would be the most convenient location for the new NMR unit.

The first order of business was to prepare a concrete slab and as much of the superstructure as possible in time for the delivery of the 7-ton magnet on September 10th.

Elscint had specified the construction of a completely shielded room to prevent any spurious RF signals and other electromagnetic noise from interfering with the faint radio signals emitted by the patient during NMR scanning. The frequency range most in need of isolation was 1-100 MHz with a requirement of 100 dB shielding effectiveness. This equates to a signal strength loss ratio of 100,000-to-1, from outside to inside the enclosure.

Interference such as computer clock pulses, CB or other mobile radio transmissions and even fluorescent light interference in the 1-100 MHz range could easily result in a lost or deteriorated NMR image, or worse, a false image.

In this case, shielding consisted of completely enclosing the magnet and scanning sensors inside a high performance, shielded enclosure. With such an enclosure in place, ambient RF signals and electromagnetic noise are either reflected or absorbed and carried directly to ground before they can be detected by the supersensitive NMR pickup devices.

An additional consideration was the requirement for non-ferrous metals in the shielding system. Any significant amounts

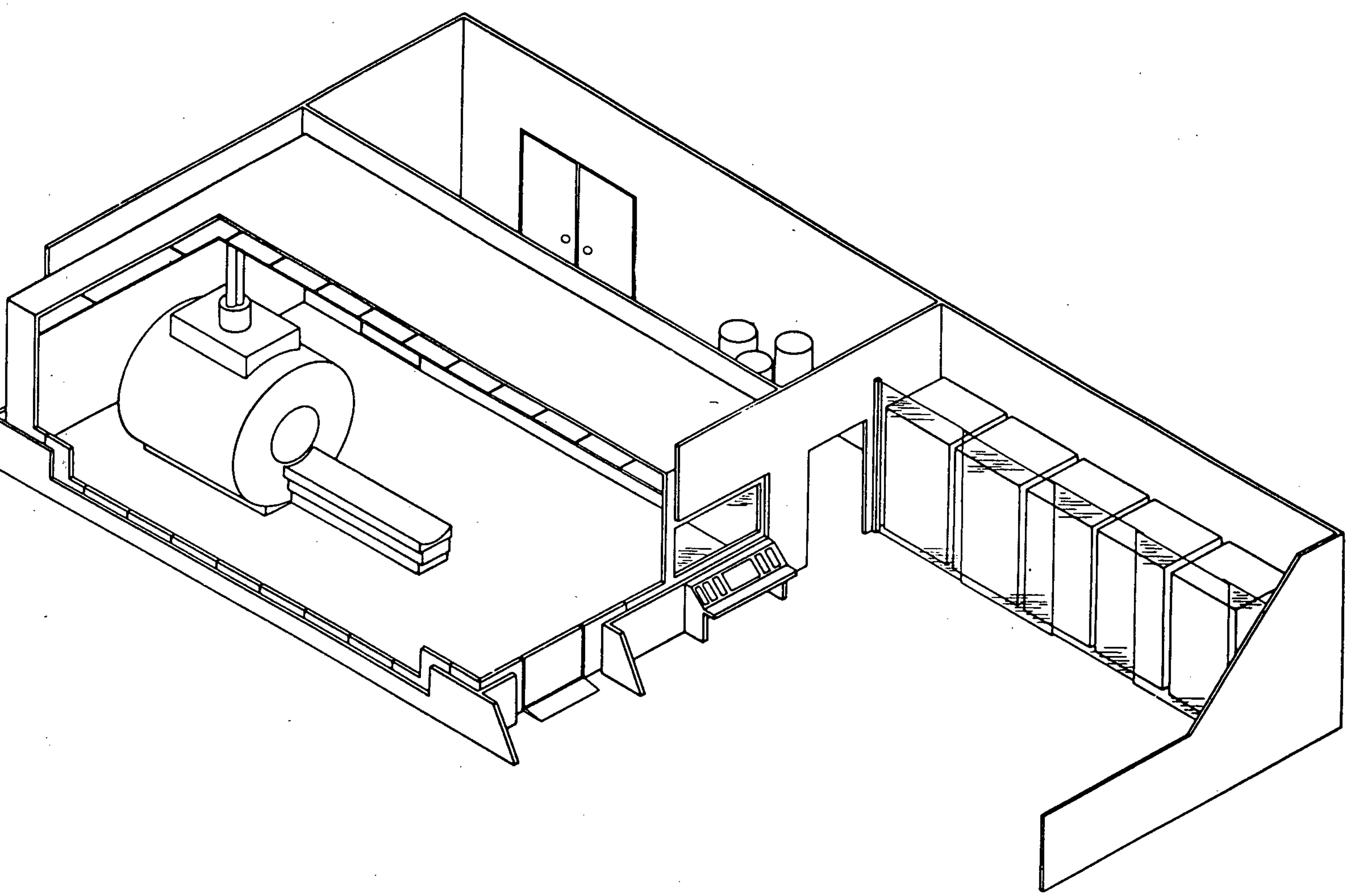

Figure 4. Skokie Valley Hospital NMR Center, Skokie, IL.

of magnetic material inside the room could disturb the finely tuned magnetic field and create distortion in the images. This made it impossible to use most RF shielding systems.

Architects also wanted the Elscint machine to be supported by a solid concrete floor making it necessary to sandwich the floor portion of the shield inside the concrete slab.

At this point, the focus of planning shifted quickly to the selection of a shielding supplier. A review of available sources disclosed that only three companies had NMR shielding installation experience.

The evaluation of sources was thorough but fast due to the pressure of time. One source provided a strong recommendation to use a solid copper shielding system with no mechanical seams in the floor. Since the objective of the shielding was long-term NMR image quality assurance, the recommendation for copper was selected.

With the decision to proceed, the installation crew immediately set to work on the floor portion of the shield which was to be covered with a second pouring of three inches of concrete. To assure reliability, heavy copper sheets were soldered together to create one continuous copper floor shield with no mechanical seams. Special wave guide penetrations were placed in the concrete floor to allow power and control wiring to enter the room beneath the magnet without compromising RF integrity.

When the huge magnet arrived on September 10th, the floor had set properly and the superstructure was nearly complete. After it was moved into place, the rest of the building and the shield were literally constructed around it.

Plans called for two shielded doors: one 3′5″x6′8″ door for patient and technician traffic, and a second 4′x7′ door at the rear for service. The rear door opened into a small utility room where the liquid helium dewar was to be stored.

Since the doors are the only active components in any shielding system, they're also the most critical. Constant opening and closing stresses can effect RF integrity over a long period of time.

In anticipation of stress, the NMR shielding doors are specially designed and built to take punishment. The doors installed at Skokie Valley Hospital are supported by four heavy-duty hinges to create a sag-free mounting. Each one is actually a double shield: two independent shielding surfaces with two independent sets of contact fingers for a double seal on the threshold and along all sides of the door frame.

These special doors are equipped with an inside 28″ panic-type bar handle which operates a three point clamping system. When this handle is pulled up, the door is drawn into an extremely tight, "leak-free," closed position.

The thresholds were ¾″ "easy roll" thresholds to accommodate patient carts and, in the case of the back door, the 400- to 500-lb. dewar of liquid helium.

One 3′x6′ viewing window was also included, allowing technicians to observe patients clearly during NMR scanning. In this case, two bronze screens, 71% open, were placed between the window panes to give the best possible visibility with no loss of shielding value.

The Skokie viewing window was constructed as a removable module to permit easy replacement with a higher visibility screening material when it becomes available.

"Leak free" air circulation is achieved by the use of ventilators made from honeycombed, tin-plated brass tubes. This type of vent allows air to pass freely while blocking unwanted electromagnetic signals.

Lighting was brought inside the shielding system by eight non-ferrous, incandescent lamp fixtures, all controlled by an external dimmer switch.

The installation of the shield was completed in just two weeks as U.L. approved, fire-treated, wood-furring strips were mounted on walls and ceiling to permit drywall finishing.

The Chicago RSNA show opened just as the last roll of wallpaper was being applied and the new facility was used as planned to demonstrate Elscint's new NMR imaging system to hundreds of radiologists.

Several aspects of this installation are remarkable. 1) The project moved from an idea to reality in just five months, as a result of extremely close coordination between the general contractor and the shielding project manager. 2) The decision to sandwich the floor shield between two layers of concrete was implemented to create a highly stable concrete platform for the huge NMR magnet. 3) The cost of the Skokie Valley NMR building and all shielding is reportedly less than one-half the cost of the installation of a similar unit installed by a large university hospital center in the same area just a few weeks earlier.

This article was prepared for ITEM '84 *by William E. Curran, President, Lindgren RF Enclosures, Inc., Addison, IL.*

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