20. Long-Term Patient Care and Maintenance

Patients who have been cryopreserved for the indefinite future are sometimes described informally as being “in storage.” This term unfortunately implies that they are comparable to products in a warehouse. The phrases “long-term care” or “long-term maintenance” are preferable, and will be used here.

Similarly, Alcor refers to the location of its cryopreserved patients as the “Patient Care Bay” (shown in Figure 20-1). Patient care during long-term maintenance includes not only protection of patients from all forms of harm, but necessary physical handling such as transfers to different containers.

Figure 20-1. Alcor’s patient care bay photographed in 2017. The original white dewar that once contained Dr. James Bedford is just visible in the center at the far end of the floor space.

Options for Maintenance

Ever since the earliest days of cryonics, the primary goal of all organizations has been to prevent chemical reactions in the human body by maintaining patients at a low temperature. While other methods of preservation are available, such as chemical fixation, reversal and revival will require major repairs on a molecular level. Generally speaking, we believe that maintenance at a low temperature may enable a better chance of revival than other options, provided we use precautions to minimize injuries associated with the cooling process.

The question is, how low a temperature is low enough?

As has been discussed in Section 17, transport of a patient from a remote location to a cryonics facility is often done in water ice. While this may be acceptable during the time taken for transport, it is not acceptable for long-term maintenance.

Carbon dioxide freezes at –79 degrees C, at which point it is often referred to as “dry ice.” Because it can be obtained fron many retail sources and is not expensive, it has been used for temporary preservation of cryonics patients when other options were unavailable, and is still used for transports that may take more than 24 hours—for example, from an overseas location.

Because the temperature at which dry ice vaporizes is –79 degrees C, tissue treated with vitrification solution will remain liquid and will be unstable against chemical change. The vitrification solution will also be unstable against formation of ice crystals. Therefore, dry ice is not suitable for long-term maintenance of cryonics patients.

The ideal maintenance temperature for a vitrified patient will be below Tg, the glass transition point, as discussed in Section 19. Therefore, a long-term maintenance temperature is ideally colder than –130 degrees C.

Low-temperature refrigerators are available commercially, capable of maintaining that temperature, but have been used very rarely in cryonics. They are expensive and relatively unreliable in the long term. They also create substantial waste heat, so that ventilation or active cooling of the environment may be necessary. For example, the Harris Cryostar laboratory freezer unit, further discussed below, can maintain samples at –130 Celsius but generates

so much heat from its 5 kilowatt electrical power draw that additional room air-conditioning is required to operate it reliably. A dewar system is preferable in several respects, as discussed below.

Most cryonics patients are usually immersed in liquid nitrogen for long-term maintenance. This is an attractive option in several respects.

A warmer object will transfer its heat into the liquid, increasing its rate of vaporization. So long as this process continues, the temperature of the liquid remains constant. This results in a stable maintenance temperature, so long as liquid remains. The system has no need for the thermostat, pumps, or power supply that are required in conventional refrigeration. The liquid lost through vaporization is often referred to as *boiloff*.

In conventional medicine, liquid nitrogen is used to cryopreserve sperm, ova, embryos and some tissue samples. In cryonics, it was used for the cryopreservation of the first cryonics patient, Dr. James Bedford, in 1967. Immersion under liquid nitrogen is still the most widely used method of patient maintenance in cryonics today.

Fortuitously, liquid nitrogen is created as a common industrial byproduct and can be delivered in most urban areas in a tanker truck. Purchased in bulk, it costs between 10 and 20 cents per liter (in 2017 prices). If a cryonics organization maintains a bulk storage tank, this can be used as a distribution point to top off insulated containers as required. The system offers several advantages:

- Very reliable.
- No power supply needed.
- Silent and odorless.
- Because nitrogen is relatively nonreactive, it can be allowed to come into direct contact with the patient.

However, there are some disadvantages:

- Maintaining patients reliably at a temperature other than –196 is difficult (although not impossible).

- When all of the liquid has vaporized, the temperature is no longer constrained.
- Reliable deliveries from a local supplier are required. The equipment and electric power necessary to liquify nitrogen from air on site would be several times as expensive as delivered liquid nitrogen, making such systems impractical except as expensive emergency backup.
- Handling nitrogen at –196 can be physically hazardous. Precautions are necessary.
- If the heat insulation of a container fails, liquid nitrogen will vaporize rapidly.
- Uncontrolled release of nitrogen gas in an enclosed, unventilated area can cause asphyxiation.
- Rapid vaporization fills an enclosed area with white mist that can reduce visibility almost to zero.

Cryonics organizations have been unanimous in their belief that the advantages of liquid nitrogen outweigh the disadvantages. The question is how to contain the liquid safely and reliably, minimizing heat incursion so that replenishment is required on a relatively infrequent basis.

Dewars and Cryostats

A cryostat is a vessel capable of maintaining a static cryogenic temperature (below –100 degrees C) internally, by any method. A dewar is a type of cryostat that is insulated by high vacuum and internal thermal radiation reflectors.

In the field of cryonics, the Cryonics Institute uses cryostats that are insulated by soft-vacuum and perlite and are fabricated from fiberglass. Alcor has preferred to use dewars fabricated from stainless steel, fabricated by companies that specialize in cryogenic storage.

In either case, an inner container is nested inside an outer container, the two being joined at the top, as shown in Figure 20-2.

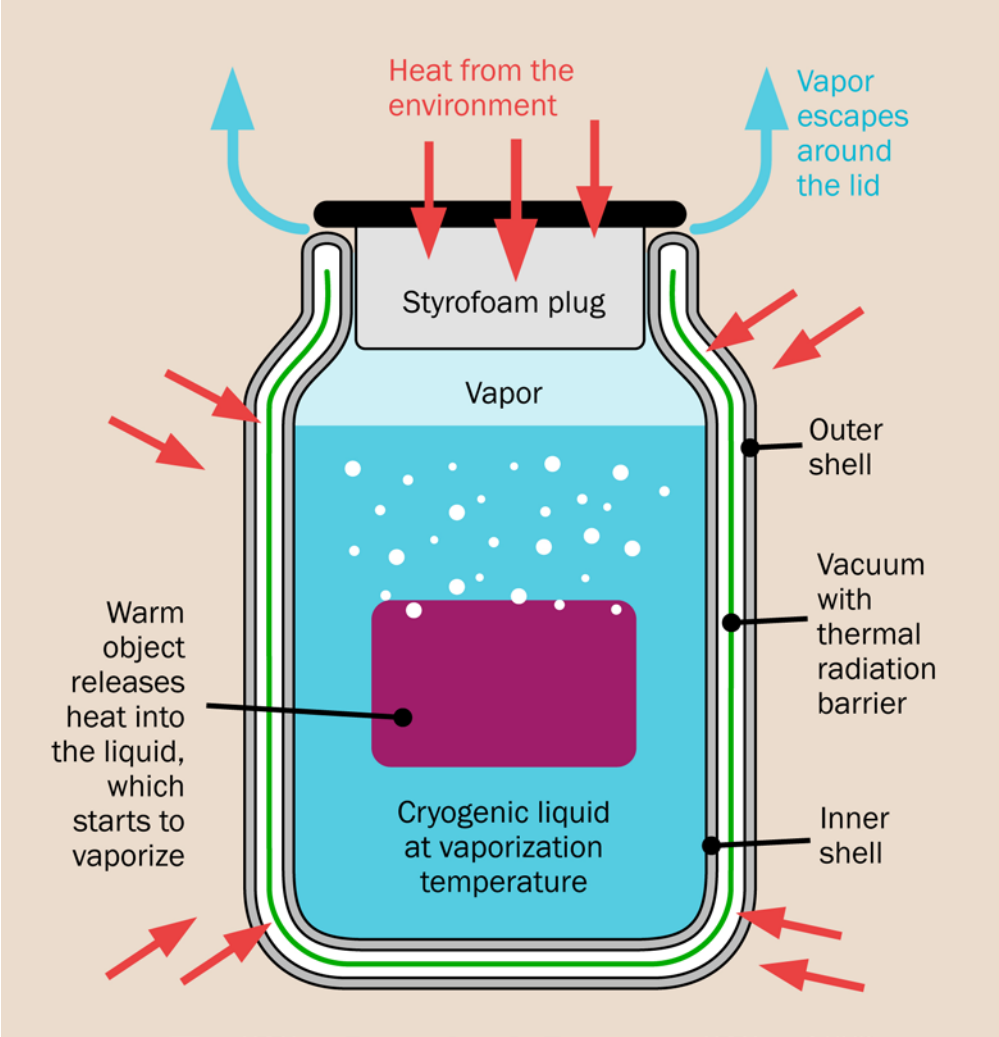

Figure 20-2. Basic features of a double-walled cryostat or dewar.

Bearing in mind that heat is transferred by convection, conduction, and infrared radiation, a dewar or soft-vacuum cryostat prevents heat incursion in all three ways:

Soft-vacuum Cryostat

- Conduction is minimized by separating the inner shell from the outer shell by approximately one foot, filling the space with porous perlite pellets, and removing air from this space to create a soft vacuum that within the perlite is more insulating than ordinary foam insulation of the same thickness.
- Convection is reduced by removing almost all air from the space between the inner and outer shell, and restricting movement of remaining air by filling the space with perlite.
- Radiation heat transfer is blocked by presence of the opaque perlite between the inner and outer shells.

Dewar

- Conduction is minimized by separating the inner shell from the outer shell by approximately one inch, and removing practically all air from this space so that the mean free path of air molecules becomes greater than the space between the shells (the threshold condition for vacuum to become thermally insulating).
- Convection is eliminated by removing practically all air from the space between the inner and outer shell.
- Radiation heat transfer is blocked by including multiple thin layers of reflective mylar "superinsulation" in the vacuum space between the shells.

The advantages of soft-vacuum cryostats are that the vacuum necessary to operate (determined by making the mean free path of air molecules larger than the very small porous cells inside the perlite) is easier to achieve than the high vacuum required by dewars, and vacuum failure is not as urgent as vacuum failure of a dewar because the thick perlite-filled wall of a soft-vacuum cryostat is a reasonably good thermal insulator even without vacuum. The advantages of a dewar are its much smaller external size and greater

portability for a given internal volume, because the wall of a dewar is very thin.

In the early days of cryonics, obtaining a suitable container for patients was the single largest expense, creating an initial barrier to providing any kind of service.

History

When Robert Ettinger's book *The Promise of Immortality* was published in 1964, readers who became excited by the concept assumed that large corporations would take on the task of fabricating the equipment and developing the procedures that seemed urgently necessary.

"The time for action is now," New Yorker Saul Kent wrote in a personal letter to Ettinger. "Research must be intensified! People must be properly informed and persuaded! Equipment for body preparation and facilities for storage must be made available!"

Ettinger shifted the onus back to Kent, suggesting that he should contact Curtis Henderson, another reader who had contacted him from the New York metropolitan area. Together they founded one of the first organizations, the Cryonics Society of New York (CSNY), with Karl Werner, who coined the term "cryonics."

Dewars were already in common laboratory use to preserve biological samples, but were not generally large enough to contain a human body, and none of the founders of CSNY had enough money to commission a custom-built vessel. However, Henderson owned stock in Union Carbide, so he went to a stockholder meeting. "I suggested they should build tanks for us," Henderson recalled in an interview many years later, "and of course they gave me a look, like—well, I got used to that look during the next few years."

Meanwhile, Robert Ettinger was appearing on TV talk shows, stating that businesses had already been formed and were ready to freeze people. "The Johnny Carson show," Kent recalled later, "was very big then . . . [Ettinger] showed a drawing of a facility allegedly being built by a company called Cryolife in Kansas City, Missouri, and he just repeated what they guy

had told him, and said there were going to be thirty of these in existence by the end of the year."

"I was sure it wasn't true," says Henderson. "There were just some people out there looking for money. And there was no money."

To settle the matter, Henderson and Kent drove across the country, checking out the businesses that Ettinger had publicized. None of them turned out to be genuine until they found a man named Ed Hope in Phoenix, Arizona.

Hope ran a small company that imported wigs from Germany, but he had made enough money to equip a manufacturing facility, had hired a couple of engineers, and was building his own cryogenic storage tanks. "We spent a couple of weeks there," Henderson recalls, "learning about high vacuum, helium-leak detectors, and all the rest of it. By this time we were facing the fact that cryonics was going to be a back-alley kind of thing."

Henderson gave Hope $200 as a down payment on a tank. Hope wanted $1,000 but he allowed the debt to be paid off over 32 months at $25 a month. This is how CSNY came to be the first cryonics organization to own the fundamental piece of equipment that would enable them to cryopreserve a human being.

Kent and Henderson extended their cross-country journey to Los Angeles, where they met Robert Nelson, president of the Cryonics Society of California. Nelson ran a TV-repair company, but had greater ambitions. Unfortunately, Henderson's work as an insurance adjuster had taught him how to run a credit check. "He was telling me all these things," Henderson recalls, "but I'd already found out that his wife was supporting him by working as a teller in a bank."

Despite its humble origins, CSNY became the largest cryonics organization in the country. But as things worked out, Robert Nelson stole the first share of glory. In June, 1966, a biologist named James Bedford had written to Robert Ettinger offering to fund cryopreservation research. Bedford's interest soon turned out to be personal: He had been diagnosed with liver cancer, which had spread to both lungs, and he was starting to consider the possibility of being frozen himself.

Since Bedford lived in Southern California, Ettinger referred him to Robert Nelson. Nelson later claimed that freezing someone was the last thing

he wanted to do, because he wanted to fund serious research, and he feared the consequences of sensationalistic publicity. Still, when Bedford was pronounced dead on January 12th, 1967 at the age of 73, Nelson organized the effort to freeze him. The rather primitive procedures were written up in *Life* magazine, after which Nelson overcame his shyness and made public appearances to promote the concept of cryonics.

James Bedford was transported on dry ice in a U-Haul vehicle to Phoenix, where he was installed in one of Ed Hope's tanks. He had left a bequest intended for research, and some of this money was probably used to finance his own long-term maintenance. In 1973 he was relocated with the Trans Time cryonics organization near Berkeley, California. He remained there until his family took possession of him, still in the same tank, in 1977. In 1982 he was moved to Alcor, and in 1991 his body was transferred into one of Alcor's dewars. The tank in which Bedford had resided remains on display in Alcor's patient care bay, and is shown in Figure 20-3. Figure 20-4 shows Curtis Henderson in his back yard in Sayville, Long Island, in a photograph taken in 1992.

Henderson legally died in 2009 and was cryopreserved by the Cryonics Institute.

Figure 20-3. The original dewar that contained James Bedford, MD.The EverAfter logo on the endcap was from later use as a movie prop.

Figure 20-4. Cryonics pioneer Curtis Henderson in his back yard in 1992, with an unknown tank formerly used for human cryopreservation.

The horizontal configuration used by Hope facilitated the installation of a patient on a narrow steel table that slid into the tank on runners, but the lid then had to be welded shut. Pipes that penetrated the lid allowed liquid nitrogen to be refilled and vented, and also allowed the use of a vacuum pump if necessary.

Curtis Henderson was the first to see the advantage of rotating a dewar to a vertical position, which eliminated the need for the vessel to be sealed and allowed removal of a patient if circumstances required it. All of the dewars and cryostats at Alcor and the Cryonics Institute now have a vertical configuration.

Equipment at Alcor

At Alcor, dewars capable of holding two whole-body patients were used until the number of cases justified a larger container. The so-called bigfoot dewar (named because of the five large casters that protrude around the edges of its base) has become the default size, with sufficient space for four whole-body patients plus five neuropatients in a central column. A bigfoot dewar is shown in Figure 20-5.

Figure 20-5. A bigfoot dewar at Alcor Life Extension Foundation.

A four-person dewar justifies its higher cost of fabrication by reducing the boiloff of nitrogen, amortized on a per-patient basis. However, this economy of scale is not fully realized until the dewar is filled with patients. A

bigfoot containing only one patient will actually be more expensive to maintain than a single-person or two-person dewar containing one patient.

The bigfoot design was modified as a result of a suggestion by Paul Wakfer, who in the 1990s was the owner of a long-term cryonics maintenance organization named CryoSpan (not to be confused with a company called Cryo-span that was associated with the Cryonics Society of New York 30 years earlier). Wakfer calculated and demonstrated that if the dewar was made about 10 inches taller, a thicker styrofoam plug beneath the lid would reduce the rate of boiloff sufficiently, in the long term, to outweigh the extra cost of fabrication. This is because the wall of a dewar blocks heat transfer so effectively that practically all heat leaking into a dewar comes down the foam plug and adjacent inner shell at the top or "neck" of the dewar. Neck design is therefore the most import determinant of dewar performance. Alcor adopted Wakfer's idea.

The vacuum between the inner and outer shell of Alcor's bigfoot dewars is rated at 4 microns, although in practice Alcor's research fellow, Hugh Hixon, states he has measured values below 1 micron. Pressure may be described using millimeters of mercury, originally defined as the additional pressure that would be exerted by a column of mercury of that height. A micron is 1/1000 of a millimeter; thus, 1 micron of pressure = 0.001 millimeters of mercury.

The inner shell of a bigfoot is separated from the outer shell by about 1 inch (2.54mm). Within this gap are 70 layers of silvered Mylar that are "dimpleized," meaning that each layer has tiny dimples stamped into it to separate it from the next layer and minimize contact. The Mylar is described as "superinsulation," and inhibits radiative heat transfer.

The bigfoot design contains four "pods," each being fabricated from sheet aluminum and sized to contain a single whole-body patient. Perforations in the pods allow liquid nitrogen to flow in while they are being lowered into a dewar.

The two parts of a pod are shown in Figure 20-6, while Figure 20-7 illustrates how a patient is strapped in. Patients are oriented head-down so that in the unlikely event that liquid nitrogen boils off rapidly, the head will be the last part to experience an increase in temperature.

A neuro patient, protected inside a cannister of the type illustrated in Section 19, may be stored in a relatively smaller dewar of the type shown in Figure 20-8. Alternatively, the bigfoot configuration allows room in the center of each dewar for a “neuro column” as shown in Figure 20-9. Five neuropatients can be stacked vertically in the column, or space at the top can be allocated for a companion animal.

Figure 20-6. The two sections of a pod that is designed to store a whole-body patient for immersion in liquid nitrogen at Alcor.

Figure 20-7. A mannekin illustrates the way in which a whole-body patient is strapped into a pod. In reality, the patient would be wrapped in a sleeping bag.

Figure 20-8. A neuropatient being lowered into a neuro dewar at Alcor.

Figure 20-9. A neuro column is designed for insertion into the center of a bigfoot dewar, among the whole-body pods.

A whole-body pod may alternately be configured to contain 10 neuro patients, each in a separate compartment, as shown in Figure 20-10.

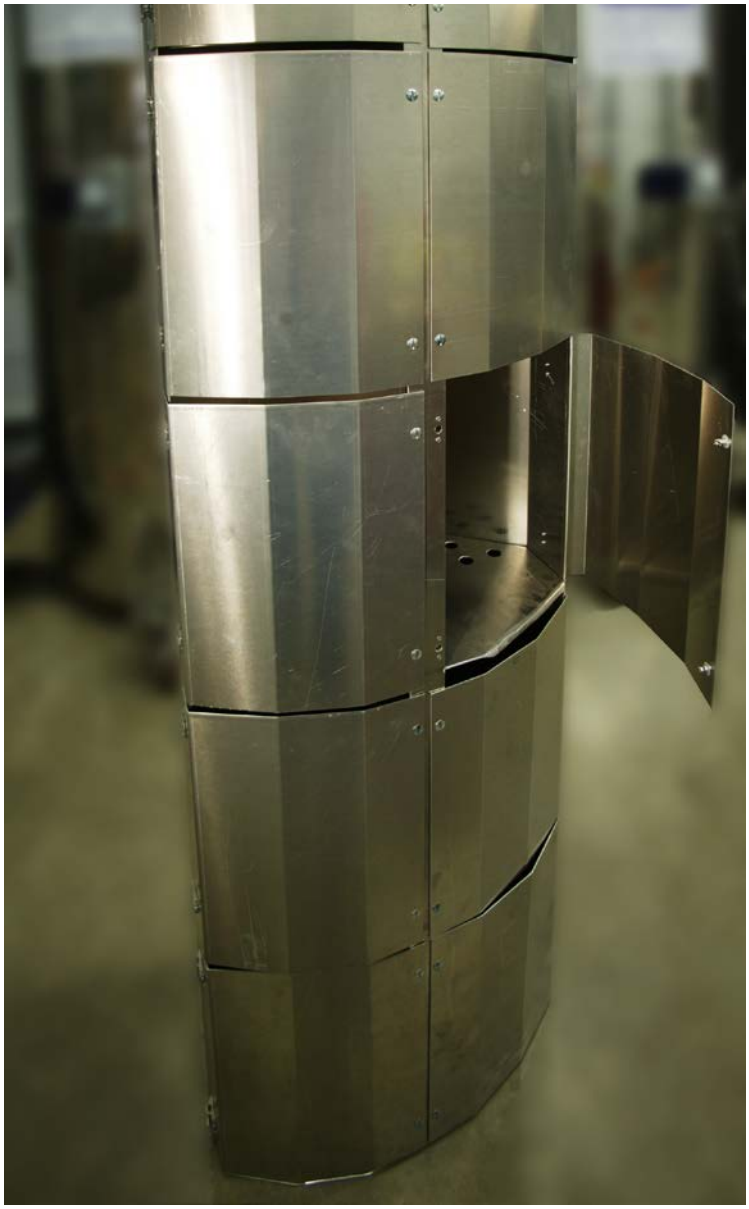

Figure 20-10. A whole-body pod can be reconfigured to hold 10 neuropatients, each in a separate compartment.

The footprint of the pods in a bigfoot dewar is shown in Figure 20-11, and is illustrated in Figure 20-12 using a 3D-printed model created by Steve Graber at Alcor.

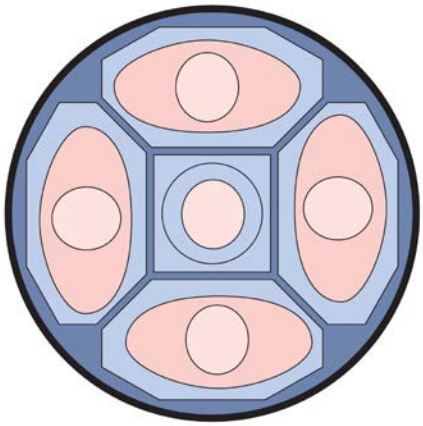

Figure 20-11. Four whole-body pods and a neuro column (all shown in pale blue) containing patients in a bigfoot dewar, seen from above.

Figure 20-12. This 3D print by Steve Graber at Alcor shows how the pods and neuro column fit into a bigfoot.

Recognizing that some Alcor members are larger than others, Hugh Hixon developed an alternate design in which two oversized pods can occupy the same space as three normal pods, as shown in Figure 20-13. At the end of 2017, two patients had required oversized pods.

Taking the concept a step further, Hixon has designed a “sumo pod” that would occupy half of the interior, but at the time of writing, no Alcor member has required this. If it was built, it would share a bigfoot dewar with one regular-sized pod and two neuro columns.

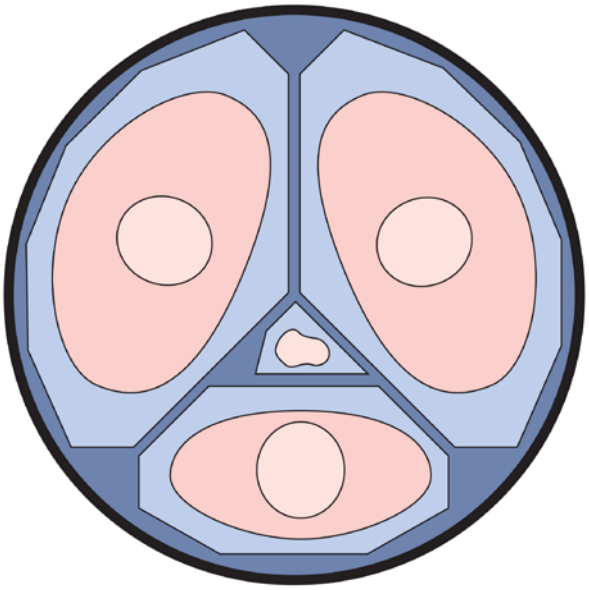

Figure 20-13. Two oversize pods for obese patients are designed to share a dewar with one normal-sized whole-body pod. Compare this layout with Figure 20-11.

The need for the pod system has been questioned by Steve Graber, Alcor’s Technical and Readiness Coordinator, who advocates podless storage in which each whole-body patient is strapped to a narrow backboard. This design would take less room, and thus would allow more patients to share the same amount of interior space. Graber is shown holding a prototype in Figure 20-14. Whether it will be adopted at Alcor remains unknown at the time of writing.

Hixon prefers to continue using pods because he believes that in the event of a dewar failure, they would provide some added protection and would facilitate removal of patients.

Figure 20-14. Steve Graber, at Alcor, holding his prototype design for a patient backboard that he believes could substitute for a pod.

Graber has designed a “SuperD” (pronounced “super dee”) dewar to hold seven patients in standard pods (or eleven patients if podless storage is used). The first dewar of this size was delivered to Alcor in 2017, and is shown in Figure 20-15, while the interior layout is shown in Figure 20-16. A SuperD allows more efficient use of floor area than a bigfoot dewar, as shown in Figure 20-17.

Figure 20-15. The seven-patient "SuperD" dewar designed by Steve Graber at Alcor, still being tested at the time of writing.

Figure 20-16. The proposed packing arrangement for patient pods in the SuperD dewar.

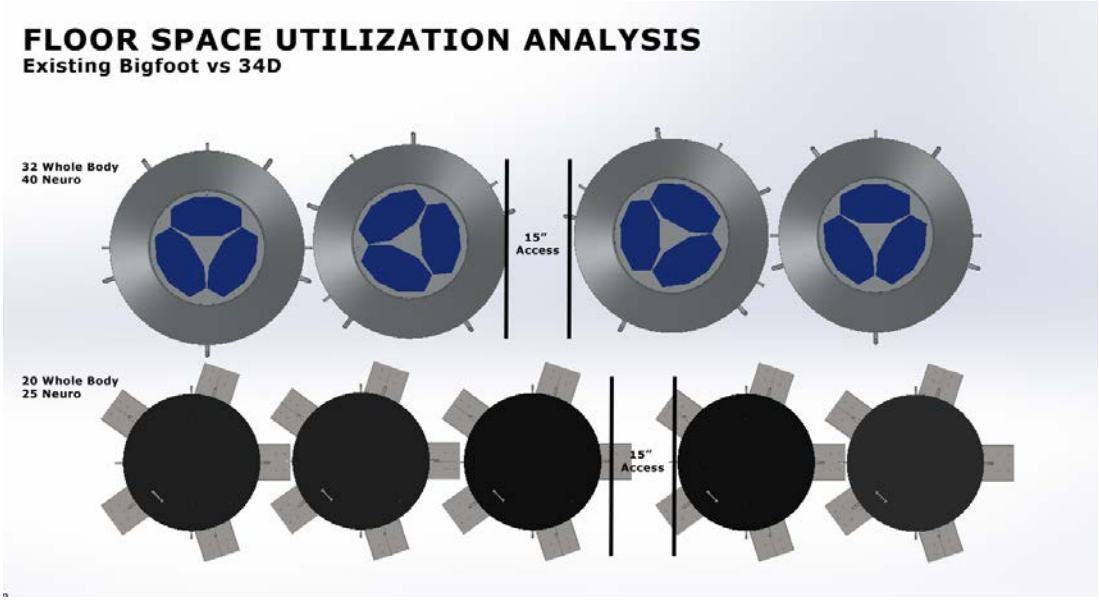

Figure 20-17. Comparison of floor-space utilization for four SuperD dewars and five bigfoot dewars.

Fabrication of the SuperD costs approximately twice as much as fabrication of a bigfoot dewar. Its weight, when filled, is approximately 6 tons. Graber hopes that eventually all whole-body patients will be moved into SuperDs, while bigfoots can be repurposed to contain neuros only.

The neck of the SuperD allows only three of the internal pods to be immediately accessible. Each of the remaining four pods must be shifted laterally into the center of the dewar for removal. This procedure is made more difficult by the height of the neck of the dewar, but Graber has fabricated a moving device consisting of a pole that descends into a sleeve in the top of a pod and locks into place.

The SuperD design will reduce the boiloff per patient when it is fully loaded. In a test of the dewar using nitrogen without patients, the level fell by about 25 inches from the fill line during 80 days. The average boiloff per day was about 15 liters, or 2.15 liters per whole-body patient. Graber estimates that if pods were installed, they would remain submerged for up to 55 days without topping off the nitrogen.

By comparison, a bigfoot dewar has a boiloff per day of about 12 liters per day, or about 3 liters per patient. Each bigfoot holds a sufficient reserve to keep the pods submerged for at least 30 days.

At the time of writing, the SuperD is completing boiloff tests and is not yet in service.

A bulk storage tank with a capacity of 900 gallons stands in one corner of Alcor's patient care bay, as shown in Figure 20-18. A delivery truck stops in the service road behind the facility once a week (as of 2017) and pumps liquid nitrogen through a flexible hose into the tank. A network of pipes and valves then distributes the nitrogen to the dewars. Some of these pipes can be seen in Figure 20-1, running laterally to each dewar.

At the end of 2017 Alcor had 155 patients preserved at its facility. This is a combined total of neuro and whole-body cases.

Figure 20-18. The bulk storage tank for liquid nitrogen in Alcor's patient care bay. Its capacity is 900 gallons.

Patient Relocation

When Alcor left its facility in Riverside, California and moved to Scottsdale, Arizona, its bigfoot dewars were moved on a flatbed truck, fully loaded with patients and liquid nitrogen. The product of careful planning, and use of a

company that specialized in moving fragile high-value equipment such as communication satellites, the move was completed without incident.

Relocation of neuro patients is a relatively trivial procedure by comparison, as a cephalon in a small dewar can be transported in an SUV or pickup truck. Indeed, neuro patients have been moved in this manner to a local imaging center where CT scans have been performed (see below).

The size and weight of a SuperD would make relocating it while full of liquid nitrogen a challenge, although Steve Graber believes it is feasible.

Patient Transfers

In Alcor's patient care bay, a winch equipped with a chain is used to raise a patient enclosed in a pod from floor level to the rim of a bigfoot dewar, after which the pod can be moved laterally and lowered into position. A similar procedure is necessary when a neuropatient is added to a neuro column in one of the bigfoot dewars. Figure 20-19 shows a column being hoisted out of a bigfoot for this purpose, while Figure 20-20 shows the column after being lowered back into the dewar. Whole body patients are protected from temperature excursions during transfers by being inside a liquid-nitrogen-soaked sleeping bag, which can additionally be sprayed with liquid nitrogen. Neuro patients are protected by their neurocanister remaining full of liquid nitrogen during movement through air at room temperature.

Figure 20-19. Raising a neuro column from a bigfoot dewar.

Figure 20-20. The neuro column after being lowered back into a bigfoot dewar.

CT Scans

In 2011, when Hugh Hixon was puzzled by erratic signals that he had picked up from a crackphone in a cephalon that had been cryopreserved, he obtained permission to investigate the problem using medical computed tomography, more popularly known as a CT scan. Radiation in this type of scan will penetrate thin aluminum and liquid nitrogen, so that a neuropatient can pass through the scanner while remaining immersed and encapsulated.

CT scans had been used previously by Alcor for cryopreserved companion animals, in cooperation with a local imaging center.

By 2017, Alcor had scanned 25 neuropatients, and Hixon would like to apply the procedure to all existing neuropatients, beginning with those that experienced the longest ischemic time. Comparative studies can then evaluate the outcome of different cryoprotection protocols.

Initially the patient (in a neurocanister) is transported to the imaging center in a small LR40 dewar, along with a second LR40 containing additional liquid nitrogen. Immediately before the scan, some liquid nitrogen is transferred into a styrofoam box that has been sized and shaped to pass through the scanner, and the can is then placed in the box. The box containing an empty can is shown in Figure 20-21.

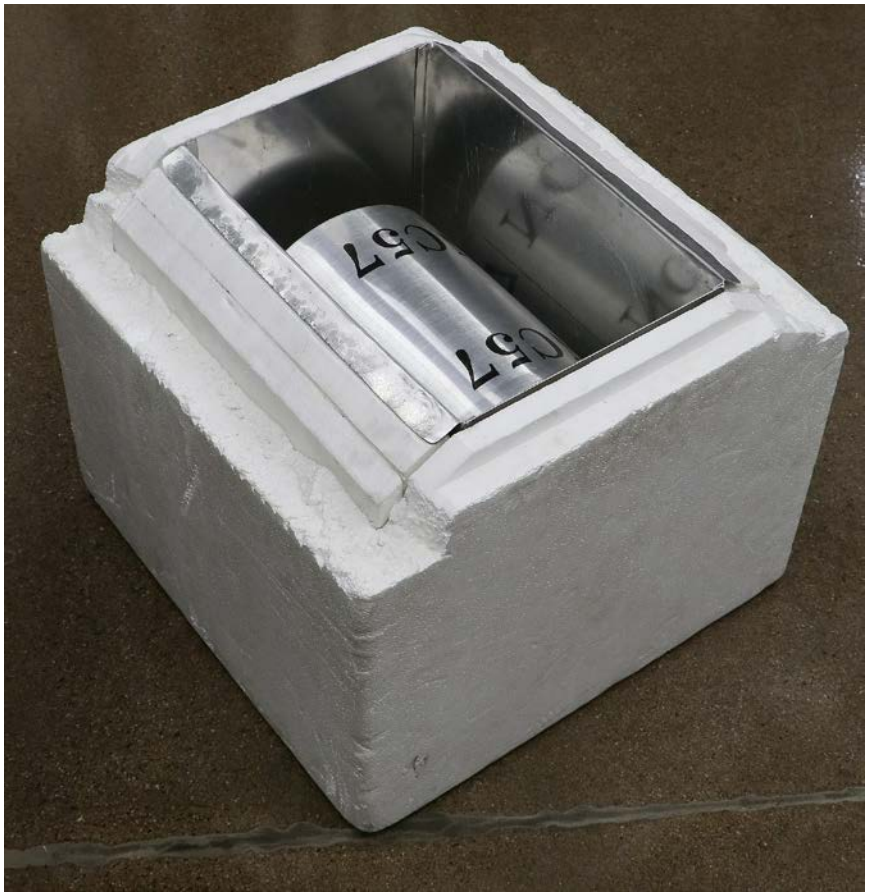

Figure 20-21. A neurocanister is immersed in liquid nitrogen in this styrofoam carrier when it is passed through a CT scanner.

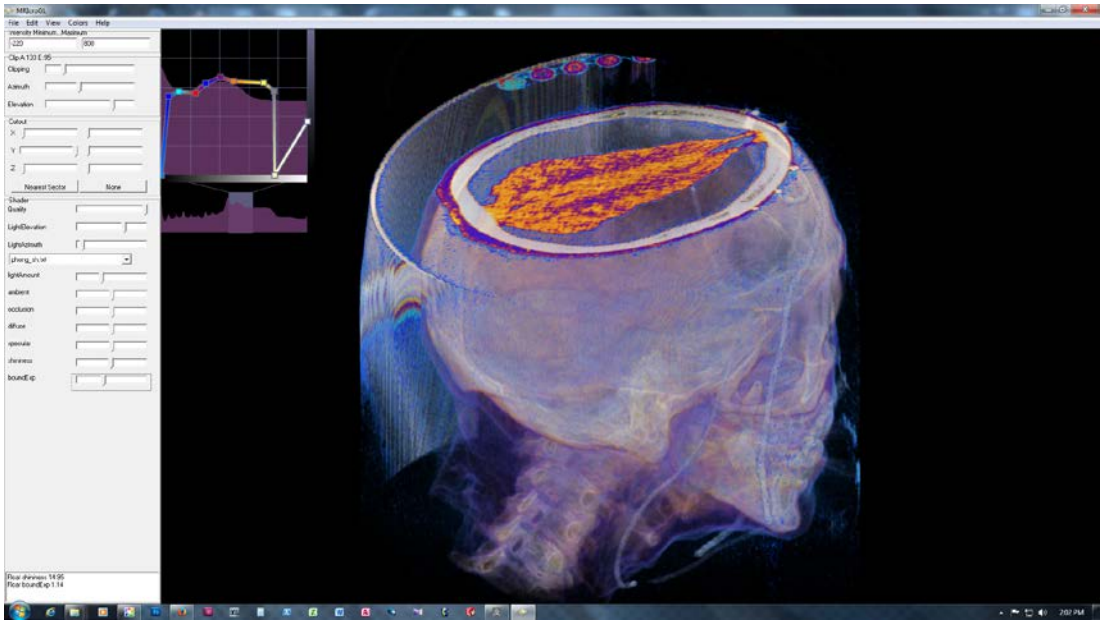

Figure 20-22. A CT scan clearly reveals the size and shape of a cryoprotected brain inside the skull, and also differentiates between frozen and vitrified areas.

Prior to this procedure, cryonics organizations could only evaluate the success of a case by using indirect evidence such as shrinkage of the brain determined by viewing its surface through burr holes in the skull.

Scanning the brain of a whole-body patient is possible if the patient is at dry-ice temperature. The body is transported to the imaging center in an insulated container open at one end. The patient is moved just far enough out of one open end of the container to allow the head to enter the scanner.

Intermediate Temperature Storage

In 1983 Alcor received three whole-body patients who had been transferred from another cryonics facility, and was authorized to convert them to neuro patients for continued preservation. This enabled post mortem examination of the bodies, which revealed multiple fractures in many organs ("Postmortem Examination of Three Cryonic Suspension Patients," *Cryonics* September 1984, pages 16-28, archived on the Alcor web site.)

In 1994, patient A-1242, who did not make her own cryonics arrangements, had to be removed from long-term maintenance as a result of a legal dispute between family members. This allowed an opportunity for post mortem examination, which revealed that the brain had fractured into five major pieces ("Exploring Cracking Phenomena," *Cryonics* 1st Qtr. 1995, pages 27-32, archived at the Alcor web site.)

During the years before CT scanning became available, Hugh Hixon compiled a list of possible fracturing events detected by the crackphone that he designed (described in more detail in Section 19). See Table 20-1.)

Alcor Case	Fracture Events	Highest Fracturing Temp	Cryoprotectant	Year
A-1030	1	Bet. -108.1 and -112	Glycerol	1995
A-1486	28	-99.3	Glycerol	1995
A-1559	39	Bet. -65.8 and -68.6	Glycerol	1995
A-1475	8	-121.3	Glycerol	1995
A-1110	22	-107	Glycerol	1997
A-1069	3	-109.3	Glycerol	1997
A-2020	5	-134	B2C	2003
A-2059	18	-127	B2C	2004
A-2063	20	-117.7	B2C	2004
A-1772	20	-75	Glycerol	2004
A-1562	17	-128.4	B2C	2004
A-2068	23	-98.5	Glycerol	2004
A-2024	7	-125.6	B2C	2005
A-2071	15	-121.9	M22	2005
A-1097	5	-134	M22	2006

Table 20-1. Total number of apparent fracturing events detected by acoustic sensors inside the cranium of cryonics patients during cooling, and temperature at which the first apparent fracture was detected.

In the hope of minimizing fracturing events, options were discussed to maintain patients at an intermediate temperature, below Tg but above the temperature of liquid nitrogen. The concept of intermediate-temperature storage came to be known by its acronym, ITS.

The first attempts to maintain patients at ITS were made when two Alcor neuro patients were held at –130 degrees C in a Harris Cryostar chest-type laboratory freezer. It included a liquid nitrogen backup system that could maintain temperature in the event of a power failure, and was filled with dry ice as thermal ballast. Still, concerns were expressed about its reliability, as it sounded its temperature excursion alarm on an erratic basis. This was especially troublesome during summer months when the ambient temperature in the space where the freezer was located sometimes exceeded 90 degrees Fahrenheit, despite room air conditioning. Although the temperature of the patients always remained close to the desired temperature because of the thermal ballast, and use of the freezer allowed fracturing to be avoided down to an unprecedentedly low temperature of –128 degrees C, better methods of ITS were desired. (See "Systems for Intermediate Temperature Storage for Fracture Reduction and Avoidance," *Cryonics* 3rd Qtr. 2011, pages 7-14, archived at the Alcor web site.)

Brian Wowk, a biophysicist at 21st Century Medicine, did extensive R&D to perfect a viable ITS system that would be dewar-based, avoiding the reliability issues and heavy power consumption of the Cryostar. Wowk's basic idea was to use very low power electrical heating elements to maintain a precise temperature inside containers of high thermal conductivity that were encapsulated by thermal insulation while being stored above the surface of liquid nitrogen in a conventional dewar (U.S. Patent 7278278B2).

Figure 20-23 shows the evolution of the concept in four simplified steps. In section A of this figure, a small pool of liquid nitrogen is at the bottom of a dewar. Because some heat from the environment enters through the lid of the dewar and makes its way downward to the liquid, the interior has a large internal temperature gradient.

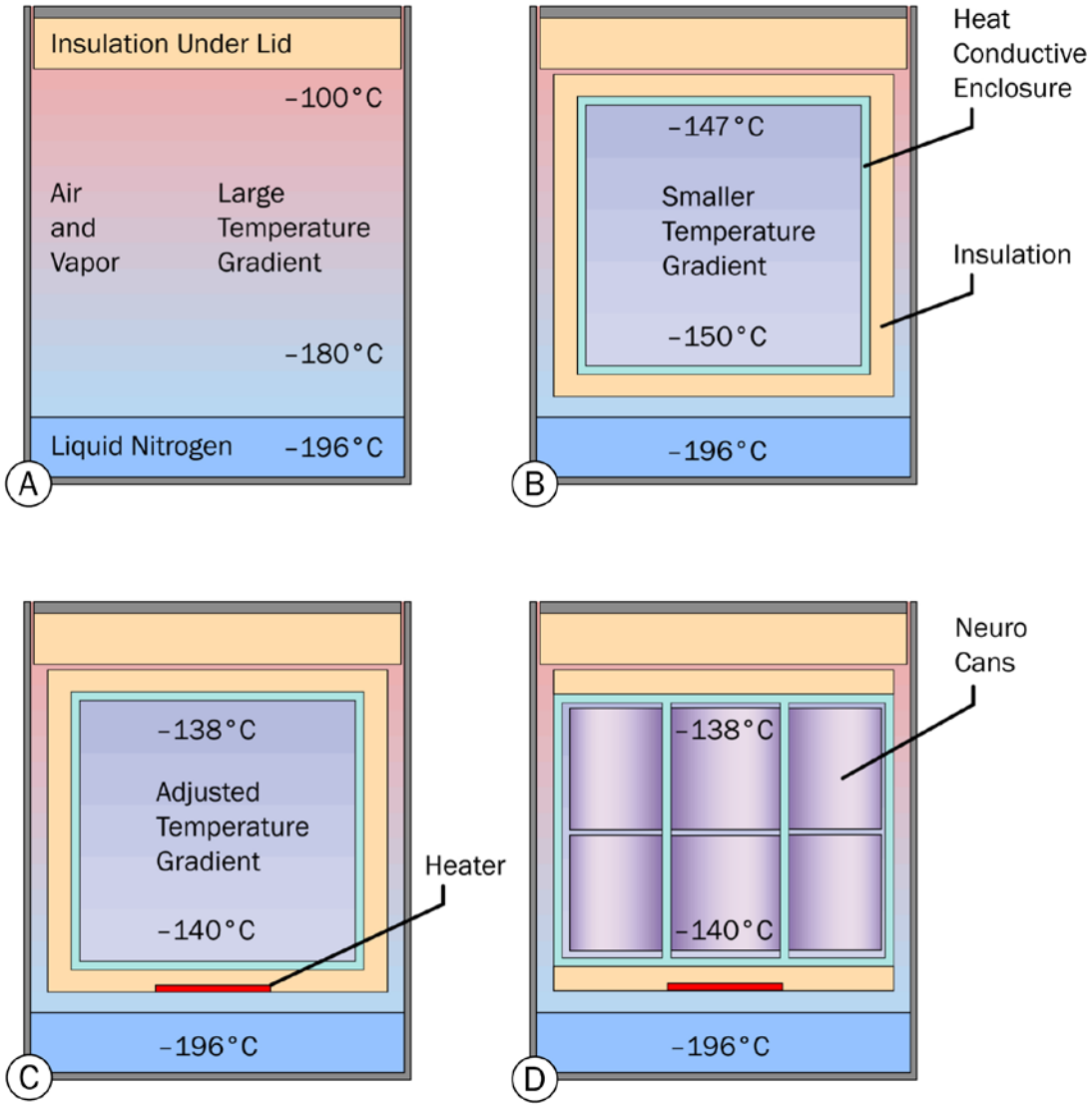

Figure 20-23. Achieving a controlled intermediate temperature for 14 neuropatients inside a dewar. See text for details.

In section B of the figure, an enclosure has been inserted in the dewar. It is fabricated from aluminum, which conducts heat very efficiently. In addition, the enclosure is surrounded with insulation. Inside the enclosure, the temperature gradient has been reduced to a much narrower range, but may still be too cold for optimum preservation of a cryoprotected neuropatient.

In section C, a heater has been added. By actively controlling the heater, the temperature in the enclosure can be adjusted upward to a desired value that is constant and relatively insensitive to temperature disturbances within the vapor space of the dewar. Section D shows this concept applied to an enclosure customized to contain 14 neurocanisters.

Figure 20-24 shows the ITS geometry seen from above (only the upper layer of two layers of stacked neurocanisters is visible). Figure 20-25 shows an exploded 3D view in which the 14 cans are displaced from the enclosure (left) and installed in the enclosure (center), with seven lids that will fit over them. The right-hand view in this figure shows the assembled enclosure with layers of insulation that will fit above it and below it when it is installed in the dewar containing a pool of liquid nitrogen.

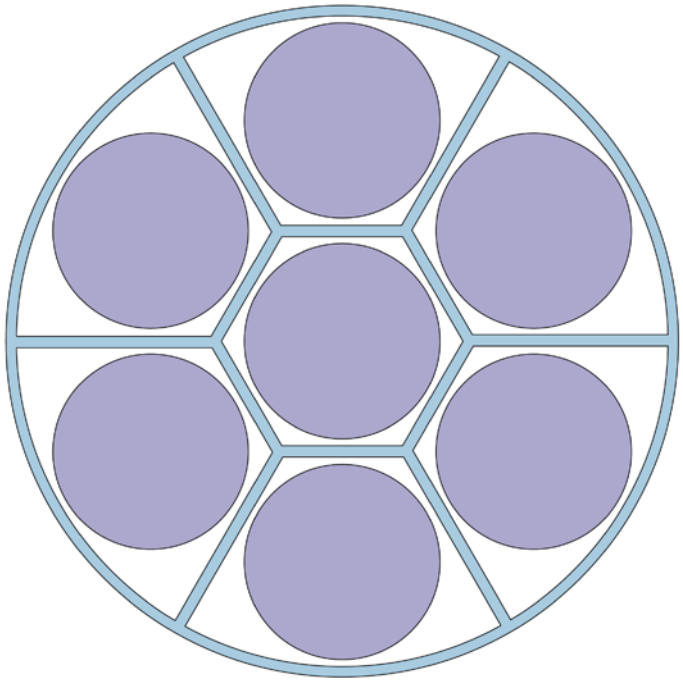

Figure 20-24. Neurocanisters viewed from above, placed inside a carrier to be inserted in a dewar for intermediate temperature storage.

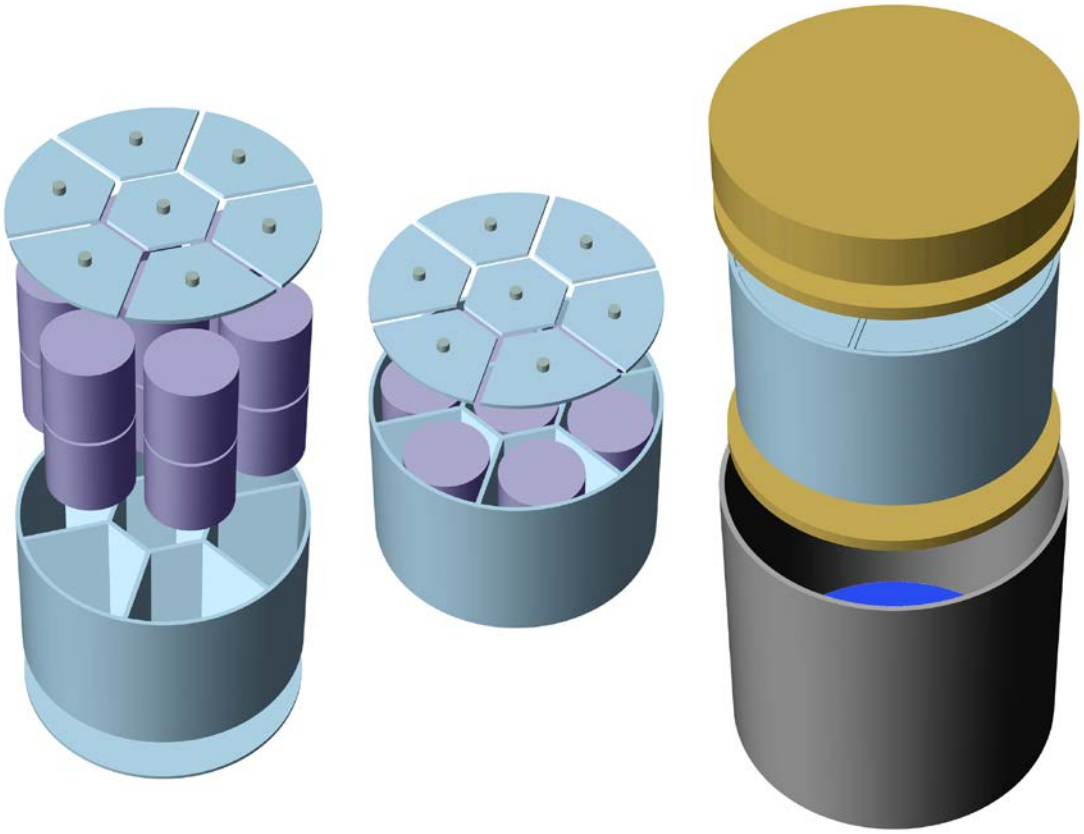

Figure 20-25. Assembly of the component parts of the intermediate temperature storage system designed by Brian Wowk.

The completed ITS system is shown in Alcor's patient-care bay in Figure 20-26. It uses a double-redundant system of heaters, temperature sensors, and controllers, and fills itself automatically from a dewar that is placed alongside. At the end of 2017, four neuropatients were maintained in this system.

Figure 20-26. The dewar adapted for intermediate temperature storage stands beside a small dewar of liquid nitrogen in Alcor's patient care bay.

The Wowk patent also includes designs for small portable ITS containers that can be held in the vapor space of unmodified dewars, and designs for containers and modified dewar vapor spaces large enough to hold whole body cryonics patients. Portable ITS containers for individual neuropatients have been built, but as of 2017 containers or modified dewars for ITS maintenance of whole body patients have not.

In 2003 a cryogenic engineer working with the Timeship initiative of the Life Extension Foundation designed and patented four new types of dewars specifically designed for ITS maintenance of whole body cryonics patients (US Patent 7299641). The most efficient designs consisted of a dewar within a dewar and had high capital costs but very low liquid nitrogen consumption. As of 2017, none of the designs had been built, although detailed drawings,

calculations, and construction cost estimates from a cryogenic engineering company exist in the custody of the Timeship project should there be sufficient interest and resources to pursue them.

It should be noted that to protect patients during transfers through warm room air, individual patient containers or pods for ITS tend to require more insulation than patient pods used for liquid nitrogen storage. Patients stored under liquid nitrogen will either be inside sleeping bags soaked with liquid nitrogen or inside neuro cannisters filled with liquid nitrogen that maintains patient temperature while boiling during transfers between dewars through room air. Patients at an ITS temperature do not have the protection of liquid nitrogen, and upon exposure to room air will begin warming at a rate determined by how well insulated they are. CT scanning of ITS patients in the cryopreserved state is problematic.

The ideal temperature for operating an ITS system for either cryonics or banking of vitrified organs in mainstream cryobiology is a complex and somewhat controversial question. The choice of temperature requires balancing risks of chemical change, ice growth, ice nucleation, and fracturing. Maintaining temperatures above Tg risks chemical change and especially ice growth. Maintaining temperatures near but below Tg risks ice nucleation, a time-progressive process by which water molecules reorganize into ice crystals of nanoscopic size that create hazards of freezing during later rewarming (see Section 19). Maintaining temperatures far below (15 or more Celsius degrees below) Tg mitigates the aforementioned risks, but makes ate least some fracturing a practical certainty.

Determining the optimum balancing of these risks requires further research into specific slow cooling and annealing protocols for fracture avoidance, differential thermal contraction tendencies of different tissues, and ice nucleation rates as a function of temperature and cryoprotectant composition and concentration. If the conservative view is taken that time-dependent changes should be avoided as a matter of principle because we do not know how long cryonics patients will have to be maintained at low temperature, then as of 2017 no “safe” ITS temperature exists that will not result in at least some fracturing. ITS is therefore best currently regarded as a fracture *reduction* technology rather than fracture *avoidance* technology.

The capital costs per patient for ITS are greater than for conventional liquid nitrogen storage of the same scale. Although there are exceptions, such as the highly efficient dewar-within-a-dewar Timeship designs, liquid nitrogen consumption and costs also tend to be higher per patient. The capital and ongoing costs for neuo patients using the particular ITS system illustrated in this chapter are three times greater than liquid nitrogen storage in a Bigfoot dewar.

Hypothetically, suppose an ITS system reduces the average number of fracturing events from 20 to 10. We have no way of knowing whether this will be seen as significant from the point of view of molecular reconstruction efforts in the future.

While proven neuro ITS technologies are scheduled to be made available to the membership at Alcor soon, no such plans or resources currently exist for whole body ITS at Alcor. To remedy this "unequal" access to ITS, and to create a sensible transition period, Aschwin de Wolf proposed the idea of "Brain-Optimized Whole Body Cryopreservation" in which the cephalon of the patient is cryoprotected and stored separately in a neuro ITS unit. The whole body is either separately cryoprotected or straight frozen and stored in a conventional Bigfoot dewar or SuperD. An additional advantage of this option is that whole-body members can reap the advantages of isolated head cryopreservation without foregoing whole body cryopreservation.

Our summary, here, of ITS development is largely derived from a much longer and more thorough presentation by Brian Wowk: "Systems for Intermediate Temperature Storage for Fracture Reduction and Avoidance," *Cryonics* 3rd Qtr. 2011, pages 7-14, archived on Alcor's web site.

Equipment at the Cryonics Institute

The Cryonics Institute has approximately 160 patients in long-term maintenance as of 2017, almost all of them whole bodies, as it does not offer an option for neuropreservation. The patients are at a facility in Clinton Township, Michigan, and the organization now claims to have a second nearby building which will be used for additional patients.

In 2009, the Cryonics Institute stated that it had ten cylindrical cryostats and three older, larger versions that are box-shaped. The designs were created by Andy Zawacki, who also fabricated many of them using fiberglass as the primary material. The cylindrical cryostats are now manufactured by an outside contractor.

Seven of the cylindrical cryostats are shown in figures 20-27 and 20-28 with a catwalk that is used for access. The largest box-shaped version is shown in Figure 20-29. Its vertical ribs are included to provide rigidity.

Figure 20-27. Cryostats at the Cryonics Institute in Clinton Township, Michigan.

Figure 20-28. A catwalk allows access to the lids of the cryostats at the Cryonics Institute.

Figure 20-29. The largest of the cryostats at the Cryonics Institute. A vacuum pump stands on a small table at bottom-left.

All the cryostats have an inner shell separated from the outer shell by a gap of about 12 inches. Vacuum pumps are used periodically to remove traces of air from the gap between the shells. According to the Cryonics Institute's web site, the pumps run on a schedule that varies depending which cryostat is involved. The most efficient, circular cryostat requires one or two 16-hour days of pumping every two months, while the least efficient, rectangular cryostat needs three days of pumping every two months.

The Cryonics Institute claims that its most efficient cryostat can attain a vacuum of 1 to 2 microns, while its least efficient cryostat gets down to about 20 microns. These numbers are attained immediately after vacuum pumps have been used.

The 12-inch gap between the inner and outer shell of each cryostat is loosely filled with perlite, a volcanic glass that normally contains 2 to 5 percent water. During the manufacturing process, perlite is heated rapidly above 870 degrees Celsius, causing the water in it to vaporize, forming tiny bubbles that cause the volume to increase by a factor of 7 to 16. The open cellular structure of dried perlite is a poor conductor of heat, and it blocks thermal radiation.

Patients are wrapped in sleeping bags, as at Alcor, but are not enclosed in pods. The cylindrical cryostats each contain 6 patients, oriented vertically, while the rectangular cryostats are in three sizes holding 7, 10, and 14 patients each, oriented horizontally.

Fiberglass designs have the advantage of being substantially cheaper than steel dewars, and may be almost as efficient, so long as vacuum pumps are used periodically. The Cryonics Institute claims an average cost of liquid nitrogen of less than $100 per patient per year. The organization is fortunate to be located in an area where the cost of nitrogen is below the national average.

Liquid nitrogen deliveries are received on the same basis as at Alcor, except that the bulk storage tank in Michigan is located outside the building, as shown in Figure 20-30, and has a capacity of 3,000 gallons. The tank receives a delivery of about 2,000 gallons every two weeks. Nitrogen from the tank is then used to top off the box-shaped cryostats twice a week and cylindrical cryostats once a week, according to the Cryonics Institute web site.

Figure 20-30. The 3,000-gallon bulk storage tank outside the Cryonics Institute.

Vacuum Failure

Dewars and cryostats may develop small leaks that allow air to penetrate their vacuum insulation. If this happens on a gradual basis, the first sign will be an increase in the boiloff rate. Alcor monitors boiloff on a regular basis.

Significant damage to the inner wall of a dewar or cryostat would be a much more serious matter, as nitrogen liquid would tend to be sucked into the insulation space, where it would vaporize rapidly. Gas pressure would then cause the inner wall to implode. Figure 20-31 shows a small dewar where the inner shell has ruptured in this way, although the cause remains unknown.

This type of failure will tend to wrap the inner wall around objects inside the dewar, making them difficult to remove.

Figure 20-31. The interior of a small dewar after the interior shell has ruptured.

A serious insulation failure that allows heat to reach the interior of a vessel can cause liquid nitrogen to boil violently, creating large volumes of vapor that escape from the vessel and create a risk of asphyxiation for anyone in the vicinity. For this reason, Alcor's patient care bay is fitted with oxygen sensors and multiple large ventilation ducts such as the one shown in Figure Figure 20-32, which has a diameter of 30 inches. If a sensor detects a falling level of oxygen, fans on the roof start immediately, and will draw air from

near the floor where nitrogen is most likely to accumulate. A trapdoor opens to allow fresh air to enter the facility from the roof.

The system has been tested by running the fans after increasing the humidity in the patient care bay and then allowing nitrogen vapor to create a dense white mist.

Figure 20-32. One of several large ventilation ducts in Alcor's patient care bay. Fans on the roof are activated automatically if an oxygen sensor suggests a buildup of nitrogen in the air.

Alcor owns a plasma cutter that may be used, in theory, like a can opener to get rapid access to a dewar, and Hugh Hixon believes that the volume of liquid nitrogen in a bigfoot dewar would take 12 hours to vaporize completely. He comments: “We could swap all the patients to another dewar within 30 minutes, so really it’s not an issue.”

If patients are stored in a SuperD dewar, Alcor plans to keep two bigfoot dewars in reserve as backup.

Neither Alcor nor the Cryonics Institute has ever reported a failure in a patient dewar or cryostat, as of the end of 2017. The relative safety of steel dewars vs. fiberglass cryostats remains an active but inconclusive debate.

Underground Storage

Generally speaking, underground storage may be hazardous because it incurs a risk of contamination with groundwater that will freeze if it seeps in around the lid of a dewar. However, in Southern California, when Paul Wakfer founded a long-term maintenance company named CryoSpan, he felt that the risk of earthquake damage above ground outweighed the negative factors of placing patients underground. He was able to do this inside a facility, so that no protection from the weather was necessary.

Mark Connaughton assisted Wakfer by designing and building two silos, each consisting of a pit lined with prefabricated cylindrical sections of concrete. A heavily reinforced concrete platform was added by Connaughton around the mouths of the dewars (shown under construction in Figure 20-33). Patients were moved from another location to CryoSpan, and the photograph of Wakfer in Figure 20-33 was taken in 1996. After he ended his relationship with CryoSpan in 1999, the patients were moved to other cryonics organizations.

The silos still remain.

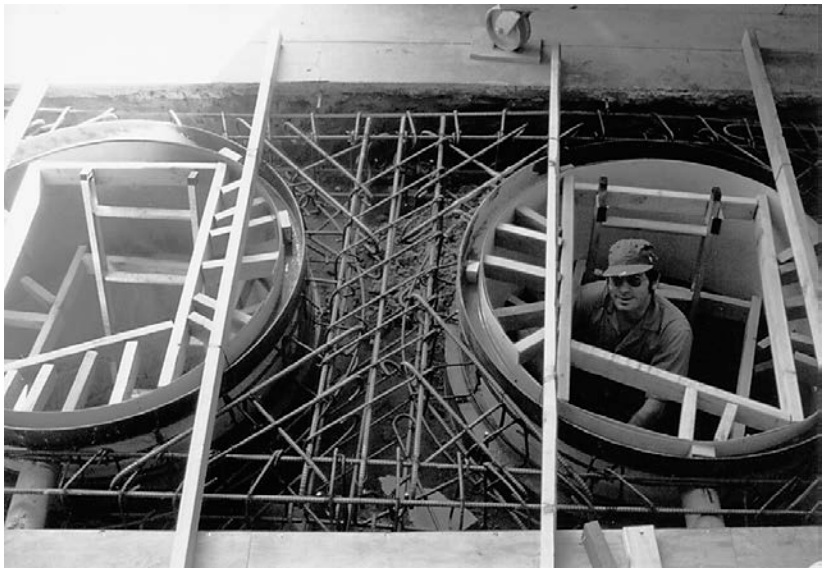

Figure 20-33. Mark Connaughton in the process of constructing underground silos in Southern California for CryoSpan.

Figure 20-34. Paul Wakfer standing beside an underground dewar in one of the silos built at CryoSpan.

The Cold-Room Concept

During 1993 several people who had been actively involved in cryonics discussed the concept of a “cold room” that would be much like a walk-in cooler at a grocery store, except that cryonics patients would be lowered into it from above. The concept seemed attractive because it might enable intermediate-temperature storage more cheaply than using dewars, and if solid

blocks of insulation were used, they would eliminate the risk of vacuum failure.

Imagine a space 2 meters high, with a floor area 1 meter square. Suppose this is enclosed with blocks of insulation around all the walls, the ceiling, and the floor. If each block is a 1-meter cube, 34 blocks will be required, as shown on the left side of the exploded view in Figure 20-35, where layers of insulation for the ceiling and the floor have been separated to reveal the cavity in the center. Including the cavity, the cold room will occupy a total of 36 cubic meters, and available storage will be less than 6% of this total.

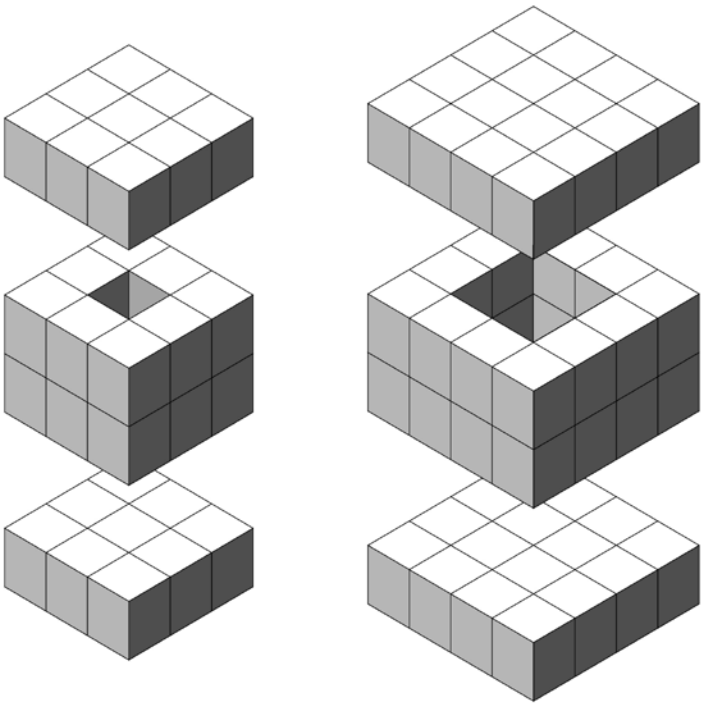

Figure 20-35. Assembly of blocks of insulation around a central volume of 1x1x2 meters (left) and 2x2x2 meters (right).

Now imagine the cold room enlarged so that the interior cavity is 2 x 2 x 2 meters, as on the right in Figure 20-34. The total volume of insulation will now be 58 cubic meters, while the interior allows 8 cubic meters of storage volume, which is about 12% of the total. As the horizontal linear dimension of a cold room increases, the percentage of the total volume allocated for storage

also increases, as shown in Figure 20-36. The efficiency in terms of materials cost per patient improves with the size of the room.

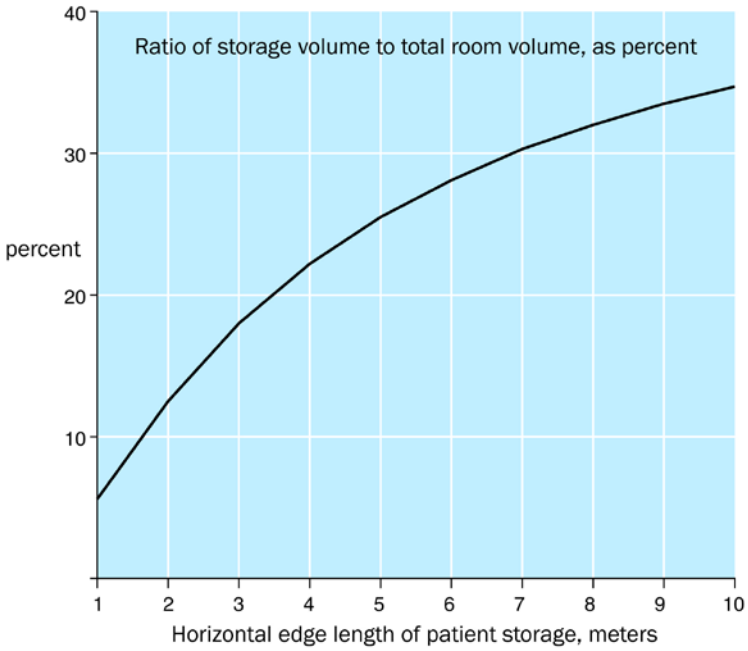

Figure 20-36. In a hypothetical cold room, the percentage of the total volume that is available for interior storage increases as the dimensions of the room increase.

Participants in the discussion suggested possible types of insulation and refrigerant that would enable intermediate-temperature storage. The concept appeared viable until a cryogenic engineer was consulted for his opinion and demonstrated that an array of bigfoot dewars would be no more expensive than a cold room, and would have the added advantage that the patients could be relocated to a different facility if necessary. Relocating patients from a cold room would be very difficult, and the concept was abandoned. It is included here in case the concept is proposed in the future by people who may be unaware that is has been explored in the past. The original discussion is stored online in the Cryonet archives.

Very Large-Scale Patient Maintenance

Various plans and suggestions have been made for the maintenance of very large numbers of patients at a hypothetical time in the future when the concept of cryonics achieves wider acceptance. The Timeship project, funded by Life Extension Foundation and coordinated by architect Steven Valentine, proposes to enclose patients in pods that are assembled in "neighborhoods" cooled by nitrogen vapor. Multiple neighborhoods would then be assembled to form "communities." A neighborhood and a community are shown in an architect's model in Figure 20-37.

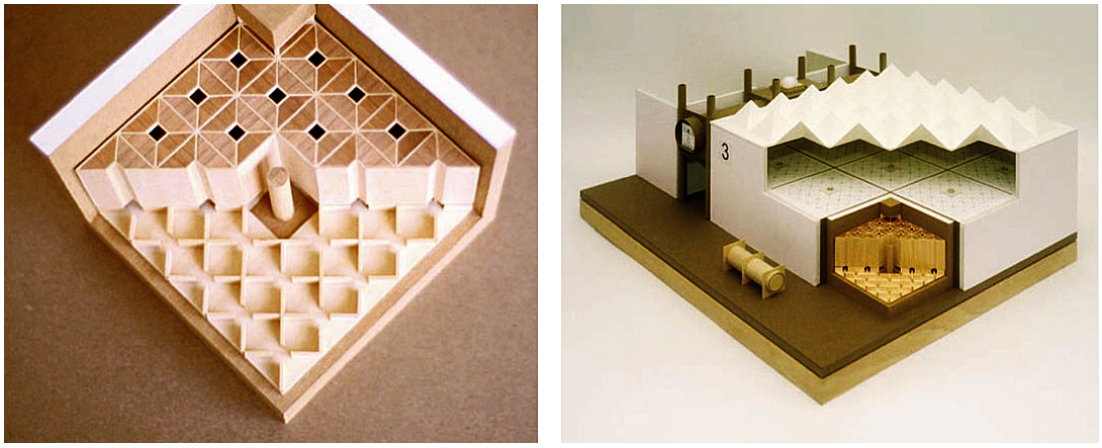

Figure 20-37. Patient pods arrayed in a "neighborhood" of the Timeship building (left), while the neighborhood is shown in a "community" (right). The Timeship project would contain multiple communities.

Land for Timeship has been purchased in Texas, in a location where there is minimal risk of flooding, tornadoes, earthquakes, and other natural disasters. Construction of the building has not begun.

In the July 2014 issue of *Cryonics* magazine, Ralph Merkle presented a thought experiment for the cryopreservation and long-term maintenance of millions of cryonics patients. Inspired by huge natural-gas storage facilities such as the 250,000 kiloliter underground tank in Yokohama shown in Figure 20-38, Merkle imagined it containing liquid nitrogen instead of liquified gas, and calculated that 5.5 million neuropatients could fit into a sphere with a

radius of 30 meters. He suggested that with these economies of scale, operating costs in this "big picture" could be $1 per person per year, or even less.

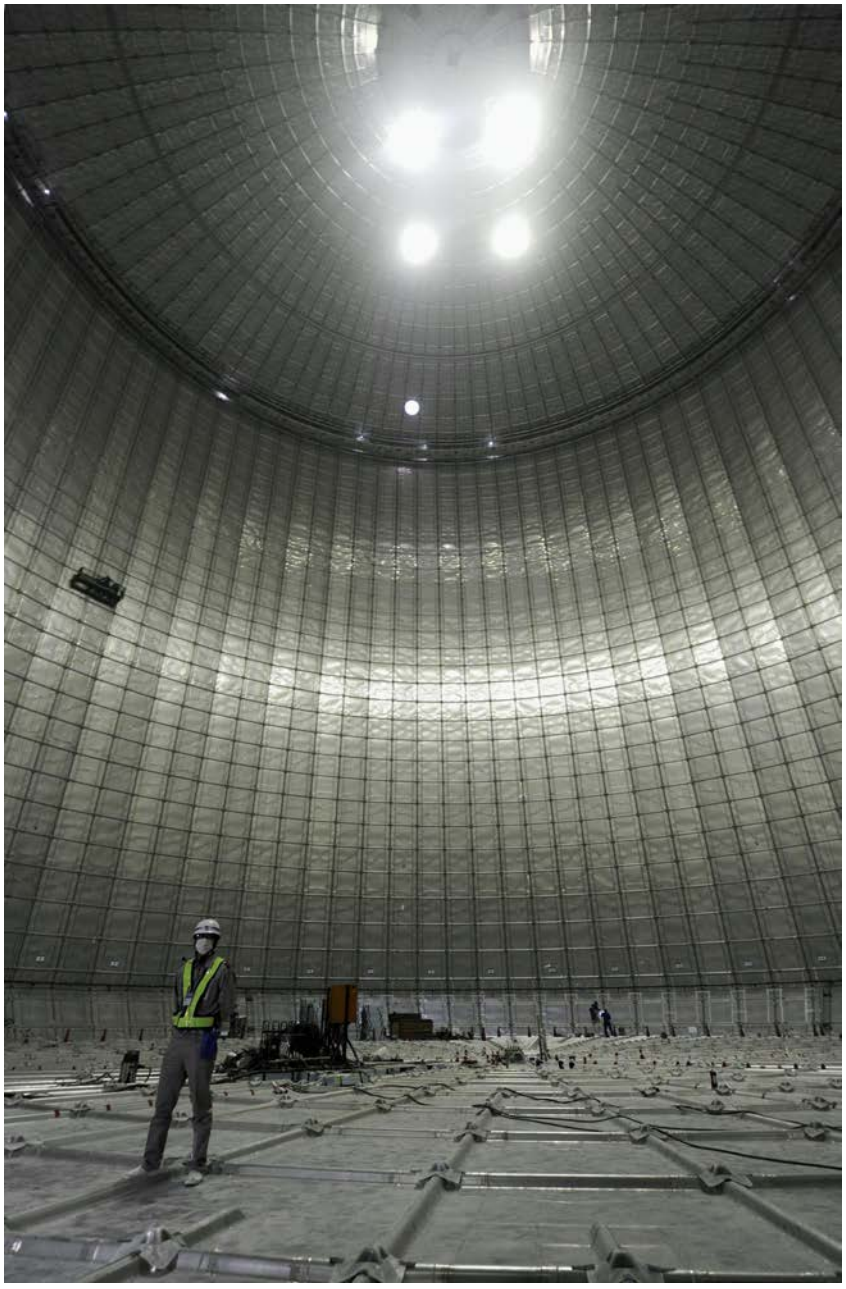

Figure 20-38. A 250,000-kiloliter liquefied natural gas storage facility under construction in Yokohama.

Thought experiments of this type are a useful antidote to conservative bias, but cryonics has often tended to err in the opposite direction. The field has an unfortunate history of underrating the complexity and expense of ambitious ideas. In particular, ever since Robert Nelson toured cryonics conferences in the late 1960s showing renderings of a cryonics facility that did not actually exist, cryonicists have been easily seduced by the concept of very large facilities for patient maintenance.

Activists in cryonics can feel proud of some remarkable achievements since the freezing of Dr. James Bedford more than fifty years ago, most notably the development of cryopreservation procedures described in this book. The work has been done with minimal funding by a relatively small number of dedicated activists. They have persevered in the face of universal skepticism and frequent hostility because they share an ethically driven belief that death is a terrible enemy of all decent people. For those who see the urgent need to develop and deliver better cryopreservation under conditions that are sometimes extremely challenging, big pictures can either be an inspiration or an unwelcome distraction.