MiniBooNE Detector Removal and Storage for Relocation

by David Finley

Introduction and Summary

This report addresses removing the MiniBooNE detector from its present location on the Booster Neutrino Beamline (BNB), placing the spherical tank at a location about 500 feet away in the direction of the target, and storing the rest of the detector, all in anticipation of being relocated on the BNB.

Two scenarios are presented. In Scenario One the tank is moved empty and everything else goes into storage. In Scenario Two the tank is moved (and stored) full and only the equipment from the electronics room needs to be stored. Variations on each Scenario are also presented.

The cost estimates listed in this report indicate the removal and storage (without relocation) would likely exceed $2,000,000 in any scenario. This does not include the cost of storing the pieces, but it is understood the pieces would be stored in a manner appropriate for sensible re-assembly in a new location on the BNB. In a scenario in which the oil is drained from the tank, removal of the tank and preparing equipment for storage would cost at least $2,000,000 and up to about $8,000,000 if a new storage facility were needed; the storage facility cost is dominated by oil storage. In a scenario in which the detector is not drained of oil before being moved the cost would be about $5,500,000; this cost is dominated by the crane needed to move the tank because of the weight of the oil.

The time estimates listed in this report indicate removal and storage would take a minimum of about 10 weeks or as long as 8 months after MiniBooNE operation is suspended until the work to open the enclosure (and remove the tank) can begin. The former time estimate assumes the tank can be moved "as is", with the oil and the equipment still in it. The latter assumes the oil and the equipment in the tank must be removed before moving the tank, and is dominated by removal of the phototubes and their support structure from the tank.

Either scenario (or variations) could begin after a clear plan is worked out, and the required people and equipment are assembled. About a month after the end of either time period given above the hall can be turned over to microBooNE for its installation. A sensible overall plan is not presented here, but coordinating the departure of the MiniBooNE detector and the arrival of microBooNE could likely shorten the times involved.

Crude estimates for resources needed to restore the detector in a new location are included (but with much less thought) to give an idea of how much a total exercise might cost. Nevertheless the estimates in this report could be helpful in partially informing a decision about what is done with the MiniBooNE detector. These cost estimates for removing, storing and relocating the experiment range from about $5,000,000 to $13,000,000.

Summary Table of Estimates

Here is a table summarizing the estimates of the various scenarios. The details on the cost estimates, the people estimates and the storage space requirements are given in the later sections. The FTE estimates do not include re-installation. Except for Scenario Five, the M&S costs include a new MiniBooNE hall and putting the tank in the new hall.

Scenario Nickname	M&S Cost	FTE weeks	Storage Space (sqft)
One: Move Tank Empty	$11,921,000	135	20,700
Two: Move Tank Full	$12,511,000	33	1,000
Variant on One: Use Less Time	$10,371,000	73	17,000
Variant on Two: Use Cheaper Crane	$ 7,491,000	193	3,500
Three: Build The New Hall First	$ 7,000,000	113	3,500
Four: Sell Then Re-Buy Oil	$ 5,491,000	113	3,500
Five: Just Start Decommissioning	$ 2,000,000	113	None

These estimates should be used with caution. The numbers that go into this table are derived from a mix of estimate methods. Many estimates are simply initial best guesses by the author (and these are identified as such in the later sections.) Others were provided by people who took some time to determine the estimates. Fermilab "overhead" is not included in any M&S. The usual cost adjustments associated with proper project management such as inflation, contingency, value engineering, etc are not included. There are additional caveats in the section "Context: Important Notes on Cost Estimates."

Organization of this Report

The first part of this report gives context and historical guidance in order to lay out what needs to be done. The second part lays out what needs to be done, including schedule and cost estimates for two scenarios for moving the tank: empty or full. Then several scenarios which were thought up during the preparation of this report are sketched.

The last paragraph in this report provides the author's unsolicited opinion.

Context: Background and Method

On August 3 2010 the author agreed to look into this issue after a conversation with Mike Lindgren indicating Greg Bock asked for estimates and needed them relatively quickly. One assumption at that time was this report was due on September 30. Various emails, meetings and discussions among the three of us subsequently transpired to redirect this effort as various assumptions were revised.

The author is a member of the MiniBooNE collaboration. He did stand enough shifts to be an author on the publications for the neutrino running but not enough for the antineutrino running. He was not involved in the design, construction or installation and commissioning, and thus he necessarily relied on others when figuring out what needs to be done for this report. Some of the information in this report is taken from the NIM article "The MiniBooNE Detector" which is available at **http://arxiv.org/abs/0806.4201** . References to this article will be indicated by NIMpxx where xx is the page number.

Information also comes from interactions with the following people: Larry Bartoszek, Dixon Bogert, Janet Conrad, Don Cossairt, Ed Crumpley, Chuck Federowicz, Gerry Garvey, Randy Johnson, Peter Kasper, Bill Louis, Peter Meyers, Geoff Mills, John Peoples, David Pushka, Bill Sands (through Larry Bartoszek), Mike Shaevitz, Ray Stefanski and Richard Van de Water. The author attempted to represent their comments accurately, and without attribution thus providing them with plausible deniability. All of the blunders in this report are the responsibility of the author.

On August 10 the author gave a 15 minute briefing to Greg Bock.

On August 18 there was a fact finding mission to the MiniBooNE detector by Ed Crumpley, Chuck Federowicz, David Finley, Mike Lindgren, Bill Louis, Geoff Mills and Richard Van de Water.

On September 8 a Fermilab Purchase Order was issued to Bartoszek Engineering (BE). References to this report will be indicated by BEpxx where xx is the page number.

On September 13 the author sent an email briefing to Greg Bock and Mike Lindgren.

On September 24 the author sent an early draft of this report to Mike Lindgren.

On September 30 the author sent a (nearly) "First Draft" to Greg Bock and Mike Lindgren.

On October 1, in order to eliminate blunders, the author sent a "First Draft" to the following MiniBooNE collaborators for a one week comment period: Bill Louis, Janet Conrad, Mike Shaevitz, Richard Van de Water, Peter Meyers, Randy Johnson, Geoff Mills and Peter Kasper.

On October 5 the author met with Greg Bock and Mike Lindgren for their comments on the "First Draft."

On October 19 BE delivered its report.

On October 21 the author sent the "Final Draft Report" to Greg Bock.

On December 17 2010 editing changes were made to the “Final Draft Report” and it was made available to the Fermilab Directorate for posting along with the BE Report and information from FESS provided to the author.

Context: Overall Assumption

The overall assumption in this report is: The MiniBooNE collaboration will vigorously continue and the experiment will take more data beyond what is currently approved.

It may be noted however there was a time, more than a year ago, when there were discussions about selling the oil to NOvA. But apparently those discussions are no longer active, and this report assumes the oil remains with the MiniBooNE collaboration.

One day a decision will be made that the present configuration of the MiniBooNE detector (no matter where it is located at that time) is “done.” When that day comes, many of the considerations in this report can serve as a starting point for its decommissioning.

Two of the biggest cost differences between decommissioning and “storage for relocation” are: the oil can be sold and also a bid can be let to cut up the empty tank and take the pieces away.

Context: Ownership

This list may not be complete. The words “ownership” and “owns” are not necessarily used here in the legal sense, but in the sense of “who has influence over how the stuff is used.”

Columbia owns the oil ($800k about 10 years ago).

Columbia owns the tank.

Some say Columbia paid for the lower half of the detector hall which serves as secondary containment for the oil; others disagree.

MIT owns 300 of the PMT’s, all of which are in the main region.

LANL owns the remaining PMT’s: 1280 – 300 = 980 in the main region, and all 240 PMT’s in the veto region.

LANL owns the wire support structures which hold the PMT’s.

Princeton owns the aluminum plates which hold the support structures used to hold the PMT’s.

LANL owns the PA’s (Power Amplifiers) which provide (in one Teflon-jacketed cable for each PMT) both signal and high voltage.

Princeton owns the Teflon-jacketed cables.

LANL owns the DAQ which receives the PMT signals from the PA’s and the connecting cables.

LANL owns the Faraday cage below the PA's.

Princeton owns most of the oil plumbing system which consists of oil pumps, piping and instrumentation.

LANL owns the oil overflow reservoir below the floor of the electronics room.

LSU owns the in-tank calibration and monitoring systems.

LANL also owns the target and some other things in the BNB target station building, but these are not considered germane to this report since the BNB serves more than the MiniBooNE experiment.

Context: MiniBooNE Stakeholders Meeting

There was a MiniBooNE Stakeholders meeting held at Fermilab on July 23, 2010. It was attended by: Greg Bock (chair), Janet Conrad, Bonnie Fleming, Peter Kasper, Mike Lindgren, Geoff Mills, Bill Louis, Regina Rameika, Mike Shaevitz, and others.

Three options related to microBooNE were discussed: 1) Disassemble MiniBooNE, 2) Move the MiniBooNE tank, and 3) Leave MiniBooNE in place and put microBooNE in a new hall. The first two would allow microBooNE to be put in the MiniBooNE hall. It is important to understand all ES&H concerns about how to move and/or disassemble the detector. It is important to get information from engineers who participated in the construction of the MiniBooNE detector, such as Larry Bartoszek (Bartoszek Engineering) and Bill Sands (Princeton).

Context: Considerations for Relocation

It is assumed the detector parts are to be stored first and then later taken to a new enclosure for re-assembly, rather than being taken directly to a new enclosure. The storage facility could be a single location, or be split among multiple locations. If it is a single location this report assumes, with no justification, it is located 500 feet upstream of the present detector location. If it is in multiple locations it is not out of the question to think of much of the equipment in the electronics room being stored at LANL, and the remaining parts being stored at Fermilab or elsewhere. If the oil is to be removed from the detector, it could be stored somewhere at Fermilab or elsewhere.

Possible locations for a future MiniBooNE enclosure are about 200 meters and about 750 meters from the target. For reference, the current location is 500 meters from the target.

This report makes no attempt to identify appropriate storage locations in existing buildings at Fermilab, nor is a specific facility for storing the parts of the detector included in this report. However, if a storage building would have to be constructed, one can contemplate (at least) two forms. One form could store everything but the tank if the tank is to be stored outside. The other form would store the tank as is (with the equipment and oil still in it) in a building constructed for this purpose, and the equipment from the electronics room would be stored elsewhere.

As an example of building sizes at Fermilab, Lab 5 in the village (if it were empty) would provide about 8,000 sqft.

Context: Conclusion from BE Report

The conclusion from the BE report is given on BEp24 and it gives a perspective (nearly) independent of the author's and thus is worth considering:

> "The four scenarios bracket the rigging costs, complexities and risks associated with moving the MiniBooNE detector to the temporary storage site.
>
> Ultimately, the choice of how to move the detector will be based on the final disposition of the detector. If the detector will have a second life in a new detector hall elsewhere on the MiniBooNE beamline, then exquisite care needs to be taken to preserve the properties of the detector and prevent it from changing. If the detector is moved but behaves in new, unexpected and not understood ways, then the money and effort to move it and set it up will have been wasted.
>
> If the fate of the detector is decommissioning, then the lowest cost (and safest for people) way of taking apart the detector should be selected. If decommissioning is the decision, then removing the spherical shell from the hall in one piece may not be necessary. Additional scenarios involving cutting the sphere apart and removing the pieces should be examined."

Context: Important Notes on Cost Estimates

The section "Summary Table of Estimates" at the beginning of this report indicates the estimates (M&S cost, FTE's, space) should be used with caution. For ease of reference those cautions about the cost estimates are repeated here along with some additional cautions about the costs estimates.

The numbers that go into the costs are derived from a mix of estimate methods. Many estimates are simply initial best guesses by the author (and these are identified as such in the later sections.) Others were provided by people who took some time to determine the estimates and who have experience with the tasks to be accomplished. This means there has been no attempt to assure that a $ in one number means the same thing as a $ in another number. Thus when they are added or compared, the reader should beware.

Fermilab "overhead" is not included in any M&S.

The usual cost adjustments associated with proper project management such as inflation, contingency, value engineering, etc are not included.

The estimates for relocation are crude but are included to give an idea of the total M&S costs of removing, storing and relocating the MiniBooNE detector.

The BE study lists tasks and items which are not included in the cost estimates in this report. They are listed here to give the reader some confidence in the phrase "at least" when a cost is quoted in this report.

These costs are not included for Scenario One in which the oil and all the equipment in the tank are removed and the tank is moved "empty":

- Cost of the below-the-hook lifting fixture: unknown
- Cost of the gravel road: unknown

These costs are not included for Scenario Two in which the tank is moved "full":

- Cost of the gravel road: unknown
- Cost of the lifting fixture and secondary containment: unknown
- Cost of the tank temperature control system: unknown
- Cost of the temporary dry nitrogen supply to the top of the tank: unknown
- Cost of the engineering study and soil testing: unknown

These costs are not included for the scenarios in which the oil is removed but the rest of the equipment is kept in the tank:

- Cost of the below-the-hook lifting fixture: unknown
- Cost of the gravel road: unknown

Historical Guidance: Enclosure

The floor of the enclosure and the lower sections of the wall serve as secondary containment to handle a complete volume of the oil. A new enclosure for the MiniBooNE detector would likely need to be designed with a similar consideration.

If another MiniBooNE enclosure were to be built today a (verbal) cost estimate from FESS is $3,000,000.

Historical Guidance: Equipment in the Electronics Room

The electronics room is located above the MiniBooNE detector. It must be emptied of equipment before the roof is removed which in turn allows the removal of the floor, and then access to the tank for its removal. In addition to the MiniBooNE specific equipment, there are other Fermilab utilities in this room.

The cables which are connected to the PMT's in the oil on one end are connected to the pre-amplifier (PA) units in the electronics room. These units provide high voltages to, and receive the signals from, the PMT's. NIMp27 says: "To achieve low noise, this amplification is done in a Faraday cage as close as possible to where the HV cables exit the tank" under the floor of the electronics room. These cables can be disconnected from the PA units and wrapped and secured on top of the detector tank and be moved along with the tank. But this imposes requirements on how the tank is to be stored.

The cables to the PMT's can be cut but obviously at an additional cost at time of re-installation. If this is considered unacceptable, then one could instead cut the splices of the cables to the "pigtails" which are connected to the PMT's. (The LANL PMT's came with PVC-jacketed cables approximately 3 feet long already attached to the bases of the PMT's, and they are called "pigtails" in this report.) This allows removal of the Teflon-jacketed cables without cutting them, but the splice is in the oil, and thus the oil would have to be removed first so people could get to the splices.

There are cables that carry the amplified PMT signals from the PA units to the DAQ QT (data acquisition charge and time) read-out electronics in a separate set of racks.

The oil circulation pumps are located in the electronics room. The oil overflow system consists of a weir near the top of the tank and a reservoir which is under the floor of the electronics room, and it can hold about 1% of the full detector volume.

Parts of the calibration and monitoring systems (see below) are in the electronics room, along with other racks of MiniBooNE equipment.

There are various other things in the electronics room which are typical of an experiment that has been running for more than 7 years and these would have to be removed and stored or relocated or tossed into a dumpster.

This report does not address utilities or infrastructure equipment which is more closely associated with Fermilab rather than the MiniBooNE experiment itself. Some of this equipment is important for

Fermilab at large and some will be important microBooNE. For example NIMp31 says: "The principal trigger … is obtained from the accelerator clock signals via the Fermilab ACNET (Accelerator Network)." This equipment includes, but is not limited to, an internet hub, electrical service, HVAC, perhaps some other Accelerator Division devices, etc. Costs associated with these items are not included here. Queries about these kinds of items should be addressed to FESS.

Historical Guidance: Tank

The MiniBooNE tank is composed of twelve welded pieces which are supported on six legs. These legs are bolted to the floor. The tank was hydro-tested for leaks. The tank was cleaned before installation work began in its interior. The inner wall has threaded bosses which serve to hold pairs of PMT's in the veto region, and to hold struts attached to aluminum plates which form part of the PMT support structure (PSS) in the main (aka signal) region. The PSS also serves as the basis of the opaque barrier between the main and veto regions. There is an access port at the top of the tank and another one near the bottom of the tank.

The threads in the bosses attached to the inner wall of the tank required refurbishing after being exposed to water. This must be a consideration in removal and storage of the tank if the oil is removed.

When the floor of the electronics room (the roof of the enclosure) is being removed it is important to prevent things from falling on the tank. This is especially the case if the Teflon-jacketed cables are affixed to the tank.

LANL has a 3D model of the tank and its insides to see how things fit. Fermilab also has a computer model of the tank. These may be of use in engineering any scenario for removal, storage and relocation of the tank.

Historical Guidance: Oil

The presentation on http://www.physics.uc.edu/~johnson/Boone/oil_page/Index.html called "Director's Review talk" was given on April 21, 1999 and it gives the technical requirements on the oil. On the same web page "Delivery Diary" indicates the oil was delivered to the detector from about mid-December 2001 to late April 2002. However note that this diary ends at about 220,000 gallons, shortly before all 250,000 gallons were put in the detector. There were 5 FTEs involved in filling the tank with oil: two techs and a supervisor plus a truck driver plus a research associate.

The MiniBooNE detector holds approximately 800 tons of mineral oil. NIMp7 says: "The Marcol 7 mineral oil was delivered to the Fermilab railhead in food-grade railcar tankers that were cleaned and dried before filling." The oil came from Texas. The oil had a nitrogen blanket over it for this trip in order to prevent oxygen from getting into the oil. The Fermilab railhead can hold two railcar tankers at once. Upon arrival at Fermilab, the container was opened, thus allowing the nitrogen blanket to disperse. The oil was inspected visually and measured to verify it was acceptable. NIMp8 says: "… it was offloaded from the railcar via clean plumbing to food-grade tanker trucks …" which were used to transport the oil from the railcar to the tank. There were 4 truck trips per railcar; in all, eleven railcars were used.

NIMp23 says: “The MiniBooNE oil plumbing system was designed to enable filling, recirculation, filtering, temperature control, and removal of the mineral oil.” The oil was taken from a truck and pumped into the detector via the pipe connected to the bottom of the tank. This pipe has an isolation valve which allows sealing the oil in the tank. There is also a pump located at the bottom of the detector vault which can be used to remove the oil, and it was used (see next paragraph.) There are two circulation pumps located in the electronics room.

There were two significant delays in the filling. Shortly after starting the fill the oil had to be removed because of a leak in the access port near the bottom of the tank. Other significant delays were due to delays in the arrival of the tanker cars.

There were several cold nights during these months on which the truck, filled with oil, was driven to a building (provided by ESH northwest of the Meson Lab) overnight. This was done because the oil could not be put directly into the detector and there was concern the temperature of the oil would change significantly if left overnight outside at Fermilab. There is a concern that the drop in temperature would cause the oil to precipitate or become cloudy and thus significantly reduce its extinction length. The oil temperature change associated with the tanker car from Texas to Fermilab was considered acceptable because of its thermal mass and design, but thermal mass of the truck is much smaller and is not designed to prevent temperature changes of its contents. (One contact recommended staying well above 40 degrees F because no measurements have been made on the extinction length below that.) Several barrels of MB oil were (and maybe still are) stored in the M1 beamline.

NIMp25 says: “The amount of emitted scintillation light and the light attenuation in the detector oil can vary strongly depending on the amount of oxygen dissolved in the mineral oil. Therefore, to maintain a stable detector medium, a nitrogen environment is maintained throughout the oil plumbing system. In addition, the (dry) nitrogen keeps water out of the detector tanks and lines and reduces the problem of oxidation on exposed metal surfaces.” Later on the same page it says 30 liters per minute of nitrogen gas were bubbled through the tank for a month, and since then the flow has been about 1 liter per minute.

Considerable experience from LSND as well as research specific to MiniBooNE was brought to bear in choosing the materials that come in contact with the oil. NIMp7 to NIM15 should be carefully consulted in choosing how to store the oil if it is to be removed from the detector with the intention of restoring it in the same condition it has today.

<u>Historical Guidance: Phototubes (PMT’s) and Phototube Support Structure (PSS)</u>

NIMp15 says: “The photomultiplier tube support structure (PSS) includes the hardware for supporting 1280 main and 240 veto photomultiplier tubes (PMT’s), the optical barrier separating the main and veto oil volumes, the fixtures for support and strain-relief of the PMT cables, and support for the various in-tank calibration and monitoring systems.”

NIMp16 and Figure 9 sketch how the PMT’s are mounted in the tank. Struts are attached to bosses on the inner wall of the tank. For the main region, a support structure made of aluminum panels holding two PMT's each are attached to the struts. NIMp17 says: "Two PMT's were mounted to each panel using existing PMT mounts from LSND (see Fig. 10), plus some new ones made to the same specifications." For the veto region, a pair of PMT's is held with wires which are attached to struts which are attached to the inner wall of the tank.

As mentioned earlier in this report, signal and high voltage are carried in a single Teflon-jacketed cable, one for each PMT. Each cable is about 100 feet long, and is spliced to a "pigtail" which is attached to a PMT base. Making these splices is a "big deal" according to those who did it. All the splices are now submerged in the oil.

The PMT's were installed by lowering them through the access port at the top of the tank. PMT installation started at the top and worked its way down because people stood on scaffolding and the scaffolding stood on the inside bottom of the tank. One of the final steps in installation was to lower the cover closing up the top polar cap; this cover has PMT's and oil monitors (see below) attached to it. The last step was to close up the access port near the bottom with a cover with PMT's on it.

NIMp21 says: "The installation of the PSS began in January 2001 and was completed in October 2001", a period of 9 months.

NIMp6 says: "Each tube was washed in a mild solution of detergent and distilled water, rinsed in clean distilled water, and then allowed to dry for 24 hours. The main purpose was to remove the scintillator-doped oil residue from LSND."

There is one more PMT; it is mounted in the oil in the "top hat" region above the sphere and below the floor of the electronics room. It is not in the active part of the detector and is even outside the veto region. It had several potential uses: check for light-tightness when the lid was opened, an additional cosmic veto, and additional muon tracking. See the very last (bottom-right) photo in http://www.hep.princeton.edu/~meyers/boone_pub/pss_install.html .

Historical Guidance: In-Tank Calibration and Monitoring Systems

NIM p36 says: The "laser calibration system consists of a … laser [in the electronics room] … and four dispersion flasks installed at various locations in the detector [oil] … [and] a bare optical fiber … The primary purpose [of the laser calibration system] is to quantify and monitor individual PMT performance parameters. It also allows for *in-situ* monitoring of the oil attenuation length over the lifetime of the experiment. Each dispersion flask is … filled with Ludox colloidal silica … laser light sent to a flask illuminates all of the PMT's … a bare optical fiber that emits light in a cone of ~10^{o} opening angle, illuminating PMT's in a small circle near the bottom of the detector. It is used to study light scattering in the detector … During normal data-taking, laser light is sent to the central dispersion flask at a rate of 3.33 Hz."

NIMp38 says: "The [cosmic] muon calibration system hardware consists of a scintillator hodoscope located above the detector and seven scintillator cubes deployed within the detector signal region. A distinct signature is produced when a muon passes through the [hodoscope] muon tracker, stops in a scintillation cube, and decays. The muon produces Cherenkov light that is detected by the tank PMT's [i.e., in the main region] as well as a coincident signal in the scintillator cube. When [the muon] decays, the resulting Michel electron also produces coincident signals as it exits the cube and traverses the tank volume. Such events, where the location and momentum of the muon and the origin of the electron can be independently determined from the muon hodoscope and cube geometry, provide a means of tuning and verifying event reconstruction algorithms."

The flasks are supported at various heights in the tank by steel cables that are connected to the PSS near the top of the tank and near the bottom of the tank. The cubes are suspended at various heights along or near the vertical diameter of the tank by cables attached to the "top hat". The other ends of the cables for the pair of cubes nearest to the bottom of the tank are located at specific points at the bottom of the tank by weights.

Scenario One: Move The Tank Empty

Scenario One: FESS Study and Bartoszek Engineering (BE) Study

In this scenario the empty tank is stored outside on caissons.

An estimate is provided in a study commissioned by FESS (delivered on July 22 2010) to open the enclosure, move the empty tank, and re-roof the enclosure. In about 3 months at a cost of $1,401,000 the dirt cover, roof and floor of the electronics room can be removed, six caissons can be put 500 feet upstream of the current MiniBooNE location by the side of a road, the empty tank can be moved from the enclosure to the caissons, and a new roof put on the hall with a removable section appropriate for use by microBooNE. In the study commissioned by FESS the cost of a crane for removing the empty tank, moving it to the six caissons and putting it down is $490,000. (The estimated cost without the crane is $911,000.)

A study for removing and placing the tank on the six caissons was done as part of this report by Bartoszek Engineering (BE). BE considered four scenarios:

Removing everything from the detector and moving the empty steel spherical tank

Moving the detector after removing the oil and the PMTs and supports, but not the cables

Moving the detector after removing only the oil

Moving the ~950 ton detector as is

(Note to those who will read the BE Report. The numbering of the BE scenarios is NOT the same as the numbering in this report. For example, BE Scenario 4 corresponds to Scenario One in this report, and BE Scenario 1 corresponds to Scenario Two in this report.)

For Scenario One the removal by crane of the 50 ton MiniBooNE tank and moving it to the six caissons is estimated by BE to cost between $200,000 and $500,000. (Recall the crane in the FESS study is $490,000.). The cost of the caissons themselves is not included. This only includes the crane rental, setup, moving the tank, and removal of the crane. It would take about 3 weeks for crane set up, and about 3 days to move the tank and remove the crane equipment. This estimate assumes either the current road is wide enough for the crane, and/or Fermilab would pay for an appropriate gravel path as needed from the current MiniBooNE hall to the location of the six caissons. This estimate does not include other expected costs (e.g., profit) which are included in the report commissioned by FESS. Thus the author concludes this estimate is in the same ball park as the estimate from the study commissioned by FESS.

The author chooses to use $500,000 for the cost of the crane to move an empty tank.

If Fermilab decided to pursue the path which moves the empty tank to a storage location, a similar crane cost would be incurred when the tank is moved to its new enclosure on the BNB.

Scenario One: Removal of Equipment from the Electronics Room

The equipment in the electronics room must be removed before the roof can be removed. It is assumed this would begin as soon as possible after Fermilab schedules the suspension of MiniBooNE data taking.

This work has to be done in either Scenario One or Scenario Two, and is assumed to be the same in both scenarios.

Fermilab will pick up the costs for maintaining or restoring the Fermilab infrastructure (equipment and services) in the electronics room associated with opening and re-roofing the enclosure. This cost is not estimated in this report.

An estimate for removal of the electronics was done as part of this report by a source familiar with the situation. The estimate for removing and packing most of the cables in the electronics room is about 13 FTE weeks. Preparing the racks would take about 8 FTE weeks. Moving the racks (carefully because they are full of electronics) would take about 8 FTE weeks. These 29 FTE weeks would be spread over about 8 work weeks.

Removing the equipment associated with the in-tank calibration and monitoring systems and the other equipment from the electronics room is estimated (by the author) to take another 4 FTE weeks spread over about 2 weeks. This includes the oil pump system and overflow system which must be isolated from the tank itself, removed and stored in a sensible manner in any scenario which moves the tank.

All together the estimated effort to clean out the electronics room is 33 FTE-weeks spread over about 10 weeks.

Scenario One: Oil Removal

One could consider the case of removing the oil by "time reversal" of what was done to fill the tank. In this case railcar tankers would be used to store the oil (at an undisclosed location off-site). Removing the oil is estimated to take about 3 months (the author's estimate.) This assumes the same equipment that filled the tank can be used again, and assumes some railcar bottlenecks will be inevitable because their availability is not guaranteed at any given time.

As mentioned in "Historical Guidance: Tank" above, the pipe coming out of the bottom of the tank has an isolation valve. After the oil is removed it would be closed, the oil in the piping removed sensibly, and the piping would be sent to storage.

One could consider a second case in which the oil is stored somewhere at Fermilab. In this case about forty containers would be used to hold the oil. The removal of the oil is estimated to take about 8 weeks (including learning how to do it) with 5 people working on it full time (or 40 FTE-weeks). This must be done before the roof of the electronics room is removed because parts of the oil pumping system are in the electronics room; but it can probably be done in parallel with removing all the other equipment in the electronics room. It is assumed the same equipment that was used to fill the tank can be reused at no cost.

Scenario One: PMT and PSS Removal

Presumably a good starting concept for PMT removal is to think of it as a time reversal of the installation. (Here the PMT support structure is included.) However, removal of the PMT's from the tank poses several challenges which were not present during installation. These challenges eventually must be met when the MiniBooNE detector is decommissioned, so these comments may be of use one day.

A source familiar with the installation estimated it could take about five months (taken to mean 21 weeks by the author) to remove the PMT's and PSS. This estimate is based on the time it took to install these items. However two time consuming installation activities do not need to be done for removal: Alignment and splicing. Nevertheless, spread over 21 weeks this estimate gives a rate of about 14 PMT's per day, which seems reasonable to the author, and it seems reasonable that three people are involved. Thus the FTE effort is about 62 FTE-weeks. (The author estimates it would take about 40 FTE-weeks just to remove the PMT's alone.)

This estimate assumes all the oil issues have been resolved.

After the oil has been pumped out, the inside wall of the tank and the equipment inside the tank will be coated with oil. The equipment includes the PMT's, the PSS, and the cables. The experience that MiniBooNE collaborators gained in removing PMTs from the oily environment of LSND will be extremely valuable whenever the need arises to do so from the oily environment of MiniBooNE. (See the next section for comments on the in-tank calibration and monitoring systems.)

One could consider cleaning this equipment (and the inside of the tank) by filling the tank with dispersants or microbes. The volume needed is 250,000 gallons. And after washing, one would consider rinsing the surfaces and again appropriately disposing of the liquid. BEp18 notes: "Choice of detergent and waste water disposal will require testing and consultation with FNAL ES&H." Of course the protection of all the surfaces of the equipment must be a top consideration in choosing the cleaning agent. Some of the surfaces may react with water, and these may have to be refurbished later.

Another choice is to work inside the tank without cleaning the oil away. In the author's view, this choice presents at least two safety concerns as well as concerns about equipment damage. Oil coatings on the various surfaces likely make the surfaces slippery; people can slip and the equipment they are handling (such as PMT's) could more easily be dropped. The tank is a confined space (within another confined space, the enclosure) and sufficient ventilation (or other sources of oxygen) for the people working in the tank must be provided. It has to be determined whether there are hazards from inhaling oil vapor or from exposure of one's eyes to oil vapor that need to be mitigated. If the oil is not removed in a controlled manner, consideration should be given to the hazard arising from gravity which will cause it to migrate, drool or drip for some period of time.

BEp20 states the concerns with this choice as follows:

> "The major risk associated with [these] scenarios … is to people. When the detector was first assembled, everything was clean and dry. The tank was well ventilated with fresh air.
>
> In this scenario, when the man hole is first opened and people are reaching in to remove the first PMTs, oil will be dripping everywhere. The tank will certainly need ventilation

> to allow people to go inside, and the fumes extracted by the ventilation may need to be processed somehow before the air can be exhausted to the outside. I do not have the expertise to know anything about how the fumes should be dealt with.
>
> It is possible that the extent of ventilation required may mean that [the choice] above cannot be made if the detector is to be reassembled. The oil remaining on the parts may be too contaminated with oxygen and other materials (clothing, gloves, dirt, etc,) to allow the part to be reinstalled without first washing it off.
>
> I do not know if the atmosphere inside the tank will be harmless with just fans blowing air through the detector. It may be that anyone inside the tank is required to wear breathing apparatus. This would have to be determined by FNAL ES&H.
>
> As the scaffolding is reassembled inside the tank it will become coated with mineral oil as parts that are removed drip on it. The fall hazard will be significant on the scaffolding."

However, the author knows it is possible to pay enough money to develop tooling which people can sensibly use to remove the equipment even if it is coated with oil. This should be considered as an option until it is determined to be a bad idea. The author estimates this could be done for less than about $2,000,000.

The author estimates it would take about 3 weeks to clean the oil off the equipment in place in the tank if the decision were made to wash and rinse. The author estimates the cost to be about $100,000 including disposal of the liquid, but the author remains leery about damaging the equipment in the tank.

When the PMT's are to be removed from storage for re-installation, it would be prudent to include a test station setup for re-installation similar to the one used for the initial installation.

Whether the aluminum plates supporting the signal PMT's are removed or left in place when the tank is moved, it must be re-established that the opaque barrier between the main and veto regions is intact before the detector works properly again.

<u>Scenario One: Removal of In-Tank Calibration and Monitoring Systems</u>

These were nearly the last things installed in the tank, and they would nearly be the first things to be removed. The comments about oil on the surfaces apply to these also, but removing them from the tank should not take too much time and it would then be easier to clean them and easier to clean the rest of the equipment still in the tank.

Removal of the parts of these systems which are not in the tank is included in the removal of the equipment from the electronics room.

<u>Scenario One: Time Estimate</u>

The time estimate of interest is how long it takes to get to the point where the work can begin to open the enclosure as described in the FESS commissioned report. The above estimate indicates it takes about 10 weeks to empty the electronics room. But this can mostly be done "in the background" compared to the other work: 8 weeks to drain the oil, 3 weeks to clean the equipment in the tank, and 5 months (which the author takes to be 21 weeks) to remove the PMT's and the PSS. It is assumed appropriate storage facilities are available before the clock starts and there are no delays in getting things into storage.

The time estimate of interest for Scenario One is about 32 weeks, or 8 months.

The FTE estimate is 135 FTE-weeks (33 for the electronics room, 40 for the oil and 62 for the PMT's and PSS.)

<u>Storage Requirements for Scenario One</u>

In this scenario the tank is stored outside on six caissons, and it may be tempting to imagine that un-insulated outdoor staging of the tank would be OK. However, protection of the tank's inner and outer surfaces from Illinois temperature and humidity variations should be a consideration (since it is assumed the tank will be reinstalled.) The author estimates this protection will take about 4 weeks and cost about $40,000.

A first estimate of the storage area required for everything other than the tank is about 20,700 square feet (sqft.) This includes the equipment from the electronics room, the equipment inside the tank and the oil. The space could be in a new building, or in one or more existing buildings at Fermilab, or elsewhere.

The author estimates the storage area for the equipment from the electronics room will be about 1,000 sqft. "Equipment from the electronics room" includes not only the electronics in racks, but the overflow tank, the piping for the oil pumping system, the hodoscope above the detector, the monitors (like the laser system), computers, etc. This estimate is based on many walks inside the electronics room by the author. The author estimates it will cost about $30,000 for storage containers to hold these things (other than the racks) and protect them. (This would have to be done in either Scenario One or Scenario Two.)

An estimate for the storage area required by main PMT's can be made by assuming two PMT's will be put in a single package still mounted to their aluminum support panels. The panels are about 2 ft x 4 ft, and the space occupied the PMT's away from the panels is about 1 ft [NIMp16 and 17]. It seems reasonable to the author that one pair of PMT's would fit nicely (including blocking to prevent movement) inside a plywood box of (outside) dimensions 53 inches by 29 inches by 15 inches. The pigtail associated with each PMT is assumed to curl up neatly inside this box. (It would be prudent, if one chose not to clean the surfaces of oil, to put the PMT pair, its aluminum panel and pigtails in a bag made of an appropriate material.) Four packages on top of one another would make a stack about 5 feet tall. Two stacks side by side would fit on a pallet of size about 58 inches by 53 inches. Since there would be 16 PMT's per pallet, one would require 80 pallets. One can put these into 4 groups of 20 pallets each, with 2 pallets back-to-back in a row 10 pallets long. On its own, a pallet group would occupy a space of about 9 feet by 96 feet. If one allows (a generous) 4 feet of clearance around each 20 pallet group in order to gain ready access to any package, one would need 1972 sqft to store the PMT's from the main region.

An estimate for the storage area required by PMT's in the veto region can be made in a similar way, but these PMTs are mounted in pairs directly to the tank wall with struts which are assumed to remain attached. Referring to Figure 9 on NIMp16, the author estimates two veto PMT's can be put in a package of (outside) dimensions 22 inches by 22 inches by 14 inches. It would take 120 packages to hold the 240 veto PMT's. Three packages on top of one another would make a stack about 42 inches tall, and 40 such stacks would be needed. Four stacks would fit on a pallet about 44 inches square, and 10 pallets would be needed. One could put these into a single group with 2 pallets back-to-back and 5 pallets wide. On its own, it would occupy a space of about 7 feet by 18 feet. If one allows (a very generous) 4 feet of clearance around it in order to gain ready access to any package, one would need about 15 ft by 26 feet or about 390 sqft to store the PMT's from the veto region. The same comments on the main PMT's about the pigtails and oil apply to the veto PMT's.

If done this way, the storage of the PMT's will require 1972+390=2362 sqft.

The author estimates the PMT storage packages to cost about $50 each, which gives a total of about $40,000 for the required 1520/2 = 760 packages. It is assumed that the equipment needed to handle these packages is available without cost.

It is assumed the storage area requirement for the in-tank calibration and monitoring systems is small compared to that for the PMT's.

The lateral hoops which form part of the PSS will also need to be stored. (For photos of these hoops being installed in the tank see the Feb 5-9, Feb 12-16 and Feb 19-23 photos at http://www.hep.princeton.edu/~meyers/boone_pub/pss_install.html .) According to NIMp16 these hoops are made of 2 inch (outer) diameter aluminum tubing with a 0.125 inch wall. They come in sections, and according to Table 2 on NIMp19 their total weight is 0.9 ton. The author estimates the total length of these hoops to be about 2080 feet (assuming the density of aluminum to be 0.098 pounds per cubic inch.) Another estimate derives from assuming the length of these hoops is the same as the total length of all the aluminum plates if they were laid side-by-side. In this case the author estimates the total length of these hoops to be about 2560 feet (assuming 2 PMT's per plate, 1280 main PMT's, and 4 feet for the length of a plate.) Splitting the difference gives an estimate of about 2400 feet for the total length of the latitudinal hoops. Again it seems the storage area required by these hoops is small compared to that required for PMT storage.

Based on these considerations and without further justification, the author chooses to raise the estimate for the storage area needed for all the things in the tank (other than the oil) by another 338 sqft to about 2700 sqft.

The storage area is dominated by the oil. Consider the case in which one stores it in “flexitanks.” A flexitank holds about 6,000 gallons in a bag which is held in a shipping container. Shipping containers are made to be stacked one on the other. About 40 flexitank units would be needed, and their purchase price is estimated to be $150,000.

(Aside: The author learned during the preparation of this report that flexitanks were invented to ship wine across the oceans less expensively than shipping it in bottles, which add weight and take up space. At the destination, the wine is taken out of the bags and put into bottles. For additional flexitank background, see http://www.eptpac.com/en/products/flexitank .)

It is assumed the oil is to be stored more than a year which is the approximate break point between renting and buying the shipping containers. If nothing clever were done (meaning they were placed side by side) they would require about 34,000 sqft. Or, if they are stacked two high (about 17 feet tall) one may assume they would require about 17,000 sqft, and this is the area assumed here.

If a flexitank were filled with MiniBooNE oil, it would weigh about 22 tons. There are several techniques currently in use at Fermilab for moving around things with this weight either on-site or off-site, so this does not appear to pose a technical concern. The cost of moving flexitanks into (or out of) their location in the storage facility (on-site or off-site) is not included in this report.

The ESH secondary containment requirement for a “two-high” stack of flexitanks is to have a container which can hold one flexitank volume. The author estimates the secondary containment for each of the 20 stacked pairs will cost about $1,000 or about $20,000 for all of them.

The oil in the MiniBooNE detector caused Fermilab ESH to require a deluge system. A similar system may be required wherever the oil is stored. The author estimates this to cost about $20,000.

In any oil storage scenario the temperature of the oil is to be kept between 50 and 85 degrees F. This is likely a tight temperature range, and the author specifies “50” and” 85” in order to challenge others to prove him wrong. The author is not aware of any characterization of the oil when exposed to temperatures below 40 degrees F. For reference, during a tour of the MiniBooNE detector on August 18 2010 the temperatures as measured by the three monitors distributed at the outside top, middle and bottom of the tank were each about 65 degrees F.

The method of storage should recognize that prolonged exposure to oxygen leads to deterioration of the extinction length; this deterioration should be avoided as much as possible. How much contamination is “too much” has not been determined as far as the author knows. Another way of making this point is given on BEp15: “When the oil was initially pumped into the tank, it was bubbled with dry nitrogen to drive off the entrained oxygen. I do not know how such a system can be applied to temporary storage tanks … Once the oil is removed from the tank, I do not see how it can be guaranteed to have exactly the same properties it has right now in the detector … I do not see how scenarios [which remove and reinstall the oil] can be reconstituted into an identical detector at the new location in the future.”

Given the current guidance (i.e., none) about the length of storage, it is prudent to consider storing the oil for 1 year or 2 years or 5 years. No matter the length of storage, the temperature of the oil should be monitored and recorded during storage. And before being used in the detector again, a plan should be developed for determining the level of deterioration of the extinction length or changes in the scintillation properties (due to oxygen contamination or other effects) and its restoration. And wherever it is stored, when the decision is made to use the oil again, it would be good to have it returned on a schedule that is sensible.

The sum of the Scenario One storage costs of the equipment identified above is $400,000. This does not include all the costs, and the author claims it is not irrational to double it to about $800,000. Adding this to the FESS cost estimate without the crane and replacing it with $500,000 for the crane gives a cost estimate for moving the empty tank and preparing everything else for storage of $2,211,000.

This number assumes storage space is free. It is not.

FESS provided a verbal cost estimate of $300 / sqft for a “low building” with the usual heating ventilation and air conditioning (HVAC). The space needed from the above considerations is: 1,000 sqft for the equipment from the electronics room, 2,700 sqft for everything in the tank (other than the oil), and 17,000 sqft for the oil; a total of 20,700 sqft. The cost of a new storage building with this area would be about $6,210,000.

A building with 17,000 sqft for storing the oil alone would be about $5,100,000.

If one chose to put all the oil in a single pool it would need about 8,000 sqft (this depends on the depth, of course.) Adding this to the 2,700 sqft for the electronics and all the equipment in the tank (other than the oil) one obtains a total area of 10,700 sqft at a cost of about $3,210,000.

The author suspects it is likely Fermilab management would be motivated to find storage in existing Fermilab buildings or to rent storage space, rather than invest several millions of dollars in a new storage facility for the MiniBooNE equipment. Thus, the cost for a storage facility in this scenario is assumed to be in the range from zero to $6,210,000 which is the cost of a new building to store everything from MiniBooNE other than the tank itself.

Cost Summary: Scenario One

An estimate of the cost of Scenario One starts with the FESS study without the crane: $911,000. The crane estimate is $500,000. Assuming zero cost for storage space, the cost for removing and preparing everything for storage is $800,000. Together these give a cost of $2,211,000. Adding the cost of storage space gives a cost between this number (if storage space is free) and $8,421,000.

When the decision is made to put the detector in its new hall, the additional cost would be $3,000,000 (for the new enclosure) $500,000 for the crane. Other costs are small compared to these, so including them gives an estimate of “at least” $3,500,000.

Altogether the M&S cost for Scenario One is at least $11,921,000.

Scenario Two: Move The Tank Full

In this scenario it is still necessary to remove the equipment in the electronics room and store it.

In this scenario it is still necessary to open and re-roof the enclosure.

In this scenario it is not necessary to remove the oil, PMT's, the PSS, or the calibration and monitoring systems in the tank.

The Teflon-jacketed cables would be wound up and attached to the top outside portion of the tank.

It should be noted that this scenario has the best chance of returning the MiniBooNE detector to its present state in a new location, assuming things go according to plan.

Scenario Two: BE Study for Moving The Tank Full

One can think of a scenario in which the tank is moved while the oil is still inside the tank with the equipment still inside the tank. After all, the tank is a perfectly good storage device for the oil and the equipment inside it.

Bartoszek Engineering (BE) was commissioned to study this scenario. The BE study cost estimate for renting a crane to move a 1,000 ton full tank is $4,000,000 according to BEp6. This is what is used in this report.

And as in Scenario One if Fermilab decided to pursue this path, a similar crane cost would be incurred when the detector would be moved to its new location on the BNB.

The BE study proposes a "grillage" to be constructed under the tank while it is in the enclosure. This will be used to support the tank and put it on a transporter for its trip to the six caissons. Because it is designed to be used for the 40 foot diameter sphere full of oil, it is not small as noted on BEp7: "The design of the lifting/grillage frame is an equivalent effort to designing a 5 story building, but the loads to be lifted are much higher than in any building of that size. It will have to be designed by structural engineers and satisfy both the AISC Code and the ANSI/ASME B30.20 Below-the-hook Lifting Devices Code." See BEp8 through 10 for additional details.

As mentioned above, the pipe coming out of the bottom of the tank has an isolation valve, and it would be closed to seal the oil in the tank when the tank is being moved. However, in this scenario consideration must be given to expansion of the oil if the outside temperature is significantly warmer than inside the enclosure. This consideration begins when the floor of the electronics room is removed, and ends when the temperature is once again under control in the storage building.

One approach to handling the possible expansion of oil would be to estimate the amount of expansion based on the expected temperature rise and thermal mass of the tank-oil system. One could remove that volume of oil with the pumping system and store this oil in "small" containers which are appropriate. Then one would close the isolation valve, remove the oil in the piping sensibly and send the piping to storage.

When moving the tank with the PMT's inside it, the presence of the oil is expected to damp small motions of the aluminum plates which hold the PMT's. Thus, this represents a reduction in risk for the PMT's. On the other hand, the oil may slosh around during movement and if so this would disturb the uppermost PMT's and aluminum panels to some level. This limits the amount of oil that can be removed, as mentioned above to avoid unacceptable expansion due to Illinois outside temperature variations.

Another approach to controlling the oil temperature is given on BEp6: "The system I imagine involves an insulated blanket with heaters and thermocouples wired into it to maintain a constant temperature. If the move happens in the summer time, the insulating blanket will need a highly reflective outer cover to reflect sunlight. The blanket would also need to be water-tight because of the high probability of rain (or snow) during a month-long exposure to the weather."

BEp8 says: "FNAL ES&H will have to be consulted to determine the need to provide secondary containment for the oil during the move. This could require that the lifting fixture have additional features sufficient to catch and hold some or all of the oil in the event of a catastrophic leak from the sphere. Assembling a leak tight basin around the bottom of the detector will be a labor intensive, expensive and difficult activity, probably requiring welding to seal the basin. It could be the equivalent of building a cylindrical flat bottom tank around the spherical tank." These costs are not included in the BE cost estimate.

BEp8 says: "The soil around the detector will have to be tested and an engineering study will have to be done to determine whether the weight of the crane plus detector poses any risk of collapse to the walls of the detector hall." These costs are not included in the BE cost estimate.

Finally, BEp11 says: "Another risk to the detector is an accident during assembly of the grillage frame that drops one of these heavy beams on the detector."

Scenario Two: Time Estimate

The time estimate of interest is determined by the 10 weeks it takes to empty the equipment from the electronics room, which is the same as in Scenario One (a total of 33 FTE-weeks.) It is assumed the time it takes to pump out "a small amount of oil" in anticipation for expansion due to the warmer outside temperature fits in this time.

The time estimate of interest for Scenario Two is about 10 weeks.

Scenario Two: Storage Requirements

A storage building to contain the 40 foot diameter sphere and provide for temperature control could be built. An informal, verbal FESS estimate for a 50 x 50 x 50 cubic foot building with concrete walls (based on the recently constructed NOvA building) is "at least $500,000."

The reason for the "at least" is because costs are not included for making the building serve as secondary containment, and for other required costs. A verbal FESS cost estimate for making the building serve as secondary containment added other $100,000 just for piling dirt around the bottom part of the concrete walls so they don't fracture from the oil pressure in the event of a complete loss of oil from the tank. Additional costs would include making the inside of the building "oil tight", a deluge system, access through the top of the building or through the upper portion of the wall (because dirt is piled up around the bottom), and other items. Thus, the total cost of a building appropriate to store the tank full is at least $600,000. But this is small compared to the cost of the crane to move the tank full.

The total storage space in the scenario is the 1,000 sqrt for the equipment from the electronics room plus the 2500 sqft of the tank storage building.

<u>Cost Summary: Scenario Two</u>

An estimate of the cost of Scenario Two starts with the FESS study ($1,401,000), removes the cost of the FESS study crane ($490,000), adds the cost of the Scenario Two crane ($4,000,000) and adds the cost of the new building ("at least" $600,000.) These add up to "at least" $5,511,000.

When the decision is made to put the detector in its new hall, the additional cost would be $3,000,000 (for the new enclosure) plus $4,000,000 for the crane. Other costs are small compared to these, so including them gives an estimate of "at least" $7,000,000.

Altogether the M&S cost is about $12,511,000.

Variant on Scenario One: Use Less Time

A variant on the "empty tank on six caissons" of Scenario One was suggested in order to reduce the time after MiniBooNE operation is suspended until the work to open the enclosure (and remove the tank) can begin. After removing the oil, one could consider leaving the PMT's, the PSS and in-tank calibration and monitoring systems in the tank, either coated with oil or cleaned up. This would reduce the time to about 10 weeks, and avoid the cost for taking the equipment out of the tank and storing it. The effort in this scenario is the same as Scenario One (135 FTE-weeks) minus the 62 FTE-weeks for removing the PMT's and PSS, for a total of 73 FTE-weeks.

If this were done, one could assume this equipment can not only survive variations in outside temperature, but as importantly it can return to service without any significant change. One could also assume various fuzzy or furry or feathered or scaly animals or insects will naturally avoid enjoying the equipment either by eating or nesting or leaving "souvenirs." If either assumption is wrong, then it will cost money to protect this equipment while it is being stored "outside."

Another concern relates to the PSS flexing with the tank itself while it is being moved. Fermilab engineers did a study of how much the tank would flex when the oil was added, and this was found to be small. (See the text following Figure 9 on NIMp16 for further discussion.) The same concern, perhaps aggravated, exists if the tank is to be moved with the PSS in place since it is attached by struts to bosses on the inside wall of the tank. And the same concern applies to variations in temperature during the year in Illinois if it is to be stored outside.

As for the cost of the crane in this variant, BEp19 says: "The detector weight in this scenario is only [slightly different from an empty tank] … an insignificant difference to cranes of this scale."

But this variant comes with increased risks to the equipment left inside the tank.

An estimate of the cost of this variant on Scenario One starts with $911,000 (the FESS study without the crane), adds $500,000 (the crane), adds $140,000 (the cost of washing, rinsing and protecting the tank), and adds $220,000 (the cost of preparing the oil for storage.) These costs add up to $1,771,000. The cost for storing just the oil is taken to be between zero if it is not on the Fermilab accounting books, and $5,100,000 if a new storage facility with 17,000 sqft is needed. (This is a crude estimate and additional costs are ignored, but expected.) These add up to $6,871,000.

When the decision is made to put the detector in its new hall, the additional cost would be $3,000,000 (for the new enclosure) plus $500,000 for the crane. Other costs are small compared to these, so including them gives an estimate of "at least" $3,500,000.

Altogether the M&S cost is at least $5,271,000 but probably not much more than about $10,371,000.

Variant on Scenario Two: Use Less Expensive Crane

A variant on Scenario Two was suggested to reduce the crane cost. This variant is based on the concept that the tank is a perfectly good place to store the oil. (This was suggested by three sources so it is probably a good idea.)

BEp13 says: "… temporarily remove the oil from the vessel to make moving the tank easier (using a smaller, cheaper crane) then putting the oil back in the tank during the temporary storage period. The oil would have to be removed and stored again when the final detector hall is ready and the detector moved from the temporary to final location."

In this variant, the oil is drained and sent temporarily to storage, for example, about 10 food-grade railcar tankers. The schedule estimates in Scenario One can be used for an estimate for this variant: 8 weeks to drain the oil and 3 weeks to clean the equipment in the tank. Thus, it takes about 11 weeks from suspension of MiniBooNE operations to turning the MiniBooNE hall over for the work to open the enclosure (and remove the tank.)

The tank, even with the PMTs and PSS and cables, is "nearly empty" in this variant. Thus a crane similar to the one in the FESS study can probably be used. Again (as stated in the previous section) BEp18 is relevant: "The detector weight in this scenario is only [slightly different from an empty tank] … an insignificant difference to cranes of this scale." The tank is moved and put on the six caissons inside the new concrete storage building of Scenario Two. The temporarily stored oil is put back in the tank, avoiding the long term cost of storage. Most of the equipment from the electronics room would still need to be stored, but the oil plumbing system (with modifications) would likely be used to put the oil back in the tank. Plumbing modifications would be needed because the tank would be above ground. The capability of the caissons would need to be evaluated for the larger loads, and this has not been done.

But this variant comes with increased risk to the oil since it must be handled multiple times compared to Scenario Two. BEp13 says: "The removal and temporary storage of the oil is non-trivial ..." and BEp15 says: "The risk of damage to the PMTs is also larger in my opinion in this scenario. In [the full tank] Scenario … the detector weighs so much that it is hard to imagine 'bumping' it or accelerating it fast enough to cause any differential motion of the liquid that could harm the PMTs, or by extension the photocathode arrays and other delicate components inside the PMTs. The riggers I spoke to thought that the motion of the crane and transporter in either Scenario [full or empty of oil] would be gentle enough to avoid damaging the PMTs, but the risk is greater in [the empty] Scenario … than in [the full] Scenario …" And this handling would be repeated when the detector is moved to its new location on the BNB.

As in Scenario One, the author estimates the storage area for the equipment from the electronics room will be about 1,000 sqft; its cost is taken to be zero because the author suspects this amount is available somewhere at Fermilab. The storage area for the tank is 50 ft x 50 ft = 2500 sqft. The total storage area is 3,500 sqft.

The effort estimate in this scenario is the same as in Scenario Two (33 FTE-weeks) plus that needed to drain and fill the tank with oil. The estimate in Scenario One is 40 FTE-weeks to remove the oil.

Assuming it is the same to put the oil back in the tank gives 80 FTE-weeks. And another 80 FTE-weeks would be needed when the new hall is available. The total FTE effort in this scenario is 33 FTE-weeks plus 160 FTE-weeks = 193 FTE-weeks.

An estimate of the cost of this Variant on Scenario Two starts with $1,401,000 (the FESS study) plus “at least” $600,000 for the concrete storage building. The cost to remove the oil, temporarily store it and put it back in the tank has not been professionally estimated, but the author would be (pleasantly) surprised if it were less than another $1,000,000. These add up to “at least” $3,001,000.

When the decision is made to put the detector in its new hall, the additional cost would be $3,000,000 (for the new enclosure), $490,000 for the crane, and about $1,000,000 to remove the oil, temporarily store it and put it back in the tank; these add up to about $4,490,000.

Altogether the M&S cost is about $7,491,000.

<u>Scenario Three: Build A New MiniBooNE Hall First</u>

The crane rental cost can be cut in about half if the crane is used once. This can be done if the new MiniBooNE hall is ready to receive the tank before it is removed from the current enclosure.

This is the same as the previous scenario (Variant on Scenario Two: Use Less Expensive Crane) except the crane is only used once. Thus the cost is $7,491,000 minus $491,000 for the second use of the crane.)

The FTE estimate of the previous scenario (193 FTE-weeks) is a good starting point for this scenario. However, in this scenario the oil is put back in the tank in its new location. This avoids one cycle of filling and emptying, or 80 FTE-weeks. The FTE effort in this scenario is 193 FTE-weeks minus 80 FTE-weeks, or 113 FTE-weeks.

The storage space is the same as the previous scenario: 3,500 sqft.

The total M&S cost is about $7,000,000.

<u>Scenario Four: Sell The Oil and Buy New Oil</u>

In the hope of reducing the cost further, in this scenario the oil is sold rather than stored, and then new oil is purchased again and put in the tank once it arrives in its new hall.

Columbia owns the oil. Thus, it is unclear to the author how the estimate in this report can be done in a way that sensibly informs Fermilab management. The author could choose to pretend that the buying and selling of the oil is a net zero cost. But the author also realizes that negotiations between Columbia and Fermilab could result in the difference in cost being covered by Fermilab funding.

The tasks in this scenario are fewer than as in “Variant: Use Less Expensive Crane” except for one cycle of filling and draining the oil. This is because oil would be put in the tank in its new location rather than put into the tank and removed.

Thus, the FTE effort for this scenario is 193 FTE-weeks minus 80 FTE-weeks, or 113 FTE-weeks.

The risk to the experiment is larger because the oil is not the same. It is worth pointing out again that the oil is not the same in any scenario except that in which the oil is kept in the tank.

The storage area again is 3,500 sqft.

The cost in "Variant: Use Less Expensive Crane" is $7,491,000. This includes about $1,000,000 to remove, temporarily store, and refill the tank with oil (once), or about $2,000,000 to do these tasks twice. Those costs can be deducted in this scenario giving an M&S cost of about $5,491,000.

Scenario Five: Just Remove The Useful Parts

This scenario tries to set a "floor" on how much it would cost to remove and preserve only that equipment which plausibly could be used for other applications including physics experiments.

However, it is assumed there is no rush because the experiment is "done" and there is not another user for the enclosure. If this is not true, then this scenario will cost more.

Since it is assumed there is not another user for the enclosure, none of the work in the FESS study need be done. This means the electronics room remains intact and available for storage space. However, since the electronics would be off, HVAC requirements in the electronics room would be relaxed.

Columbia owns the oil and it could sell it. There are many uses for oil, not just in HEP. Fermilab would pay some of its employees to work with Columbia and the buyer of the oil to develop a plan. There may or may not be schedule pressure to remove the oil, but the oil must be out of the tank before the PMT's can be removed.

The electronics, owned by LANL, could be disconnected for use in other experiments. This includes the PA's and the DAQ. Or this generation of electronics could be declared "too old" and discarded. But disposal would require a review of exactly what materials are in the electronics so that ESH rules are complied with. LANL would lead this effort but Fermilab or LANL employees could do the work.

The cables, owned by LANL and Princeton, could be used in another experiment. Or they could be sold for scrap to recover the copper and other metals in them. The author chooses to ignore the cables in this scenario.

The PMT's, owned by MIT and LANL, can be used in other experiments. Fermilab employees would work with MIT and LANL to specify what condition the PMT's are to attain after removal. There is probably enough space in the electronics room to store them (assuming they are not attached to the PSS plates.)

The effort to do these things is mainly the same as in Scenario One (135 FTE-weeks), except the PSS is not removed which saves about 22 FTE-weeks. Thus the FTE effort is about 113 FTE-weeks.

Doing more than this short list (oil, electronics, cables and PMT's) will cost more money depending on how it is done.

For example, the PSS (owned by Princeton) could be sold for scrap to recover the aluminum and this would probably not cost much money. The same hold true for the holders for the PMT's, which are owned by LANL (unless they are to remain attached to the PMT's.)

The destiny of the tank, owned by Columbia, would be worked out with Fermilab. For example, one could consider selling it for scrap after cutting it up while in the enclosure. However, although the current access to the enclosure is large enough for people, it very likely will be necessary to spend money to make a more appropriate access to remove tank parts.

The author estimates it will take about $2,000,000 M&S to do these things.

On the other hand the tank could be abandoned in place in its enclosure and thus arrive at the current status of many other items from Fermilab experiments which are "done."

List of Major References

Available on a Fermilab Website

This report, “MiniBooNE Detector Removal and Storage for Relocation”, will be available at the Fermilab Directorate website

http://www.fnal.gov/directorate/program_planning/studies/index.html

FESS Study: August 26 2010 Memo “MiniBooNE Removal Memo.pdf” will also be available at the Fermilab Directorate website mentioned above.

FESS Study: July 2010 “Final_MicroBooNE_Report_2010_for D Finley.pdf” will also be available at the Fermilab Directorate website mentioned above.

Bartoszek Engineering Study: October 19 2010 “BE Moving MiniBooNE Report-revC.pdf” will also be available at the Fermilab Directorate website mentioned above.

Available On Other Web Pages

“The MiniBooNE Detector” NIM article: **http://arxiv.org/abs/0806.4201**

Professor Randy Johnson’s web page: http://www.physics.uc.edu/~johnson/Boone/oil_page/Index.html

Professor Peter Meyers’ web page:
http://www.hep.princeton.edu/~meyers/boone_pub/pss_install.html

Closing Remarks

The author has not been asked formally to include his opinion on how to proceed. However, the author is pleased to know he is not in possession of all the constraints on which path to choose, and thus he is grateful that the decision on which path to choose is not his to make. Nevertheless, it appears that the path which uses minimum resources for maximum physics use of the Booster Neutrino Beamline is the one which leaves MiniBooNE where it is (until it is declared “done” in its present location) and puts microBooNE in a hall tailored to its needs.

End of Report.