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SNS Drift-Tube Linac Recovery and Production Plan

A U.S. Department of Energy Multilaboratory Project

SPALLATION NEUTRON SOURCE

Argonne National Laboratory • Brookhaven National Laboratory • Thomas Jefferson National Accelerator Facility • Lawrence Berkeley National Laboratory • Los Alamos National Laboratory • Oak Ridge National Laboratory

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SNS DRIFT-TUBE LINAC RECOVERY AND PRODUCTION PLAN

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SNS DRIFT-TUBE LINAC RECOVERY AND PRODUCTION PLAN

1. Executive Summary

The Spallation Neutron Source employs a linear accelerator (linac) to produce a 1 GeV proton beam that generates neutrons in a mercury target. The first element of the linac is a Drift Tube Linac (DTL) which accelerates a 2.5 MeV H^- beam from the Front End up to 86.7 MeV and delivers it to the Coupled Cavity linac. Los Alamos National Laboratory (LANL) has completed the physics design (April 26, 2002) and has started manufacturing of the SNS drift-tube linac (DTL). The DTL is 36 m long and includes 6 resonant radio-frequency (rf) cavities, 210 drift tubes, 68 slug tuners, 129 post couplers, and a variety of other components (see figure 1 below).

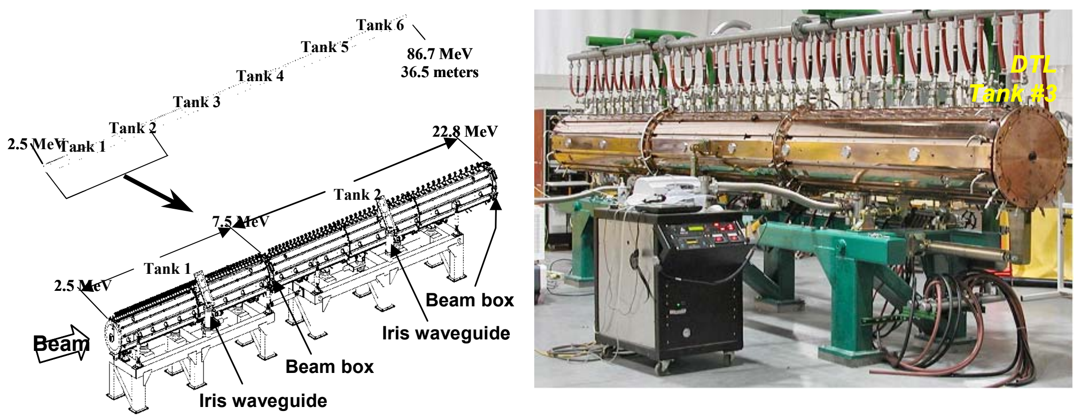


Figure 1: On the left is a sketch of all six DTL tanks, with tanks 1 and 2 shown in more detail in the foreground. On the right is a photo of DTL 3 after assembly in Oak Ridge. Within each tank, the drift tubes get subsequently longer as the beam energy increases.

Proposals were solicited from commercial vendors for the production of each group of common components. Awards were made on a *lowest-cost meeting specification* basis for vendors to build components to *end-product drawings*. Los Alamos provided statements of work but minimal process guidance. Vendors were expected to develop or subcontract a variety of critical fabrication technologies and to manage the entire production process. In the case of the drift tubes, two vendors were required to submit two prototypes for evaluation before award of the production contract.

Sequential installation would require Tank 1 to be built first; however, Tank 3 was the first DTL section to be assembled with the intent to use this tank as a test vehicle. The tank was initially assembled in Los Alamos and was shipped to Oak Ridge on May 23, 2002 to meet the integrated project schedule (IPS). In preparation for tunnel installation (scheduled for completion on August 15, 2002, in advance of the *SNS Project Execution Plan* milestone), and while improving the mechanical stability of each drift tube in parallel, the tank was pumped down for initial vacuum testing. At that point a sufficient operating vacuum could not be achieved, and 11 drift tubes were subsequently found to have leaks from the water-cooling channels to the vacuum side along e-beam welds at the outside surfaces of the drift tubes. The leaks were present in spite of all the drift tubes having been previously vacuum tested by the vendor. In addition, a variety of other less important deficiencies were found. After considerable investigative work that included at first an external review chaired by Pierre Grand (expert in the field of accelerator construction with more than 40 years of experience), the cause of the leaks were identified as flawed e-beam welds that introduced porosity into the copper, which was in turn exposed by a subsequent machining operations. Figure 2 shows a sketch of a drift tube with the outer contour before machining, the location of the welds, and the final machining contour that exposed the welding root.

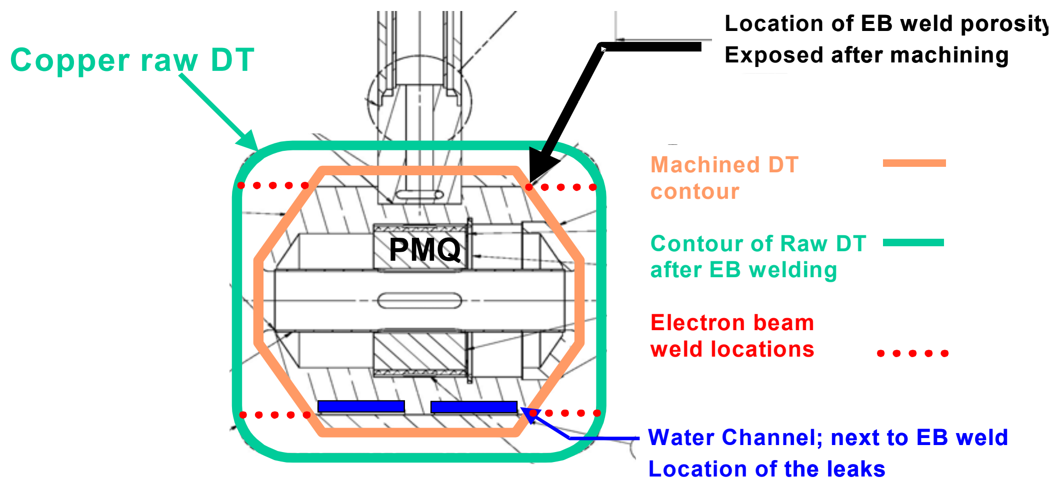


Figure 2: Sketch of a drift tube with the outer contour (green) before machining. The stem is indicated at the top, and the permanent magnetic quadrupoles (PMQs) are in the middle (shaded). After machining (orange), a substantial portion of the electron beam (e-beam) weld is removed and the root of the weld is exposed. Because the root is adjacent to the water channel, the porosity in the weld root causes water channel to vacuum leaks.

Figure 3 shows a metallographic section through a leaking drift-tube weld joint. In this typical case, the welder made three passes using very narrow welds of different depths.

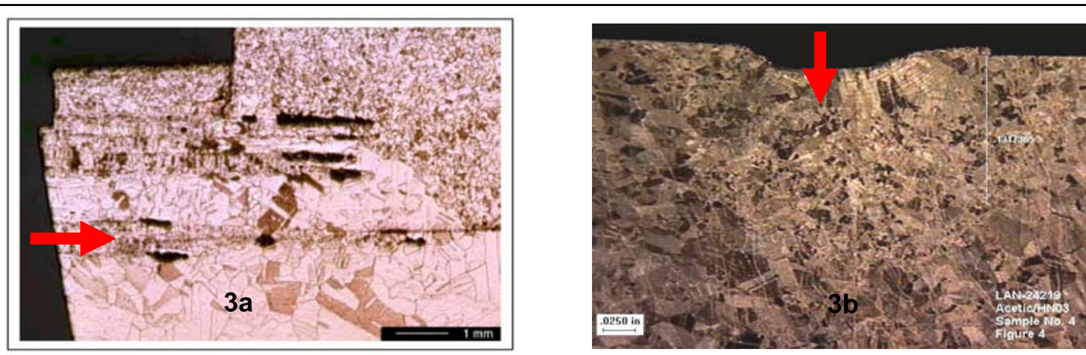


Figure 3: E-beam weld with porous root around the weld exposed after sectioning a leaking drift tube (3a). The image on the right shows a qualified weld that was used during repair and that will be used in future production. The red arrows indicate e-beam weld direction.

Each pass created porosity, and visible voids in the copper as can be seen in the right-hand side of Fig. 3a.

Further investigation revealed additional procedural errors in the manufacturing process, and production was stopped immediately. At that point, all drift tubes for Tank 1 were already completed. In Tank 1, the permanent magnet quadrupole (PMQ) lens lies close to the drift-tube face. While welding the bore tubes in place (inner support tubes of the drift tubes), a nonvacuum, “cosmetic” weld, the e-beam penetrated the drift-tube bodies and the PMQs were destroyed.

Between tanks 3 and 1 are a total of 92 drift tubes. Of those, at least 18 exhibited vacuum leaks, 17 had damaged magnets, and 24 had been copper-plated to correct handling damage or machining errors and are therefore not suitable for simple repair.

The DTL vendor did not follow meaningful principles of quality control, or adequately monitor subcontractor performance. Also, technical oversight and execution of a meaningful, as well as independent, quality assurance program did not exist. Meanwhile, several internal and external reviews have been conducted on the status, the investigation and the repair proposals, and qualification of new procedures (especially on welding and leak checking) were developed and are now in place.

After having stopped drift-tube production, Los Alamos is canceling or amending all contracts that had similar problems with the same vendor. Production of drift tubes and waveguide transitions has resumed, with Los Alamos staff managing every aspect of all linac component production.

To ensure appropriate leadership, management, and oversight, 25 experienced Los Alamos staff members have been reassigned to augment the SNS DTL recovery effort in Los Alamos. Production strategies and schedules have been developed and support the latest revision of the integrated project schedule (IPS) that was presented at the November 2002 DOE SNS semiannual review. With basically no float left for Tank 1 installation, the commissioning date of Tank 1 beginning May 23 is at risk. Nevertheless the plan presented here still supports the overall commissioning plan of the SNS project. This plan, after being discussed in great detail, has been agreed on by senior SNS project management at Los Alamos and Oak Ridge.

The following sections of this document describe in greater detail the status of production and the assessment of the various problems. It then presents the technical and managerial solutions and finally presents a resource-loaded schedule that supports the IPS. A number of crucial and visible milestones are extracted and listed. These milestones will be tracked closely to ensure timely delivery and to ensure early corrective action and more support if necessary. The financial impact of the recovery plan to the project will be assessed in detail during the next estimate to complete and will be presented at the May 2003 DOE semiannual SNS review. All external and internal review reports are available. The executive summaries of the two reviews conducted by Pierre Grand are attached.

2. Introduction

The SNS drift tube linac (DTL) is designed to accelerate a 38-mA H-minus ion beam from 2.5 to 86 MeV at 60 times a second with a pulse length of 1 millisecond. In the DTL, the drift tubes increase geometrically in length as the energy and hence the velocity of the ions increase. This makes the first drift tubes geometrically challenging, especially since focusing magnets and diagnostics are incorporated into the drift tube body. The DTL is comprised of 6 tanks each powered by a single 2.5-MW klystron at 402.5 MHz. The designs of all but Tank 1 have been optimized for power efficiency. Tank 1 has been designed to optimize beam dynamics performance and is the most complicated tank.

While Tank 1 is the first tank required for beam commissioning, it was recognized early on that it is the most complicated of the 6 to build, assemble, align, tune, install, and condition. Therefore it was decided to perform all these tasks on Tank 3 before Tank 1 to allow for an opportunity to debug the procedures and transfer the technology to Oak Ridge. Under this scenario Tank 3 is supposed to serve as a test vehicle for construction, assembly, tuning, installation and conditioning with high power rf.

Following this philosophy Tank 3 assembly was completed on schedule during early spring '02 and delivered to Oak Ridge when ~30% of the Tank 3 drift tubes were discovered with vacuum leaks. At this point almost all of the drift tubes for Tank 1 had already been fabricated, essentially on schedule. While initiating an investigation (first external review chaired by Pierre Grand; August 10, 2002) to determine the cause of the leaks, similar leak rates were observed in Tank 1 drift tubes. Production was halted. Sensitized to an apparent lack of quality control a variety of issues were pursued and it was discovered that in addition almost half of the PMQs in Tank 1 had been damaged during e-beam welding.

The purpose of this report is to summarize all findings, including those from several external and internal reviews, present and assess the status of all DTL fabrication, outline a strategy to assure the fabrication and installation of reliable hardware and present a viable schedule supporting SNS beam commissioning.

The final delivery to Oak Ridge of all parts for all tanks is due August 01, 2003. This is necessary to support installation of all tanks by December 01, 2003 so commissioning of the drift tube linac can start on time. Nevertheless, the schedules for DTL Tank 3 (April 15, 2003) and Tank 1 (May 21, 2003) are obviously the most critical ones and will be discussed throughout this report in great detail. All technologies, procedures and developments are directly applicable to tanks 4,5,6 and 2.

3. DTL Mechanical Features

Each DTL tank includes the following components:

Tank sections. DTL Tank 1 consists of two sections and the other DTL tanks have three sections. The tank sections are machined from mild steel forgings and then copper plated. The sections are bolted together to form a common vacuum/rf cavity.

Tanks are temperature controlled to maintain resonance while dissipating about half of the DTL's average power, the other half being dissipated on the end walls and drift tubes. At 7% duty, the total average power is 24 kW for Tank 1 and 91 kW for the other five tanks.

Drift tubes. Two thirds of the drift tubes in the DTL contain lenses (PMQs), which form a strong focusing beam transport channel. Some drift tubes contain Beam Position Monitors (BPMs) while others contain Electromagnetic Dipoles (EMDs) to facilitate steering. Some drift tubes remain empty. The distribution of magnets and diagnostics is summarized in table 1.

Table 1. Drift Tube Type Summary

Tank No.	PMQ	Empty	EMD	BPM	Total
1	39	16	4	0	59
2	32	9	4	2	47
3	22	5	4	2	33
4	18	3	4	2	27
5	15	2	4	2	23
6	14	1	4	2	21
Total	140	36	24	10	210

End walls. Each DTL tank is terminated by end walls that form a resonant rf cavity. In addition 5 serve as vacuum bulkheads. End walls are turned from solid copper and contain integral cooling channels and a half drift tube. Each end-wall half drift-tube contains either a PMQ or a Beam Current Monitor (BCM). Table 2 summarizes the distribution of magnets and diagnostics in the end walls.

Table 2. Tank Section, Tuner, Coupler and End-Wall Diagnostics Summary

Tank No.	No of Sections	Slug Tuners	Post Couplers	Up-Stream End Wall	Down-Stream End Wall
1	2	8	19	PMQ	PMQ
2	3	12	23	BCM	BCM
3	3	12	16	PMQ	PMQ
4	3	12	27	BCM	PMQ
5	3	12	23	PMQ	PMQ
6	3	12	21	BCM	BCM
Total	17	68	129		

Beam boxes. The linac tanks are spaced relative to each other to preserve the periodicity of the transport lattice. The inter-tank drift space is used to locate intercepting beam diagnostic instruments required for beam commissioning and subsequent operations. The diagnostics are mounted in beam boxes attached to the upstream end walls of tanks 2 through 6. Bellows and a vacuum gate valve occupy any remaining space.

The tanks 1-2 and 2-3 transitions are special cases. Because of the very short distance available, there is no space for beam line bellows to provide compliance between the tanks. The boxes in these locations fill the entire inter-tank space and incorporate bellows at the tank diameter.

Slug tuners. After installing and aligning the drift tubes, dummy slug tuners are installed and adjusted to achieve the desired stabilized rf field distribution throughout the tank. In all but Tank 1, the design field distribution is flat. In Tank 1 the field increases by a factor of 3 from the low- to the high-energy end. After the tank is completely tuned, the penetration of all slug tuners is measured and the permanent, copper slug tuners are machined to the proper length. Slug tuners are water-cooled but otherwise passive. Table 2 lists the number of slug tuners required in each tank.

Post couplers. To assure stable beam delivery, post couplers are used to stabilize the field distribution in each linac tank in the presence of frequency perturbations caused by vibration or temperature gradients. After finishing tuning with a set of adjustable aluminum post couplers the copper post couplers are e-beam welded and machined to match the length and orientation of the aluminum post couplers. The copper posts are water-cooled and are not adjustable in length or orientation. In Tank 1 the post couplers mounted opposite every third drift tube alternating from one side of the tank to the other. In tanks 2-6 post couplers are mounted opposite every other drift tube alternating from one side of the tank to the other. The number of post couplers required is summarized in table 2.

Waveguide-to-coupling-iris transition. Up to 1.3 MW of peak rf power is magnetically coupled into each DTL tank through a very small coupling slot, or iris. The transition includes a tapered section of ridged waveguide to concentrate the fields at the slot. The transition is water-cooled and has its own vacuum system to protect the window. The final geometry of the slot must be adjusted in place to optimize the match. This is done after the tank is completely assembled and tuned. The small slot is expected to perturb the cavity field distribution and frequency by a negligible amount. However, final machining 1 or 2 nearby slug tuners is delayed in case small compensating corrections need to be made.

Drift tube mounts. Drift tubes are suspended from the top of the tank, aligned and held in place by the “top-hat” assembly that provides both a vacuum and an rf seal. An outer shroud adds stability and assures long-term alignment of the drift tubes. A total of 210 mounts are required.

Other components. These include support stands, vacuum pump-out grills, rf field probes, water manifolds, water carts, vacuum systems, etc.

4. Mechanical Fabrication Philosophy

Los Alamos developed the detailed physics design of the DTL and then generated a set of mechanical drawings and documents for all the components described above. In general, all fabrication contracts were awarded on a “lowest-cost meeting specification” basis in which vendors’ bids were based on “end product drawings.” Los Alamos provided detailed statements of work (SOWs) but minimal process guidance.

Four vendors were solicited to submit proposals for the fabrication of drift tubes. In the solicitation, Los Alamos provided 2 drawings and a table of dimensions for each tank describing the final critical dimensions of each drift tube in that tank. In addition, Los Alamos provided a statement of work, general fabrication process notes as well as specifications for materials, leak tests at 1 atmosphere, cleaning, pressure, and flow tests.

Two vendors were selected to develop a manufacturing process, at Laboratory expense, for drift tube production. Both vendors were required to generate all process drawings and documents and develop a plan to manage the entire production. In addition, they were required to develop some specialized fabrication processes such as diamond machining, brazing, e-beam welding, TIG welding, copper plating, and vacuum leak checking. Where they lacked in-house expertise, the vendor had to develop and qualify subcontractors.

The Laboratory evaluated the two vendors on the basis of two prototype drift tubes built to "prove" their manufacturing capability. Both vendors' prototypes were deemed acceptable and bids were solicited from both for drift tubes containing PMQs, BPMs and EMDs. Competitive bids were received for all three jobs. The lowest bid on all 3 was Coronado Machine Inc. (CMI) who was awarded contracts to manufacture all 173 drift tubes. Los Alamos provided all the PMQs, EMDs and BPMs as listed in Table 1

On the basis of their demonstrated expertise, CMI was subsequently awarded the contract to produce 36 empty drift tubes on a noncompetitive basis.

In the case of the waveguide-to-iris transition sections the Laboratory solicited 3 vendors to submit proposals to produce these parts based on "end-product drawings." Two bids were received and the job was awarded to CMI, the low bidder.

5. Component Status

Many parts are complete and have been delivered to Oak Ridge on schedule. Serious problems were encountered during the fabrication of three major components, the end walls, waveguide-to-iris transitions and drift tubes, which threaten to delay the project schedule. The status of the DTL components is listed in detail below.

Tank sections. Los Alamos let separate contracts for forging, machining and plating. After final machining, the tank sections are copper plated inside and out. During the plating process, the tank sections are hung vertically in the plating baths. The end tank sections must be hung so the module ends are always facing downward. Each section has a groove on both ends, designed to hold a Viton o-ring that is used as a gasket when finally assembled. If left unmasked the groove would collect air bubbles, resulting in uneven plating. These o-ring grooves are therefore masked which leaves the bare steel exposed in the bottom of half of the grooves.

The end-flange o-ring grooves were originally sized to seal with 15% compression using lubricated o-rings. While this is marginal for lubricated o-rings, for dry o-rings at least 25% compression is required, which is the present design that was implemented to minimize the potential for migration of lubricants throughout the vacuum system into the superconducting linac, which is especially sensitive to surface contamination.

Therefore all o-ring grooves in the tank sections had to be re-machined to accept oversized o-rings and provide the correct compression. In addition they will be polished to assure a good seal dry and nickel plated to prevent corrosion. SNS personnel in Oak Ridge will carry out this work. The status of all tank sections is summarized in Table 3.

Table 3. Tank section Fabrication Status

Tank No.	1	2	3	4	5	6
Forging	X	X	X	X	X	X
Final machining	X	X	X	X	X	X
Cpper Plating	X	X	X	X		
O-Ring groove mod.	X					
Deliver to ORNL	X	X	X			

All three tank sections of Tank 3 have been assembled, leak checked and the quality factor (Q-value) measured. Both the vacuum and rf quality are well within the required values.

End walls. Los Alamos contracted **Major Tool & Machining** to produce all of the end walls. The production involved copper machining, furnace brazing, vacuum leak checking, pressure and flow tests, etc. It became obvious early in the production that the vendor did not appreciate the complexity of the job and had submitted a low bid. The production suffered from numerous machining errors, brazing errors and damage due to careless handling. Because of schedule and cost considerations the Laboratory accepted numerous nonconformance reports (NCRs). Each individual NCR accepted was examined and evaluated by the project engineer and/or physicist and determined to represent an acceptable risk. In many cases NCRs were not accepted, incurring more cost on the vendor. Acceptable end walls were ultimately produced but the procurement and fabrication effort consumed excessive amounts of project resources.

All end walls have a flat sealing surface that mates with the tank o-ring. The backside of up-stream end walls 2 through 6 contain an o-ring groove that seals to a beam box. As described above for tank sections, these 5 o-ring grooves must be remachined to accept oversized o-rings and provide the correct compression to seal dry.

As shown in table 4 all end-walls are complete except the up-stream unit for Tank 1. Five units will be returned to the vendor to have their o-ring grooves resized. Based on tuning studies using our Tank 1 aluminum cold model an annular tuning ring was developed for the low-energy end wall that causes the natural field distribution to match the design value. This ring tuner is being attached to the end wall.

Table 4. End Wall Fabrication Status

Tank No.	1	2	3	4	5	6
Copper Forging	X	X	X	X	X	X
Rough machining	X	X	X	X	X	X
Braze cooling channels	X	X	X	X	X	X
Final machining		X	X	X	X	X
Weld fittings	X	X	X	X	X	X
Inspect, leak, pressure & flow test		X	X	X	X	X
O-ring groove modification	n/a					
Clean & deliver to ORNL		X	X	X	X	X

Tank 3 end walls have been mounted on the assembled tank, leak checked and the Q measured. Both the vacuum and rf quality are well within the required values.

Beam boxes. All beam boxes have been completed. Units 1 and 2 will be returned to the vendor to have their o-ring groove modified.

Table 5. Beam Box Fabrication Status

Tank No.	1	2	3	4	5	6
Rough machining	X	X	X	X	X	X
Welding	X	X	X	X	X	X
Final machining	X	X	X	X	X	X
Weld fittings	X	X	X	X	X	X
Inspect, leak, pressure & flow test	X	X	X	X	X	X
O-ring groove modification			n/a	n/a	n/a	n/a
Clean & deliver to ORNL						

Slug tuners. All slug tuners have been completed. Following tank tuning they will be cut to length and shipped to Oak Ridge for installation.

Table 6. Slug Tuner Fabrication Status

Tank No.	1	2	3	4	5	6
Copper Forging	X	X	X	X	X	X
Rough machining	X	X	X	X	X	X
Braze cooling channels	X	X	X	X	X	X
Final machining	X	X	X	X	X	X
Weld fittings	X	X	X	X	X	X
Leak, pressure, flow test	X	X	X	X	X	X
Tune cavity			X			
Cut to final length			X			
Inspect, leak, pressure & flow test			X			
Clean & deliver to ORNL			X			

All but 2 slug tuners for Tank 3 have been cut to length. The last two will be sized and installed following iris tuning.

Post couplers. Tank 3 has been tuned and post coupler lengths determined. A complete set of post couplers was finished and delivered to Oak Ridge. Because they were furnace brazed copper they were found to be very soft and difficult to handle. The new design has a stem that is e-beam welded to the mounting flange. Final assembly of the Tank 3 units is presently awaiting certification of the welding procedure.

Table 7. Post Coupler Fabrication Status

Tank No.	1	2	3	4	5	6
Rough machining	X	X	X		X	
Braze fittings			X			
Weldtip to stem						
Trim to length						
Weld stem to mount						
Finish machine						
Inspect, leak, pressure & flow test						
Clean & deliver to ORNL						

Waveguide-to-coupling-iris transition. These components are fabricated from GlidCop, an alumina-dispersion strengthened OFE copper "alloy." It is hard and strong but retains most of the electrical and thermal properties of copper. Production of these units involves machining, brazing, electron beam welding, vacuum leak checking, pressure and flow tests, etc. To date one unit has been delivered. It has machining errors and vacuum leaks that make it unusable as delivered. A second unit has been rough machined but was inadvertently brazed.

Table 8. Waveguide Transition Fabrication Status

Tank No.	1	2	3	4	5	6
Procure material	X	X	X	X	X	X
Prepare stock	X	X	X	X	X	
rough machining	X		X			
machine internal features			X			
Braze halves & fittings			X			
Finish machine			X			
Weld fittings & vacuum nipple			X			
Repair						
Machine seals						
Inspect, leak, pressure, flow test						
Clean & deliver to ORNL						

Drift tube mounts. The top hats were machined from 303 stainless steel. This sulfur-bearing free-machining alloy is inappropriate for this vacuum application. They will be remade from 304 stainless steel.

Table 9. Drift Tube Mount Fabrication Status

Tank No.	1	2	3	4	5	6
Top hat						
Shroud	X	X	X	X	X	X

Other components. Many other components are complete. Table 10 summarizes a few.

Table 10. Fabrication Status of Other Components

Tank No.	1	2	3	4	5	6
Support stand	X	X	X			
Pump-out grills			X			
rf probes	X	X	X	X	X	X
Water carts	X	X	X	X	X	X
Water manifolds	X	X	X	X	X	X

Tank 3 drift tubes. DTL tanks will be installed in the order: 3, 1, 5, 6, 4, 2. This schedule allows for rf conditioning of Tank 3 while commissioning of the RFQ & MEBT with beam is ongoing. It likewise will allow us to carry out beam commissioning experiments on Tank 1 in parallel with installation of the rest of the linac.

All 33-drift tubes for Tank 3 were originally delivered and installed. Of those 11 have water-to-vacuum leaks indicating potentially a systemic problem. The source of the leaks has been isolated to a faulty body-to-sleeve e-beam weld.

The drift tube procurements were all placed with CMI after careful evaluation of prototype units. Following contract award CMI learned how to modify their manufacturing process to further reduce their costs, the impacts of which only came to light much later. In addition they changed their e-beam welding subcontractor.

The new fabrication procedure involved e-beam welding groups of drift tube bodies that were subsequently machined to length. Metallographic sections of flawed drift tubes clearly show that the deep welds introduced significant porosity in the copper that was exposed by machining. These leaks are large and should have been detected by conventional leak detection techniques. Small leaks may have been subsequently masked when water was introduced into the cooling channels during a later process step, making them undetectable to the vendor's vacuum subcontractor in later tests. However even the large leaks were not identified and in one case the leak was so large that the finished drift tube wept. While not all Tank 3 drift tubes leak, they have been declared unreliable from a vacuum point of view.

The coaxial cables in both Tank 3 BPM drift tubes have been damaged during a stem welding process resulting in mismatched but usable signals. The vacuum potted coils for the EMDs, provided by the Laboratory, contain air bubbles and cracks. While passing all electrical and magnetic field tests, these flaws can lead to further cracking allowing moisture to enter the assembly potentially shorting the coils. Six drift tubes have been copper plated (unauthorized) presumably to accommodate correction of machining errors or handling damage. None of the PMQ magnets in Tank 3 have been damaged. The detailed status of Tank 3 drift tubes is summarized in table 11.

Table 11. DTL Tank 3 drift tube status

Drift tube No.	Type	Dimension Pressure & Flow	Vacuum @ 70 psi	Magnetic Field	Cu Plated	rf Condition	Long Term Prognosis
1	PMQ	ok	ok	ok		weld repair	
2	BPM	ok	failed	-	nose & bore	weld repair	rebuild
3	PMQ	ok	ok	ok	yes	weld repair	rebuild
4	PMQ	ok	failed	ok		weld repair	
5	empty	ok	ok	-		weld repair	
6	PMQ	ok	failed	ok		weld repair	
7	PMQ	ok	ok	ok	nose	weld repair	
8	BPM	ok	-	-		weld repair	rebuild
9	PMQ	ok	failed	ok	weld zone	weld repair	rebuild
10	PMQ	ok	failed	ok		weld repair	
11	empty	ok	ok	-	nose	weld repair	
12	PMQ	ok	ok	ok		weld repair	
13	PMQ	ok	failed	ok		weld repair	
14	empty	ok	ok	-		weld repair	
15	PMQ	ok	failed	ok		weld repair	
16	PMQ	ok	failed	ok		weld repair	
17	empty	ok	failed	-		weld repair	
18	PMQ	ok	ok	ok		weld repair	
19	PMQ	ok	failed	ok		weld repair	
20	empty	ok	ok	-		weld repair	
21	PMQ	ok	ok	ok		weld repair	
22	PMQ	ok	ok	ok		weld repair	
23	EMD	ok	failed	-	nose & bore	repair leak	rebuild
24	PMQ	ok	ok	ok		weld repair	
25	PMQ	ok	ok	ok		weld repair	
26	EMD	ok	ok	-		ship as is	rebuild
27	PMQ	ok	ok	ok		weld repair	
28	PMQ	ok	ok	ok		weld repair	
29	EMD	ok	ok	-		ship as is	rebuild
30	PMQ	ok	ok	ok		weld repair	
31	PMQ	ok	ok	ok		weld repair	
32	EMD	ok	ok	-		ship as is	rebuild
33	PMQ	ok	ok	ok		weld repair	

Tank 1 drift tubes. All but 4 Tank 1drift tubes have been delivered. One has a water leak and at least 7 contain vacuum leaks. In 17 drift tubes the PMQs have been damaged by the e-beam itself during a "cosmetic" welding operation. Eighteen drift tubes were copper plated. Ten have been damaged beyond repair or otherwise sacrificed for study. The coils for the 4 EMDs, provided by Los Alamos, do not fit into their respective drift tubes and will be rewound. The detailed status of tank 1 drift tubes is summarized in table 12.

Table 12. DTL Tank 1 drift tube status

Drift tube No.	Type	Delivered	Dimension Pressure & Flow	Vacuum @ 70psi	Magnetic Field	Plated	Prognosis
1	empty	X	ok	-	-	yes	rebuild
2	PMQ	sacrificed	ok	-	ok	yes	rebuild
3	PMQ	X	ok	-	ok	yes	rebuild
4	empty	X	ok	-	-	yes	rebuild
5	PMQ	X	ok	-	ok	yes	rebuild
6	PMQ	X	ok	-	failed		rebuild
7	empty	X	ok	ok	-	yes	rebuild
8	PMQ	X	ok	-	ok	yes	rebuild
9	PMQ	X	ok	-	ok	yes	rebuild
10	empty	X	ok	-	-	yes	rebuild
11	PMQ	X	ok	ok	ok	yes	rebuild
12	PMQ	X	ok	ok	ok	yes	rebuild
13	empty	X	ok	-	-	yes	rebuild
14	PMQ	sacrificed	ok	-	ok	yes	rebuild
15	PMQ	X	ok	-	ok	yes	rebuild
16	empty	X	ok	-	-		rebuild
17	PMQ	damaged	ok	-	failed	yes	rebuild
18	PMQ	X	ok	-	ok		rebuild
19	empty	X	ok	-	-		rebuild
20	PMQ	X	ok	failed	failed		rebuild
21	PMQ	damaged	ok	-	failed		rebuild
22	empty	X	ok	-	-	yes	rebuild
23	PMQ	X	ok	failed	failed		rebuild
24	PMQ	X	ok	ok	failed		rebuild
25	empty	X	ok	ok	-		repaired
26	PMQ	X	ok	ok	failed		rebuild
27	PMQ	X	ok	ok	failed		rebuild
28	empty	X	ok	ok	-		repaired
29	PMQ	sacrificed	ok	ok	failed		rebuild
30	PMQ	X	ok	-	ok		repaired
31	empty	damaged	ok	ok	-		rebuild
32	PMQ	sacrificed	ok	failed	ok		rebuild
33	PMQ	X	ok	ok	ok		repaired
34	empty	X	ok	-	-		repaired
35	PMQ	X	ok	ok	failed		rebuild
36	PMQ	X	ok	ok	failed		rebuild
37	empty	X	ok	-			repaired
38	PMQ	X	ok	ok	failed		rebuild
39	PMQ	X	ok	failed	failed		rebuild
40	empty	X	ok	ok	-		repaired

Table 12. DTL Tank 1 drift tube status (continued)

Drift tube No.	Type	Delivered	Dimension Pressure & Flow	Vacuum @ 70psi	Magnetic Field	Plated	Prognosis
41	PMQ	X	ok	-	failed		rebuild
42	PMQ	X	ok	-	failed		rebuild
43	empty	X	ok	failed	-		repaired
44	PMQ	X	failed	failed	ok		repaired
45	PMQ	sacrificed	ok	-	ok		rebuild
46	empty	X	ok	-	-		repaired
47	PMQ	X	ok	ok	ok		repaired
48	PMQ	X	ok	failed	ok		repaired
49	EMD		interference	-	-		in process
50	PMQ	X	ok	ok	ok		rebuild
51	PMQ		ok	-	ok		rebuild
52	EMD		interference	-	-		in process
53	PMQ	X	ok	ok	ok		repaired
54	PMQ	damaged	ok	-	failed		rebuild
55	EMD		interference	-	-		in process
56	PMQ	X	ok	-	ok	yes	rebuild
57	PMQ	X	ok	-	ok	yes	rebuild
58	EMD		interference	-	-		in process
59	PMQ	sacrificed	ok	-	failed		rebuild

Drift tubes for tanks 2, 4, 5 & 6. There are 4 types of drift tubes as described above. Los Alamos provides all of the magnets and diagnostics to the drift tube vendor for assembly. Because so many PMQs have been damaged replacements have been ordered. Fortunately all PMQs have the same gradient and are interchangeable so a temporary shortage of lenses should not impact the fabrication of drift tubes for the early tanks. Likewise all BPMs are identical and interchangeable. Table 13 summarizes the status of the drift tube magnets.

Table 13. Drift Tube Magnet and Diagnostics Status

Tank No.	1	2	3	4	5	6	Total Required
PMQs	X	X	X	X	X		140
EMD poles	X	X	X	X	X	X	24
EMD coils							24
BPMs	n/a	X	X	X	X		10

While all drift tube fabrication has been stopped, a great deal of rough machining has been completed for tanks 2, 4, 5 and 6.

6. Recovery Plan

The problem. An engineering review committee, recently convened to assess our situation, concluded that, while serous problems have arisen during production of DTL components, their technical design remains sound. Problems, reflecting the vendor's inexperience and inability to manage complex multi-process productions, have compromised the hardware's integrity, the project schedule and budget. Contracts for all of the drift tubes as well as all of the waveguide transitions were placed with the same vendor and both components suffer from these issues.

The vendor failed to fully understand critical fabrication processes and did not develop and certify suitable procedures. They did not appreciate the detailed technical requirements of the end product. It is clear in hindsight that, in spite of delivering acceptable prototype drift tubes, this vendor was not capable of managing such a complex, multi-technology production job or follow meaningful quality control principals.

Los Alamos was asked to deliver the SNS DTL because of their record of innovative technology development and successful linac projects managed in the past. The Laboratory however, for such critical components should have procured on a "best value" basis like for most other major subsystems. For the DTL, the "lowest-cost meeting spec" basis in combination with not recognizing early on, that none of the bidders was qualified to manage the complete job, lead to subsequent failures. At the same time Los Alamos did not provide adequate technical oversight or maintain an effective quality assurance program at this vendor. Many of the technical problems that were encountered might have been identified early by more active involvement of experienced accelerator engineers and physicists.

The solution. To assure the delivery of high quality accelerator hardware Los Alamos will assume process control of all remaining manufacturing efforts. Production contracts for all drift tubes and waveguide-to-iris transitions will be terminated or amended and Laboratory staff will manage all future work.

To deliver components in a timely manner in support of the integrated project schedule IPS, components will be manufactured in parallel under the supervision of dedicated teams. Where appropriate and necessary, additional shops for machining, e-beam welding and brazing will be qualified to speed production of parts on the critical path.

All hardware designs will be reviewed and corrected as necessary and appropriate. Every part and every manufacturing process will be fully documented giving little latitude for misunderstanding or misinterpretation. Process or design changes will be qualified and proven before implementation.

To ensure the quality of manufactured components, a graded approach to quality is being implemented. A dedicated Quality Assurance Specialist has been assigned to assist engineers and managers to ensure that quality control measures are utilized. The cornerstone of this quality initiative is the implementation of an effective "traveler" document. The traveler is a quality and work control document that accompanies the part or component during the manufacturing process. This important document is written cooperatively by Los Alamos and each supplier with the purpose of ensuring that key engineering, quality and procurement requirements are fulfilled and documented.

Examples of these requirements are material inspections, process steps, quality hold points, leak checking, handling and shipping controls. To ensure adequate control of procurements, Los Alamos engineers, supplier liaisons, quality assurance personnel, and procurement personnel are assigned to and frequently visit each vendor to ensure implementation of required controls. Finally, the SNS Quality Assurance Manager will assist by providing oversight, guidance, and assurances that adequate quality controls are being implemented.

Los Alamos engineers have developed and certified e-beam welding procedures for PMQ and empty drift tubes. These procedures will be used to repair existing drift tubes where appropriate and for the production of new units. Los Alamos personnel will supervise all welding operations.

All future brazing operations will be carried out in hydrogen furnaces following Los Alamos standard procedures where possible. Where no previous experience exists, suitable procedures will be developed and certified. Los Alamos personnel will supervise all brazing operations.

All vacuum leak checking will be carried out by Los Alamos personnel or by Los Alamos certified personnel following written procedures.

The Los Alamos project engineer and chief scientist will supervise the system integration.

Staffing plan. To implement this ambitious manufacturing effort the SNS Engineering Group has been augmented with the temporary reassignment of 25 experienced staff from other Laboratory programs. These employees have been organized into teams dedicated and focused on the production of specific DTL components.

Team 1 is responsible for the delivery of PMQ and empty drift tubes for tanks 1 and 3.

Team Member	Discipline	Sponsoring Group	Acclerator Experience
S. Ellis	Lead Eng.	ESA-WR	yes
T. Ilg	Mech. Eng.	SNS-3	yes
D. Richards	Mfg. Liaison	SNS-3	yes
R. Lujan	Designer	SNS-3	yes
W. Chavez	Designer	ESA-DE	
M. Crow	Designer	SNS-3	yes
Heilbrun	Welding Eng.	contractor	yes

Team 2 is responsible for the delivery of PMQ and empty drift tubes for tanks 2, 4, 5 & 6.

Team Member	Discipline	Sponsoring Group	Acclerator Experience
R. Gentzlinger	Lead Eng.	ESA-WR	yes
P. Smith	Mfg. Eng.	ESA-WMM	yes
E. Newman	Mfg. Liasion	ESA-DE	yes
D. Sattler	Designer	SNS-3	yes
D. Montoya	Designer	ESA-DE	yes
G. Bustos	Designer	ESA-DE	
D. Perchectol	Welding Eng.	contractor	yes

Team 3 is responsible for the delivery of the waveguide-to-iris transitions for all 6 tanks.

Team Member	Discipline	Sponsoring Group	Acclerator Experience
R. Valdiviez	Lead Eng.	LANSCE-1	yes
D. Schrage	Mech. Eng.	LANSCE-1	yes
W. Clark	Mfg. Liaison	LANSCE-1	yes
F. Sigler	Designer	LANSCE-1	yes
J. Ledford	Designer	LANSCE-1	yes
F. Martinez	Brazing Spec.	LANSCE-1	yes

Team 4 is responsible for the delivery all EMD and BPM drift tubes.

Team Member	Discipline	Sponsoring Group	Acclerator Experience
J. O'Hara	Lead Eng.	LANSCE-1	yes
R. Wood	Mech. Eng.	LANSCE-1	yes
T. Hunter	Magnet Eng.	SNS-3	yes
H. Salazar	Designer	contractor	yes
P. Patterson	Designer	LANSCE-1	yes

Team 5 is responsible for the delivery of all post couplers and slug tuners.

Team Member	Discipline	Sponsoring Group	Acclerator Experience
L. Rowton	Mfg. Liaison	DX-5	yes

Team 6 is responsible for the delivery all tank sections, endwalls, beam boxes & support stands.

Team Member	Discipline	Sponsoring Group	Acclerator Experience
G. Johnson	Lead Eng.	SNS/ORNL	yes
J. Turon	Mech. Eng.	ESA-EM	

Team 7 will provide physics, engineering and design support including vacuum, design, checking, ECNs, work tracking and documentation.

Team Member	Discipline	Sponsoring Group	Acclerator Experience
J. Sims	Proj. Eng.	ESA-DE	yes
J. Stovall	Chief Scientist	SNS	yes
L. Young	Physics	SNS	yes
J. Billen	Physics	SNS	yes
S. Jones	QA	SNS	
W. Tuzel	Mech. Eng.	DX-5	yes
R. Valicenti	Mech. Eng.	ESA-DE	yes
D. Barlow	Magnet Phys.	LANSCE-1	yes
S. Hopkins	Technician	SNS	yes
M. Hood	Designer	contractor	
D. Custer	Design/Check	DX-5	
S. Cordova	Furnace op.	LANSCE-2	yes
V. Vigil	Furnace op.	LANSCE-3	yes

Implementation. Our earliest deliverables include all components required to assemble Tank 3 for rf power conditioning. The last parts are due to be delivered by 28 February 2003.

Our second deliverables include all components required to assemble Tank 1 for commissioning with beam. The last parts are due to be delivered by 31 March 2003.

Subsequent parts delivery will support assembly and installation of the remaining 4 tanks in the order 5, 6 ,4 & 2.

The planning, logic and schedule for our first two major deliverables, Tanks 3 & 1 are discussed below.

Tank sections. Tanks 3 & 1 have been delivered to Oak Ridge. Their o-ring grooves have been modified. Tank 3 has been reassembled and will be leak checked late December (Tank 3) and early January (Tank 1).

End walls. Both end walls for Tank 3 the high-energy end wall for Tank 1 have been delivered to Oak Ridge. The low-energy end wall is being modified to incorporate a ring tuner and is expected to be delivered on schedule

Beam boxes. Beam boxes are not required for the initial tests of tanks 3 & 1. Tank 1 mates to a dummy beam box which is a part of the diagnostics beam line.

Slug tuners. All but 2 units for Tank 3 are ready for installation. Units for Tank 1 await final sizing pending tank tuning.

Post couplers. Los Alamos has certified the welded design and fabrication can proceed on schedule. Units for Tank 3 will be finished to length. Units for Tank 1 will be finished pending tank tuning. Neither post couplers nor slug tuners are required for initial assembly and tuning of a tank.

Waveguide-to-iris transition. A repaired unit will be delivered for conditioning of tank 3. This unit will have no pump-out grill and a small vacuum leak has been repaired using a technique inappropriate for long-term operation. This temporary unit will be delivered on schedule while a new unit will be built to replace it at a later date. Fabrication of a transition for Tank 1 is under way.

Drift tube mounts. New top hats will be made for all tanks.

Tank 3 drift tubes. A “ring-weld repair” procedure has been developed and certified for Tank 3 drift tubes in which a thin copper ring is e-beam welded into a groove machined in the face of a drift tube and subsequently faced off. All but 4 Tank 3 drift tubes will be repaired using this technique and delivered to Oak Ridge for installation to support rf conditioning. Three EMD drift tubes will be delivered as-is. The fourth EMD drift tube has a very small leak that will be repaired. The 2 BPM-, 4 EMD- and 2 PMQ-drift tubes will be rebuilt and reinstalled at a later date prior to beam commissioning. The status and strategy for Tank 3 drift tubes is summarized in table 14.

Table 14. Tank 3 Drift Tube Status and Strategy

Type	Dimension Pressure & Flow	Failed Vacuum @ 70 psi	Magnetic Field	Plated	Deliver As Is	Ring Weld Repair	Other Repair	Rebuild
PMQ	ok	8	ok	3	-	22	-	2
EMD	ok	1	-	1	3	-	1	4
BPM	ok	1	-	1	-	2	-	2
Empty	ok	1	-	1	-	5	-	
Total		11		6		29	1	8

Tank 1 drift tubes. A similar “ring-weld repair” has been developed for Tank 1 drift tubes. Eighteen drift tubes were found to have been copper plated which precludes their repair using this technique. Thirteen have been repaired using this technique. The 4 EMD drift tubes whose fabrication was stopped will be completed. Forty-seven total drift tubes will be rebuilt for beam commissioning. The status and strategy for Tank 1 drift tubes is summarized in table 15.

Table 15. Tank 1 Drift Tube Status and Strategy

Type	Failed Pressure or Dimension	Failed Vacuum @ 70 psi	Damaged Magnet	Plated	Complete Initial Units	Ring Weld Repaired	Rebuild
PMQ	1	6	17	12	-	6	33
EMD	4	-	-	-	4	-	5
Empty	-	1	-	6	-	7	9
Total	5	7	17	18	4	13	47

Other components. Support stands, water carts & manifolds for tanks 3 and 1 have been delivered to Oak Ridge. The pump-out grills and rf probes for Tank 3 have been delivered.

7. DTL Fabrication Schedule

The schedule for production of DTL components is summarized for tanks 3 and 1 separately on the following 2 pages. For the purpose of tracking the progress 17 milestones, which are listed in table 16 & 17, have been identified. These milestones are indicated on the schedule as well. Also Attached is the assembly and installation schedule for both tanks once the parts arrive in Oak Ridge.

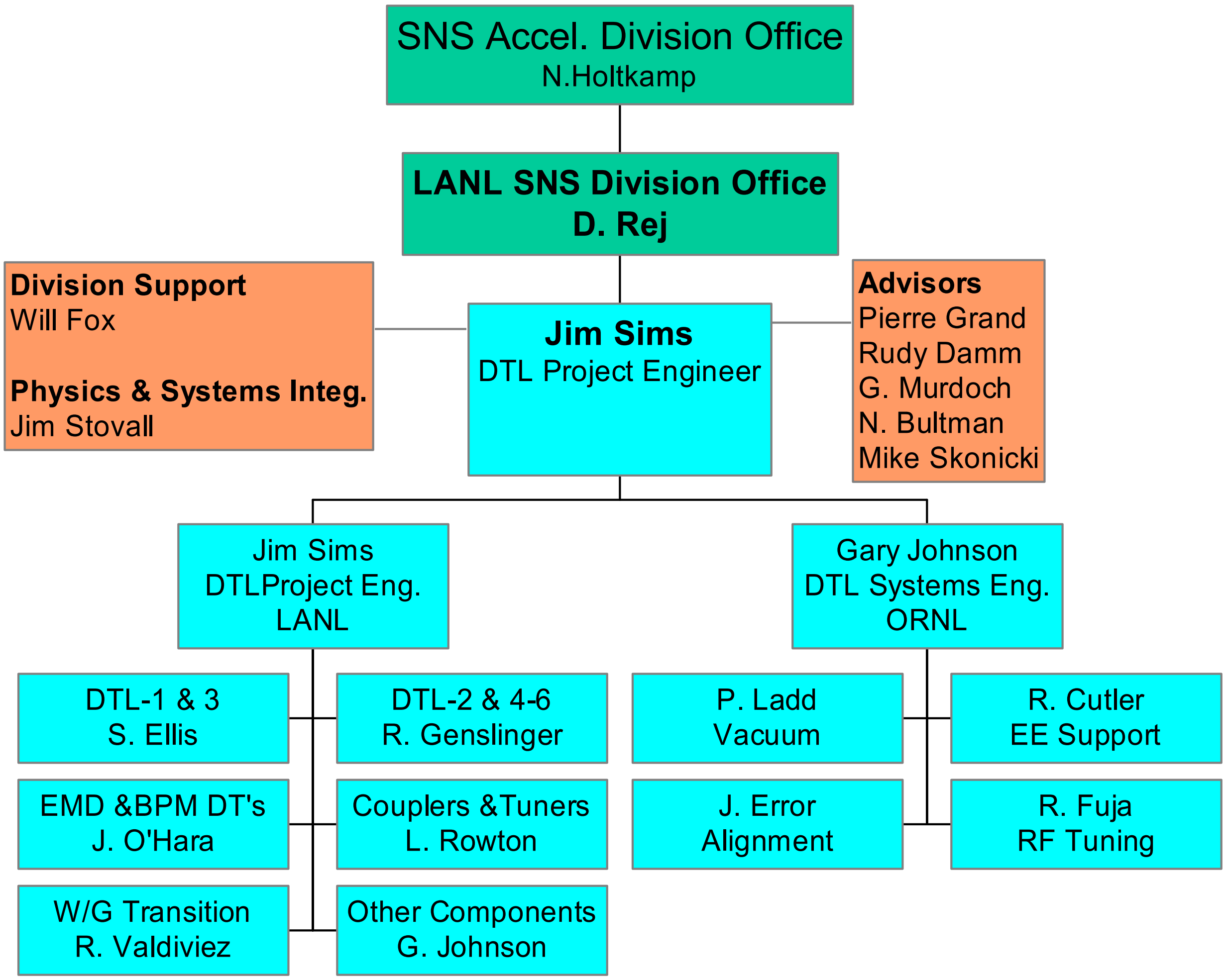
Table 16. Tank 3 milestones

Milestone	Activity	Date Complete
1	Repaired drift tubes, repair welds complete	13-Jan-03
2	Post-couplers, tips welded to stems	27-Jan-03
3	Waveguide-iris transition, finish machining complete	27-Jan-03
4	Top hat finish machining complete	31-Jan-03
5	EMD drift tube repair complete	5-Feb-03
6	Post-couplers, finish machining complete	18-Feb-03
7	Drift tubes, field, vacuum, flow & pressure tests complete	21-Feb-03
8	All DTL components delivered to ORNL	28-Feb-03

Table 17. Tank 1 Milestones

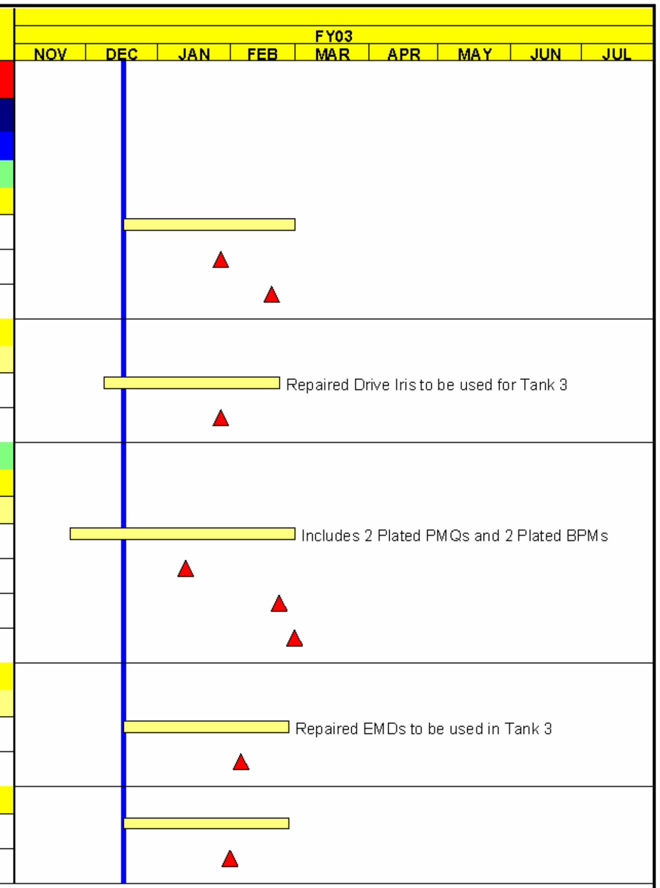
Milestone	Activity	Date Complete
1	Rebuilt drift tubes, 1st 10 diverters machined	7-Jan-03
2	Repaired drift tubes, finish machining complete	14-Jan-03
3	Post-coupler tips welded to stems	3-Feb-03
4	Waveguide-iris transition assembly braze complete	7-Feb-03
5	Top hat finish machining complete	7-Feb-03
6	Rebuilt drift tubes, all stems welded	11-Feb-03
7	Repaired drift tubes, final unit delivered to ORNL	17-Feb-03
8	Low-energy end-wall tuning-ring weld complete	5-Mar-03
9	All DTL components delivered to ORNL	1-Apr-03

Roles and Responsibilities for DTL Effort



DTL Tank 3 Production Schedule

Activity ID	Activity Description	Rem Dur	%	Early Start	Early Finish
1 Spallation Neutron Source Project					
1.04 1.4 Linac Systems (LANL)					
1.04.02 1.4.2 DTL Systems					
1.04.02.02 1.4.2.2 DTL Structure					
1.04.02.02.07 Post Couplers					
LN142260E0	Post Coupler (T3) (Hammock)	48*	0	18DEC02	28FEB03
LN142260M6	Post Coupler (T3) Weld tip to Stem Complete	0	0		27JAN03
LN142260M7	Post Coupler (T3) Finish Machining Complete	0	0		18FEB03
1.04.02.02.08 Drive Iris					
1.04.02.02.08.03 Drive Iris Repair					
LN142270AA	Drive Iris/RLWG Repair/Salvage Tank 3 (Hammock)	43*	0	09DEC02A	21FEB03
LN142270M2	Drive Iris Mach Drive Iris Flange Tank 3 Complet	0	0		27JAN03
1.04.02.03 1.4.2.3 DTL Drift Tubes					
1.04.02.03.01 PMQ Type Drift Tubes					
1.04.02.03.01.01 PMQ Drift Tube Repairs					
LN142310FX	PMQ DT Tank 3 (Hammock)	48*	0	25NOV02A	28FEB03
LN142310M6	PMQ/EMP DT Weld Repairs Tank 3 Complete	0	0	13JAN03	
LN142310M8	PMQ/EMP DT Mag Meas/Flow Test Tank 3 Complete	0	0		21FEB03
LN142310XX	Tank 3 Hardware Delivered to ORNL	0	0		28FEB03
1.04.02.03.02 EMD Type Drift Tube					
1.04.02.03.02.01 EMD Drift Tube Repair					
LN142320FY	EMD Drift Tube Repair T3 (Hammock)	45*	0	18DEC02	25FEB03
LN142320M1	Weld Repair & Leak Test Tank 3 Complete	0	0		05FEB03
1.04.02.03.15 DT Tophat Assemblies					
LN142340E0	DT Tophat Tank 3 (33) (Hammock)	45*	0	18DEC02	25FEB03
LN142340M2	DT Tophat Final Machining Tank 3 Complete	0	0		31JAN03



Start Date	01OCT96
Finish Date	22MAR06
Data Date	18DEC02
Run Date	20DEC02 11:45

Early Bar
Progress Bar
Critical Activity

LN12 - LINA

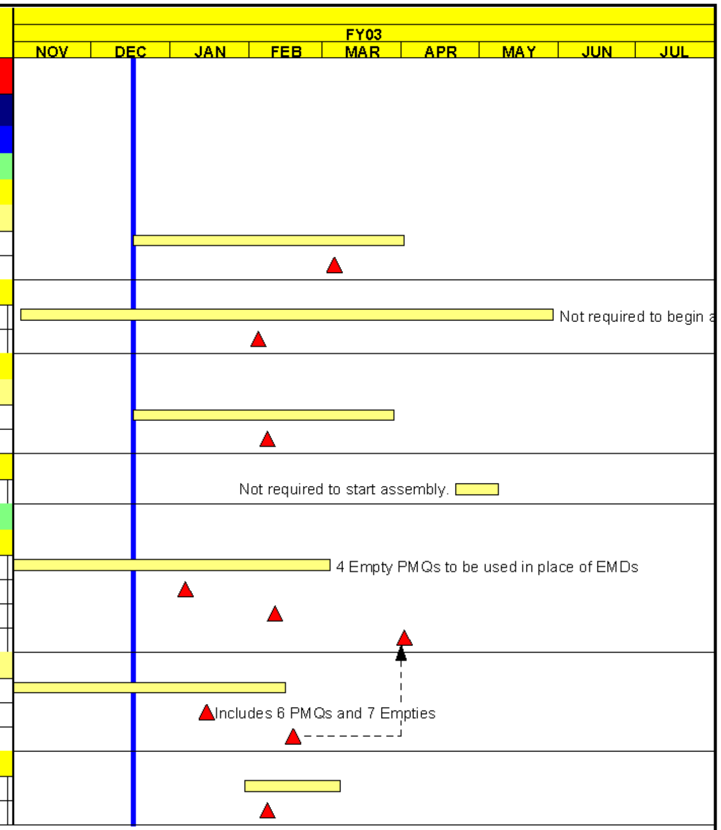
Sheet 1 of 1

DTL 3 Summary

Integration Cycle #52

DTL Tank 1 Production Schedule

Activity Description	Rem Dur	%	Early Start	Early Finish
1 Spallation Neutron Source Project				
1.04 1.4 Linac Systems (LANL)				
1.04.02 1.4.2 DTL Systems				
1.04.02.02 1.4.2.2 DTL Structure				
1.04.02.02.04 Endwalls				
1.04.02.02.04.02 Endwall Fabrication				
Endwalls (T1) (Hammock)	70*	0	18DEC02	01APR03
Weld Tuning Ring (T1) Complete	0	0		05MAR03
1.04.02.02.07 Post Couplers				
Post Coupler (T1) (Hammock)	112*	0	04NOV02A	29MAY03
Post Coupler (T1) Weld Tip to Stem (19)	0	0		03FEB03
1.04.02.02.08 Drive Iris				
1.04.02.02.08.02 Drive Iris Fab				
Drive Iris Tank 1 (Hammock)	68*	0	18DEC02	28MAR03
Drive Iris Furnace Braze Tank 1 Complete	0	0		07FEB03
1.04.02.02.09 Slug Tuner				
Slug Tuner (T1) (Hammock)	13*	0	22APR03	08MAY03
1.04.02.03 1.4.2.3 DTL Drift Tubes				
1.04.02.03.01 PMQ Type Drift Tubes				
PMQ DT Tank 1 (Hammock)	49*	0	01NOV02A	03MAR03
PMQ/EMP DT 1st 10 Diverters Fabed Tank 1	0	0	07JAN03	
PMQ/EMP DT 1st 10 Stem Weld Tank 1Complete	0	0	11FEB03	
Tank 1 DTL Hardware Delivered to ORNL	0	0		01APR03
1.04.02.03.01.01 PMQ Drift Tube Repairs				
PMQ DT Repair Tank 1 (Hammock)	39*	0	15OCT02A	14FEB03
PMQ/EMP DT Final Machining Tank 1 Complete	0	0		14JAN03
PMQ/EMP DT Ship to ORNL Tank 1 (13)	0	0		17FEB03
1.04.02.03.15 DT Tophat Assemblies				
DT Tophat Tank 1 (59) (Hammock)	26*	0	30JAN03	07MAR03
DT Tophat Final Machining Tank 1 Complete	0	0		07FEB03



Start Date	01OCT96
Finish Date	22MAR06
Data Date	18DEC02
Run Date	20DEC02 10:57

Early Bar
Progress Bar
Critical Activity

LN12 - LINA

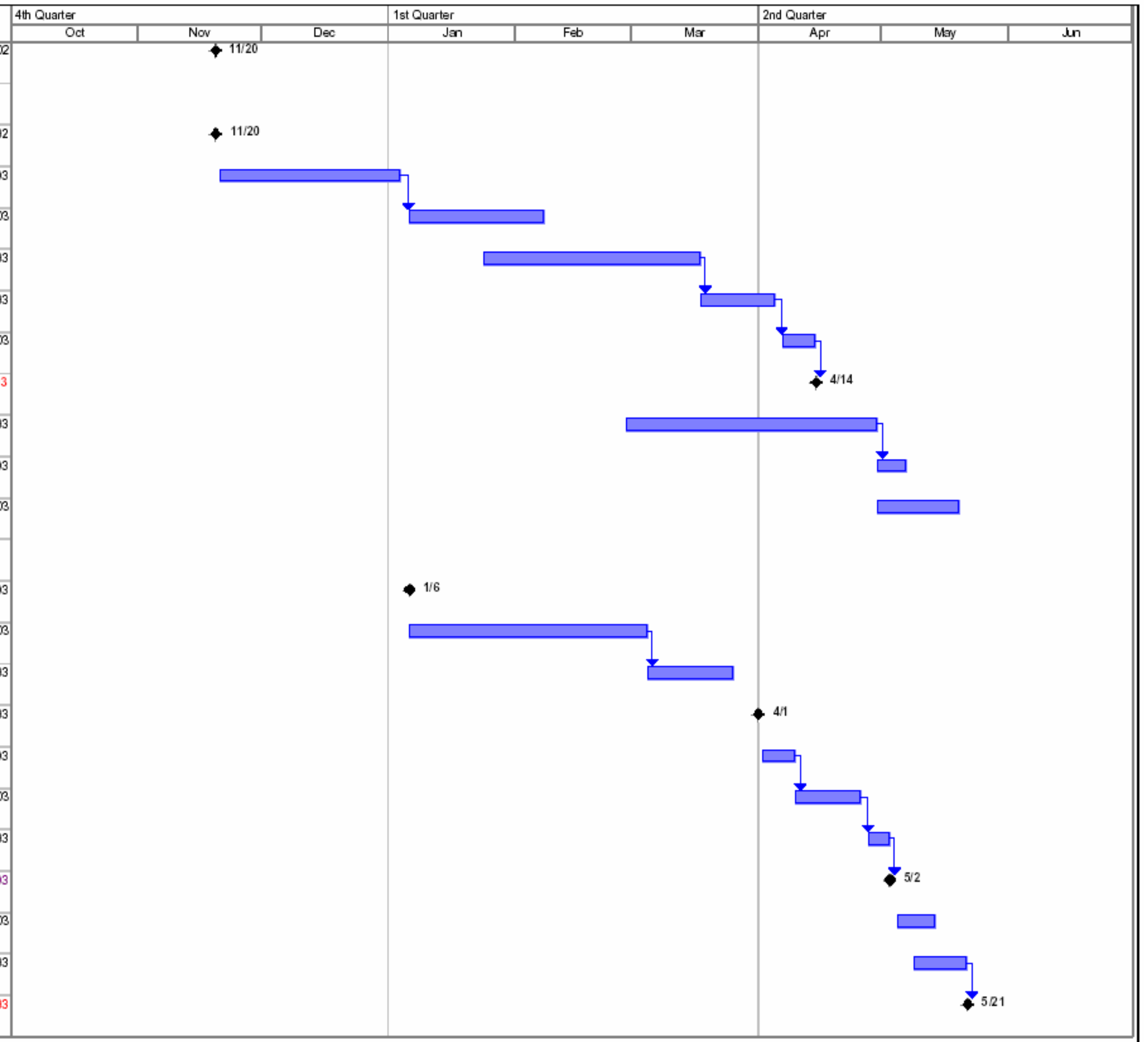
Sheet 1 of 1

DTL 1 Summary

Integration Cycle #52

Roll-up of DTL Tank 1 and -3 Assembly and Installation Schedule

ID	Task Name	Duration	Start	Finish
1	DTL-3 and DTL-1 Summary Schedule	0 days	Wed 11/20/02	Wed 11/20/02
2				
3	DTL-3 Activities	0 days	Wed 11/20/02	Wed 11/20/02
4	DTL3 tank prep.(RATS)	32 days	Thu 11/21/02	Fri 1/3/03
5	DTL3 transport and connect in tunnel	25 days	Mon 1/6/03	Fri 2/7/03
6	DTL3 DT prep, installatin and alignment	37 days	Fri 1/24/03	Mon 3/17/03
7	DTL3 tune, adjust, and confirm	14 days	Tue 3/18/03	Fri 4/4/03
8	DTL3 vac install&final leak check	6 days	Mon 4/7/03	Mon 4/14/03
9	DTL3 installation complete	0 days	Mon 4/14/03	Mon 4/14/03
10	DTL-3 HVCM and HPRF Installation and Test	43 days	Fri 2/28/03	Tue 4/29/03
11	DTL3 RCCS test (with LLRF+HPRF)	5 days	Wed 4/30/03	Tue 5/6/03
12	DTL3 condition	14 days	Wed 4/30/03	Mon 5/19/03
13				
14	DTL-1 Activities	0 days	Mon 1/6/03	Mon 1/6/03
15	DTL1 tank prep.(RATS, no DTs)	42 days	Mon 1/6/03	Tue 3/4/03
16	DTL1 transport and connect in tunnel	15 days	Wed 3/5/03	Tue 3/25/03
17	DTL-1 DT's received at RATS	0 days	Tue 4/1/03	Tue 4/1/03
18	DTL1 DT prep, installation and alignment	6 days	Wed 4/2/03	Wed 4/9/03
19	DTL1 tune, adjust , and confirm	12 days	Thu 4/10/03	Fri 4/25/03
20	DTL1 vac install &connect&leak check	5 days	Mon 4/28/03	Fri 5/2/03
21	DTL1 assembly complete	0 days	Fri 5/2/03	Fri 5/2/03
22	DTL1 HPRF and RCCR testing	7 days	Mon 5/5/03	Tue 5/13/03
23	DTL1 condition	9 days	Fri 5/9/03	Wed 5/21/03
24	DTL1 installation & test complete	0 days	Wed 5/21/03	Wed 5/21/03



Project: DTL3DTL1 V1 12-14-02
Date: Fri 12/20/02

Task		Progress		Summary		External Tasks		Deadline	
Split		Milestone		Project Summary		External Milestone			

Page 1

Appendix 1: First External Review on DTL manufacturing

COMMITTEE REPORT

Assessment and Recommendations
SNS Linac Drift Tubes Vacuum Leak Problem
August 15th, 2002

Background: The Los Alamos National Laboratory is under contract to DOE to design, fabricate and deliver the Alvarez type linear accelerator or proton linac that constitutes the first 84-MeV of the Spallation Neutron Source (SNS) at the Oak Ridge National Laboratory. This 84-MeV linac, made up of a number of resonant cavities or tanks, contains 210 drift tubes. Each drift tube is a water cooled shell which must operate in vacuum. It is essential that each drift tube be leak tight and meet the required maximum leak rate specification of <10-9 atm. cc helium/s. This is a zero tolerance requirement.

The LANL SNS Division has delivered to date tanks 1 and 3 containing 59 drift tubes. These had all been leak tested at the vendor and accepted by LANL. Leak checking was subcontracted by the vendor to Scientific Sales Co., a local rep. for vacuum equipment. Subsequent leak testing at Oak Ridge and LANL under different and more stringent conditions showed that 10 to 20 % of the drift tubes leaked. This appears to be a systemic problem.

An independent committee, combining more then 200 man years experience in the technology, was formed to review the situation, determine the root cause of the problem, recommend a fix, if any, for the drift tubes already completed, and recommend actions to be taken to alleviate the problem in the remaining drift tubes to be manufactured.

This committee consists of:

Mark Franks	LLNL/NIF	Mechanical Engineering
Pierre Grand	TechSource,Inc	Accelerator Expert
Carl Necker	LANL	Metallurgist
Don Precechtel	Fluor/Hanford	E-beam welding expert
Mike Skonicki	ORNL/SNS	Quality Assurance expert
Kimo Welch	consultant	Vacuum expert

This report presents the consensus of this committee as to the cause of the problem, and recommends specific fixes and preventions for the future. It addresses the issues without going into discussions. The contributions of each committee member are attached as appendices for more details.

The committee met with Los Alamos staff responsible for this project and the drift tubes design and fabrication, and together with them visited Coronado Machine Inc.

(CMI), the prime for the drift tubes fabrication, and its electron beam welding subcontractor, the ISYS Manufacturing Co. Without going into details, CMI and its subcontractors are fully qualified to undertake this work. The drift tubes failure addressed in this report is the result of unforeseen circumstances. Now to the issues:

Root (no pun) cause of the problem: Electron beam welding of the drift tube ends to seal the water coolant passages is a proper approach to do the job. The e-beam weld is done at the rough machine stage of the drift tube body. In order to save money, the rough machined bodies are done in groups requiring deep penetration welds as much as 0.400” to 0.500”.

Subsequently, the drift tube is machined to its final dimensions, in some cases removing as much as 0.350” of the weld from its front face. The net result is that it leaves only the root of the weld, which usually is porous, poorly defined (having suspect weld properties). This is evident from visual inspection of finished drift tubes presented at the meeting.

CTC, a materials analysis and testing company, did an autopsy on drift tube # 1-32.The resulting micrographs taken at six azimuth locations, and at both ends (top and bottom), have confirmed our earlier observations. In fact porosity is present at each section, more prevalent than expected. This leaves us with questions as to the basic cause of the problem. Another point of interest is the difference in grain size of two drift tube body parts after the brazing process. This is clearly seen in the CTC report, figure 18b for example. Although not relevant to the vacuum issue, it is nevertheless a puzzle. The CTC reports (top and bottom) are attached as appendices 6 and 7.

In addition, to achieve this deep penetration weld required the use of a high voltage, high current, well focused beam to minimize the power deposition in the copper. Thus the weld width is about 0.035”, making the weld susceptible to misalignments and possibly missing the interface at the root area. In fact, earlier, according to CMI, deficiencies were discovered at ISYS resulting in both circular and cylindrical runout of the weld joint with respect of the electron beam. This has been corrected.

Proposed Rework: On observation of the design and understanding of the e-field issues involved, there is no obvious reason that finished drift tubes of tanks 1 and 3 cannot be salvaged with a minimum of risks. The fix would consist of rewelding the area with a wide e-beam of the order of >0.100”, the beam directed normal to the face of the drift tube to minimize RF problems. The depth of the weld shall be at least 0.100” wherever possible. In this case root porosity is unlikely to be a problem because the weld is not very deep as well as being wider. This of course must be demonstrated.

A second welding pass will likely be required to smooth the weld surface (cosmetic pass). Such cosmetic passes have been developed in the past for a similar purpose. Again this will require development to assure success.

The combination of these two welds will have minimal effects on frequency shift or sparking, as the welds are not in the high field region of the drift tube.

In view of the importance of this work, the development of the weld and related procedures will require close supervision and cooperation between the LANL staff and the vendors at all levels. A paper titled “Electron beam welding of Thick Cross Section Copper with Minimum Porosity” supplied by Mark Franks is attached as appendix x. A similar LANL paper titled “GTA-24 Drift Tubes for Cryogenic Operation” is also enclosed as appendix x. These papers will be helpful in that development.

How about non leakers ?: On the basis of having as many as 20 % of the drift tubes of tanks 1 and 3 leak, and of having determined the cause of it (i.e., weld porosity) means that all drift tubes are suspect to some degree. Now if the proposed rework is a success, one might want to consider applying the same treatment to all remaining drift tubes. This decision need not be acted upon at this time, but wait until such time real data is available as to the success of the program.

How about the remaining unfinished drift tubes ?: Any drift tube in an unfinished stage should be rough machined leaving only 0.030” to 0.040” for finish machining, before doing the e-beam welding. Similarly to the proposed fix, use a first pass, wide beam, with a penetration of 0.150” to 0.200”, followed by a second cosmetic pass. This approach, minimizing the material removal after welding, should solve the problem.

Vacuum leak checking: It is unclear from the leak checking history of the drift tubes to date why leakers were not discovered earlier. It is likely that the major actor was the presence of water in the joints. In the course of fabrication water is introduced in the coolant passages for cooling and hydrostatic tests.

This committee recommends that: 1. Finished drift tubes which have been pressurized with water, be vacuum baked at >100 ° C for several hours before final leak checking. (We recognize that the PMQs are sensitive to high temperatures, hence the lack of a hard number, however the higher the better.) 2.That drift tubes in process not be exposed to water before final leak check. The high pressure test can be done with gas. 3. That proper fixtures be fabricated and proper procedures be established and used for leak checking. And 4. That final leak checking use the bomb method, namely by evacuating a volume external to the drift tube, the leak detector being integral to this chamber, while flooding the drift tube water passages with helium.

Quality Assurance: Specifically for this drift tubes recovery program, it is recommended: 1. That individual weld procedures be created drift tube assembly, or group thereof, to accommodate differences in weld penetration and part geometry; also that metallographic weld samples be produced and confirmed acceptable prior to fabrication. 2.That YSIS confirm the calibration and reproducibility of the fixturing used in the EB welding process. A proper document should be provided, validating conformance, prior to resumption of EB welding. And 3. That a single leak test procedure, including proper fixtures, be established and adhered to for leak check during the fabrication process.

Brazing Issues: The committee did not investigate the problem of the braze diverter leaks. However, a look at the brazing specification goes a long way to explain the problem. The braze joint uses a silver/copper eutectic alloy filler whose liquidus temperature is 1435°F. The brazing specification calls for soaking the copper parts being brazed at 1550°F and soak at that temperature for 10 to 20 minutes, this is a recipe for failure, the brazed joint is starved, the filler material has flowed away. This is clearly seen as excessive wetting of the drift tube body surface, and it is also clearly seen as a puddle in the cooling channel, see fig. 15b of the CTC report.

Successful brazing with eutectic silver/copper alloy, aside from the appropriate joint design, depends on proper thermometry. The copper parts must all reach the brazing temperature, 1435°F, then immediately let to cool off so as not to lose the filler material. Proper calibration, distribution and location of thermocouples is critical. In addition the brazing cycle is usually accomplished by bringing the furnace to about 1400°F, let soak there for 30 minutes or more, then bringing it up to about >1450°F to 1500°F and when all thermocouples agree, turn it off.

Appendices:

1. Contribution Mark Franks
2. Contribution Carl Necker
3. Contribution Don Precechtel
4. Contribution Mike Skonicki
5. Contribution Kimo Welch
6. CTC Report (TOP)
7. CTC Report (BOTTOM)
8. Paper titled “Electron Beam Welding of Thick Cross-Section Copper with Minimal Porosity” by R. Mark Franks etal, LLNL. April 1997
9. Paper titled “GTA-24 Drift Tubes for Cryogenic Operation” by Henri Mignardot etal, LANL, May 1990

Written for the Committee by Pierre Grand,
August 15th, 2002

COMMITTEE REPORT

REVIEW AND ASSESSMENT OF THE

Drift Tube Linac Recovery Plan

Dec. 3 – 5, 2002

Background:

The Los Alamos National Laboratory is under contract to DOE to design, fabricate and deliver the Alvarez type linear accelerator or proton linac for the Spallation Neutron Source (SNS) at the Oak Ridge National Laboratory (ORNL). It constitutes the first 84-MeV section of the linear accelerator. This 84-MeV linac, made up of a number of resonant cavities or tanks, contains 210 drift tubes. Each drift tube is a water cooled shell which must operate in a vacuum environment. It is essential that each drift tube be leak tight and meet the required maximum leak rate specification of <10-9 atm. cc helium/s. This is a zero tolerance requirement.

As early as July 2002, the project discovered that drift tubes fabricated for tanks 3 and 1, (in that order because of installation schedules) were not vacuum tight. This appeared to be a systemic problem. This committee (somewhat different from that outlined below) convened in August to assess the problem and recommend solutions. The problem had to do with a combination of poor fabrication judgment and e-beam welding issues. Thanks to Will Fox who undertook the development necessary to solve the problem, this issue is now resolved.

Subsequent to August, other defects showed up requiring a thorough reevaluation of the drift tube design and fabrication processes. This negated the quick fix proposed earlier for the e-beam welds, completely throwing off the original delivery schedule. The LANL SNS project was then asked to prepare a new recovery plan to fix the defective drift tubes where possible and rebuild new ones where required, with the goal of meeting a delivery schedule of April 1st, 2003. The afore-mentioned committee was reconvened to assess this recovery plan and make recommendations as necessary.

This independent committee, combines well over 200 man years experience in "accelerator engineering". It brings to the table specific expertise in project management, vacuum technology, e-beam welding, brazing, mechanical design, etc… The committee's charge was to review the drift tube linac design in view of making sure that all important design and fabrication issues have been addressed, and review and comment on the LANL recovery plan.

This committee consists of:

Mark Franks	LLNL/NIF	Mechanical Engineering
Pierre Grand	TechSource, Inc.	Project Management
Mike May	FNAL retired	Mechanical Engineering
Ray McKenzie-Wilson	BNL retired	Mechanical Engineering
Don Precechtel	Fluor/Hanford	E-Beam Welding Expert
Kimo Welch	BNL/SLAC retired	Vacuum Technology

This report presents the consensus of this committee with comments on various aspects of the DTL design, and recommendation on the recovery plan. It addresses the issues as the committee saw them without long drawn out discussion. It should be noted that there was remarkable agreement among the committee members in reaching that consensus. The contributions of each committee member are attached as appendices for more details.

8. DTL Design

Design Issues:
In general, the committee agreed that the drift tube design was basically sound. Most of the problems encountered had to do with poor execution of the fabrication process. However, the committee's charge included a review of the DTL design as well as going over installation and maintenance issues. In the spirit of this charge, and in view of the fact that the committee brought to the table over 200 man years experience in particle accelerator hardware design, many design details were addressed. The following comments address some of these design issues. None are show stoppers, however they will likely affect reliability, hardware lifetime, maintenance, etc…

Vacuum System:
The large number of Viton O'ring seals will put a disproportionate gas load on the pumps, thus pumping speed available appears insufficient.
The choice of aluminum in line valves with Viton stem seals is a poor choice as these valves are in the highest radiation field to be expected, at least in the area above 50 MeV. Also one must avoid contact between aluminum and copper, as it leads to galvanic action if humidity is present.
Although NEG pumps have a place in certain application, it appears to be a poor choice to pump the iris transition/rf window area. They are poor at pumping H_2O and need regeneration at each venting to atmosphere.
The use of 303 free machining stainless steel is not advised for vacuum application. The material contains 0.15 – 0.28 % sulfur which leaches out in vacuum.

Cooling System:
The use of thermally conductive grease in the cooling channels is not advised. It will eventually flow unless it is held under gravity which is not the case. We strongly suggest the use of copper cooling tubes epoxied in place with thermally conductive epoxy (e.g. Devcon or equivalent).

Brazing Specification:
Brazing still appears to be an issue. It should not be. The liquidus temperature for eutectic silver/copper is 1435 ^{0} F. Above this temperature it has little or no viscosity to speak of. It is imperative that the assembly being brazed not stay at temperatures much above liquidus for any length of time. Thus we recommend that the assembly being brazed be brought to about 1420 ^{0} F and soaked at this temperature long enough to ascertain that the entire assembly is at temperature, then heat to about 1450^{0} F to cause the alloy to flow, then immediately cool down. The development needed to braze the diverter must address clearance and tolerances as well as braze material amount, location, and the thermal cycle.

Use of Vacuum Grease:
The DTL is admittedly loaded with Viton O'ring seals. Most of the outgassing to be expected will be water vapor. If vacuum grease is used, other gases, mostly large organic molecules which will be very difficult to detect with a QRGA, will be present. It, however, is most improbable that these will migrate through 50m. of CCL structures without first being pumped by the surfaces of the DTL and CCL, and their respective pumps. The idea is a red herring!

Design Details and Tolerances:
Although we have not addressed detail drawings, the presentations indicated that there were gross inconsistencies with respect to dimensioning and dimensional tolerances. For instance, we questioned the need for tight tolerances on drift tube OD, (unnecessary) and heard that each drift tube has a different face angle (totally unnecessary) as these can be done in batches, all having the same dimensions except for the overall length. At the same time there were dimensional tolerances left at the discretion of the vendor!

Steering Dipole Drift Tube:
This design appears extremely complicated (the drift tube assembly has 36 e-beam welds). From looking at this design in more details, it is evident that there was no attempt to provide some design integration. This design ought to be reviewed in view of simplification and ease of fabrication.

Assembly and Installation of Drift Tubes in Situ:
The committee believes that although not optimal, it can be done without undue hardship. We have seen worse situations. Installation however must be done under clean conditions, especially in view of the limited pumping speeds available for start up. Climate control or compensation must be considered during the installation of DT's in

the tanks. Temperature compensation features on some laser trackers have been used with varying degrees of success.

Other design issues have been discussed. These may show up in individual comments of committee members according to their biases. However, it is worth repeating, there doesn't seem to be show stoppers in the design. It is basically sound.Design differences are more a mark of a young design team unencumbered by accelerator design experience.

9. Management and Schedules

Management Issues:

If the SNS Division is to succeed in developing and implementing a recovery plan to meet the desired schedule goals, it must face the fact that the division management has weaknesses; mostly a lack of technical and motivating leadership, this needs to be addressed. The reaction of management to the fabrication fiasco of the recent past, somewhat aggravated by the reviews imposed on the project, is: "We screwed up, so this time we are going to do things right, even if it costs time to the project". This leads to a number of resulting decisions which will likely slow down the process. More specifically, the committee perceives the following:

Staffing:

There is an obvious and recognized lack of senior experienced personnel on board to address all these issues. The problems have been evident since August or before, and nothing was done to add the right people since that time. The additional resources that were presented, as required, don't seem to be coming into place with any urgency.

Vendor Oversight:

The committee feels that a major cause of the problem not being discovered sooner was the lack of experienced, competent oversight of the fabrication processes. We see no specific plan to address this issue. The SNS project needs to take control and responsibility for all fabrication processes due to a lack of a qualified vendor to do the entire job. This, however, will require qualified people to direct the work and integrate the efforts of several vendors involved with fabrication.

Paper:

The committee was surprised by the amount of paper the recovery plan involves. We heard the need for 4000 to 5000 fabrication drawings, a full up QA program to guarantee that every step in the fabrication process is adhered to, etc… This alone will cost time, people and money, none of which are readily available.

Schedules:

The recovery schedule presented, with delivery date for tank-1 drift tubes of May 21st, was obviously well thought out, where every step in the recovery process was more or less accounted for. It was a bottom up schedule prepared by Will Fox and Jim Simms, who gave the impression "once burned, twice shy, let's make sure we do things right". It is still based on using CMI as the sole machine shop to do the tanks 1 and 3 drift tubes work. From this schedule, CMI is standing out as being on the critical path. Also from the schedule presented one could see areas where time could be gained by overlapping various activities. However, strong and constant leadership must coordinate all activities to assure this will happen. This schedule is tight, but it is still based on utilizing one vendor, working one shift, five days per week. This provides considerable slack in the schedule. This leads us to the conclusion that, given the proper leadership, the project's desired schedule can still be achieved.

Recommendations:

Develop a Top Down Schedule with the sought for delivery date of April 1st, 2003 as the starting point. This schedule to be predicated on the following recommended steps:

1. Eliminate the steering and BPM drift tubes as these are likely to end up on the critical path. They can always be retrofitted later. Replace them with empty drift tubes, (four of them).
2. Review the detail drawings in view of relaxing dimensional tolerances and standardizing parts where possible, e.g. face angles can be common for batches of drift tubes.
3. Minimize the paper trails. We estimate that 200 to 250 drawings are sufficient for the job. Similarly, the QA trail can be minimized, providing the right people are doing the job. However it is imperative that "travelers" be used to follow each drift tube during the manufacturing process.
4. Take calculated risks and short cuts where feasible, realizing that this schedule is a totally success oriented approach. However, we think that it is possible without compromising the success of the enterprise.
5. Outsource part of the work. We realize that outsourcing more puts greater demands on an already thin staff resource, both at the procurement and oversight levels. It was suggested that Mike May be made available to bring in FNAL qualified machine shops in the Chicago area to participate. This might help.
6. The need for added staff is not a question of quantity rather than quality. Bring in four or five qualified, experienced people with the ability and authority to drive the program through. If they have the proper backing from management and the LANL infrastructure, we believe they can pull it off.

Appendices:

A. Comments from Mark Franks

B. Comment from Mike May

C. Comments from Ray McKenzie-Wilson

D. Comments from Don Precechtel

E. Comments from Kimo Welch

F. “Paper-Less” CAD/CAM for accelerator components
by Mark Franks et al, LLNL. PAC Meeting 2001