SANDIA REPORT
SAND2010-7261
Unlimited Release
Printed October 2010

Option study of an orthogonal X-ray radiography axis for pRad at LANSCE area C, Los Alamos

Bryan V. Oliver, David L. Johnson, Josh Leckbee and Peter Jones

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Sandia National Laboratories

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

Printed in the United States of America. This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831

Telephone: (865) 576-8401
Facsimile: (865) 576-5728
E-Mail: reports@adonis.osti.gov
Online ordering: http://www.osti.gov/bridge

Available to the public from
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Rd.
Springfield, VA 22161

Telephone: (800) 553-6847
Facsimile: (703) 605-6900
E-Mail: orders@ntis.fedworld.gov
Online order: http://www.ntis.gov/help/ordermethods.asp?loc=7-4-0#online

SAND2010-7261
Unlimited Release
Printed October 2010

Option study of an orthogonal X-ray radiography axis for pRad at LANSCE area C , Los Alamos

B. V. Oliver[1], D.L. Johnson, J. Leckbee, and P. Jones[2]
Sandia National Laboratories
P.O. Box 5800
Albuquerque, New Mexico 87185

Abstract

We report on an option study of two potential x-ray systems for orthogonal radiography at Area C in the LANSCE facility at Los Alamos National Laboratory. The systems assessed are expected to be near equivalent systems to the presently existing Cygnus capability at the Nevada Test Site. Nominal dose and radiographic resolution of 4 rad (measured at one meter) and 1 mm spot are desired. Both a system study and qualitative design are presented as well as estimated cost and schedule. Each x-ray system analyzed is designed to drive a rod-pinch electron beam diode capable of producing the nominal dose and spot.

[1] Email: bvolive@sandia.gov
[2] Permanent address: Ktech Corp., Albuquerque, New Mexico, USA

Acknowledgements

We would like to thank Andy Saunders and Brian Hollander (LANL) for leading tours of the pRad facility and providing facility layout drawings. Members from L-3 Pulse Sciences also provided valuable costing information on the Cygnus accelerators. We also acknowledge C. Barnes and D. Fulton (LANL) for enabling this study.

Contents

Figures

Tables

I. Introduction

This report summarizes the results of a study to determine the cost and schedule for deploying an equivalent (equivalent to the radiographic capability of pRad) x-ray radiographic capability at the existing proton radiography (pRad) facility located in Area C at LANSCE, Los Alamos National Laboratory. The x-ray radiography source must fit in the existing facility and provide imaging perpendicular to the proton radiography beam line-of-site. This second axis is expected to provide experimenters with additional radiographic information including off-axis imaging and the potential for radiography across magnetic field lines of magnetically driven experiments. Precise radiographic requirements are not yet determined, so it is assumed that the existing (at the Nevada Test Site) Cygnus radiography capability is used as a reference. The Cygnus x-ray source is presently used to radiograph similar sized objects and line of site masses that are presently fielded in front of pRad. The Cygnus accelerators, located in the U1a drift at the Nevada Test Site (NTS), each drive a rod-pinch diode x-ray source which produce 4 Rad at 1-m from a ~1.0 mm diameter source [1-5].

Two accelerator options are discussed in this report, each being capable of driving a rod-pinch diode. The first is a Cygnus-like accelerator that uses the same cavity and Marx design as the existing Cygnus machines. The capability of the Cygnus accelerators is well documented and some spare hardware exists which would significantly reduce cost. The second option is based on the Linear Transformer Driver (LTD) technology developed at Sandia and the Russian High Current Electronics Institute [6-7]. A 2-2.5-MV LTD is being built and tested at Sandia. These tests will demonstrate the radiographic capability of an LTD based system, which is expected to be similar to that of an Inductive Voltage Adder (IVA) based system like Cygnus.

A number of assumptions are made in conducting the study including: 1) the system will provide a single axis, single pulse, Cygnus-like x-ray capability (2.25 MeV, 1mm spot, 4-5 rad@m), 2) the downstream radiographic imaging/line of site not considered to be an impediment to the design (i.e. downstream imaging can be accommodated), 3) the Area C Spectrometer is not moved/dismantled and thus the system must fit in the existing available footprint, 4) no large external oil storage is provided and thus the systems must be self-contained, 5) there is no existing crane access, 6) electrical and plumbing piping/conduit around the outer walls of the facility can be moved, 7) the costs and schedule associated with facility modifications are not included, 8) and that installation of the radiographic system can occur during pRad “down” time (otherwise schedule will increase)

II. Option 1: Cygnus Replication

The Cygnus accelerators are two inductive voltage adder (IVA) accelerators located in the U1a drift at the NTS. Figure 1 shows photographs of one Cygnus accelerator as fielded at Los Alamos before relocation to NTS. Each accelerator has a single Marx capacitor bank in an oil tank with a closed lid. The Marx is discharged into a single coaxial pulse forming line (PFL) with two self-breaking water insulated spark gap switches and a self-breaking oil spark gap switches. The output of the PFL is connected to a long coaxial water insulated line with a stepped diameter center conductor that acts as an impedance transformer to better match the impedance of the PFL to an oil filled manifold and IVA cells. The oil manifold connects the coaxial water line to the three IVA cells and is designed to drive each cell with approximately the same voltage. The three cells are connected in series with a long central anode stalk forming a coaxial vacuum transmission line. Ideally, the three cells would be driven sequentially so that the pulses from each cell arrive at the load simultaneously. The connection of the water line to the oil manifold is placed so that the voltage pulse arrives at each cell close to the ideal time.

The output of each Cygnus accelerator is a 2.25-MV, 60 kA, 60-ns pulse into a ~40-Ω diode load. Some of the design requirements for the Cygnus accelerator are shown in Table 1. The cost and complexity of the Sub-Critical Experiments (SCE) program at the NTS demands that the Cygnus accelerators have high reliability, driving design limitations to be very conservative. The reliability of the Cygnus accelerators has been experimentally demonstrated and is documented in references 2 and 4. Each accelerator drives a self-insulated rod-pinch diode which produce 4 rads, measured at one meter, of hard x-ray radiation in a 1 mm diameter spot. Typical output voltage and radiation output waveforms from Cygnus are shown in Figure 2 a) and b), respectively. The radiation dose rate shown in Figure 2 b) is also compared to a model radiographers equation for the radiation output as inferred from the voltage and current [3]. This is relevant to the study for option 2 below, as we use the same radiographers equation to estimate the radiation output from the anticipated accelerator current and voltage output.

Table 1. Design Criteria for Cygnus and LTD Options

Peak diode voltage	2.25 MV
Diode Current	~ 60 kA
Rod-pinch diode impedance	~ 40 Ω
X-ray pulse width	~ 50 ns
Vacuum line cathode peak field stress	200 kV/cm
Failure Rate	<1 in 200 shots

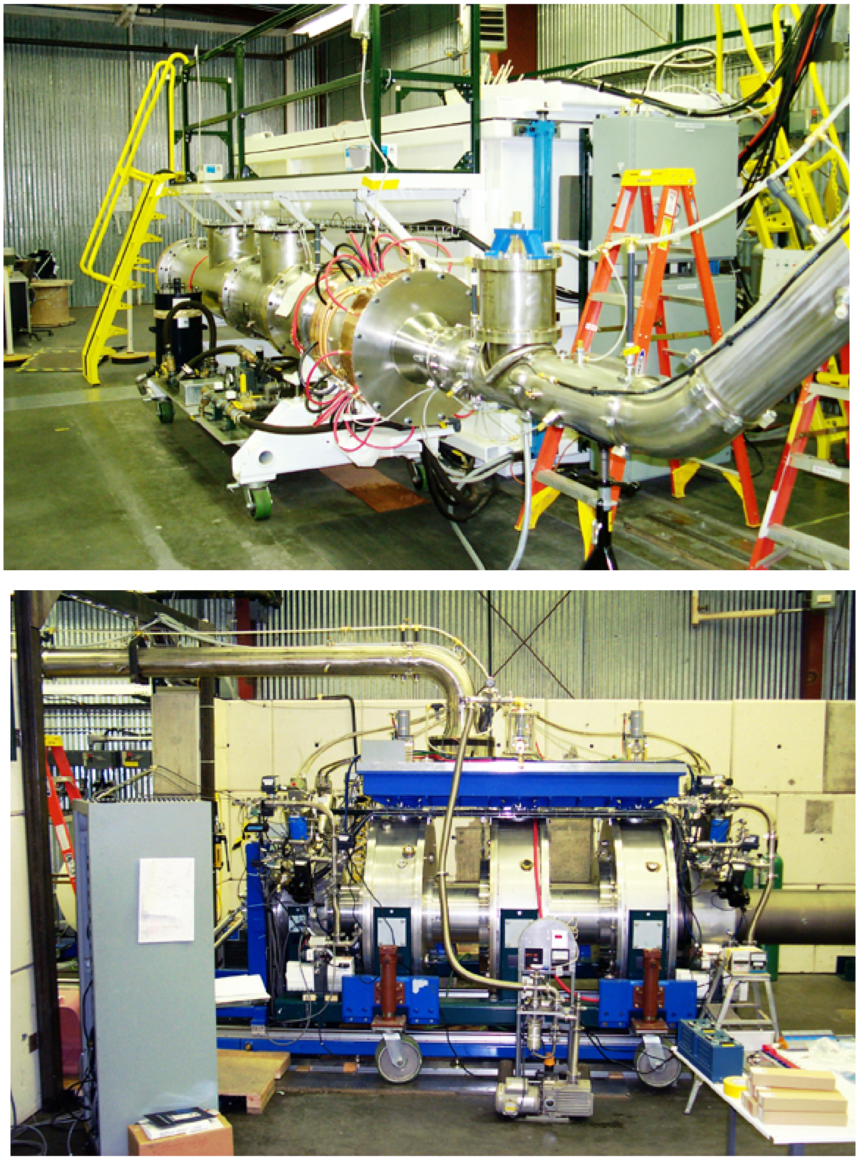


Figure 1. Photographs of the Cygnus accelerator during testing at Los Alamos.

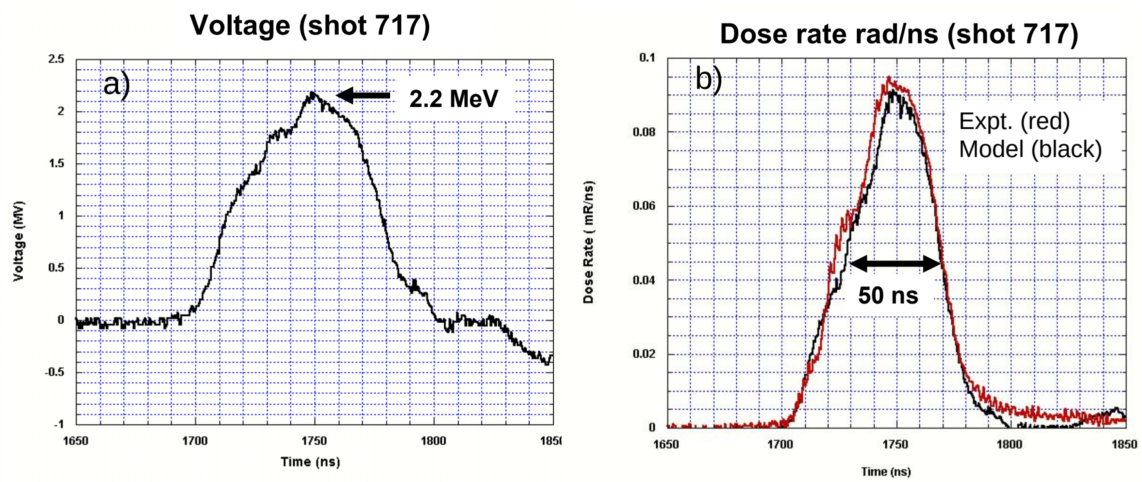


Figure 2. The output voltage a) and radiation b) from Cygnus shot 717. In b) the expt. radiation output is compared to model calculations of the radiation output based on the experimentally measured voltage and current

IIa. Cygnus Design Changes for LANSCE Area C

Figure 3 shows the Cygnus-like accelerator in area C of the LANSCE facility. The basic machine design is the same as the Cygnus accelerators used in U1a with a few minor changes to configure the accelerator for the available laboratory space. The Marx generator is the same as in the existing Cygnus accelerators however, the tank was built for Cygnus when tested at Los Alamos. The PFL is identical to the existing Cygnus accelerators, but the water transmission line has been reconfigured to allow the Marx tank to be located adjacent to the IVA cells rather than behind the accelerator. The new water line is shorter than on the existing Cygnus accelerators, but is long enough to provide the required impedance transformation. This is a small change that will not impact the performance of the accelerator. As shown in Figure 4 and Figure 5, the PFL and water line form a folded geometry where a section of the water line is directly above the PFL. The oil manifold and cells are identical to the existing Cygnus accelerators. The output vacuum insulated transmission line (VITL) center stalk is the same except without the 30^{o} angled diode section on the end (because of space requirements at Cygnus, in order to fit two axis lines of site, the machines are configured such that their diodes are angled at 30^{o} off the accelerator centerline).

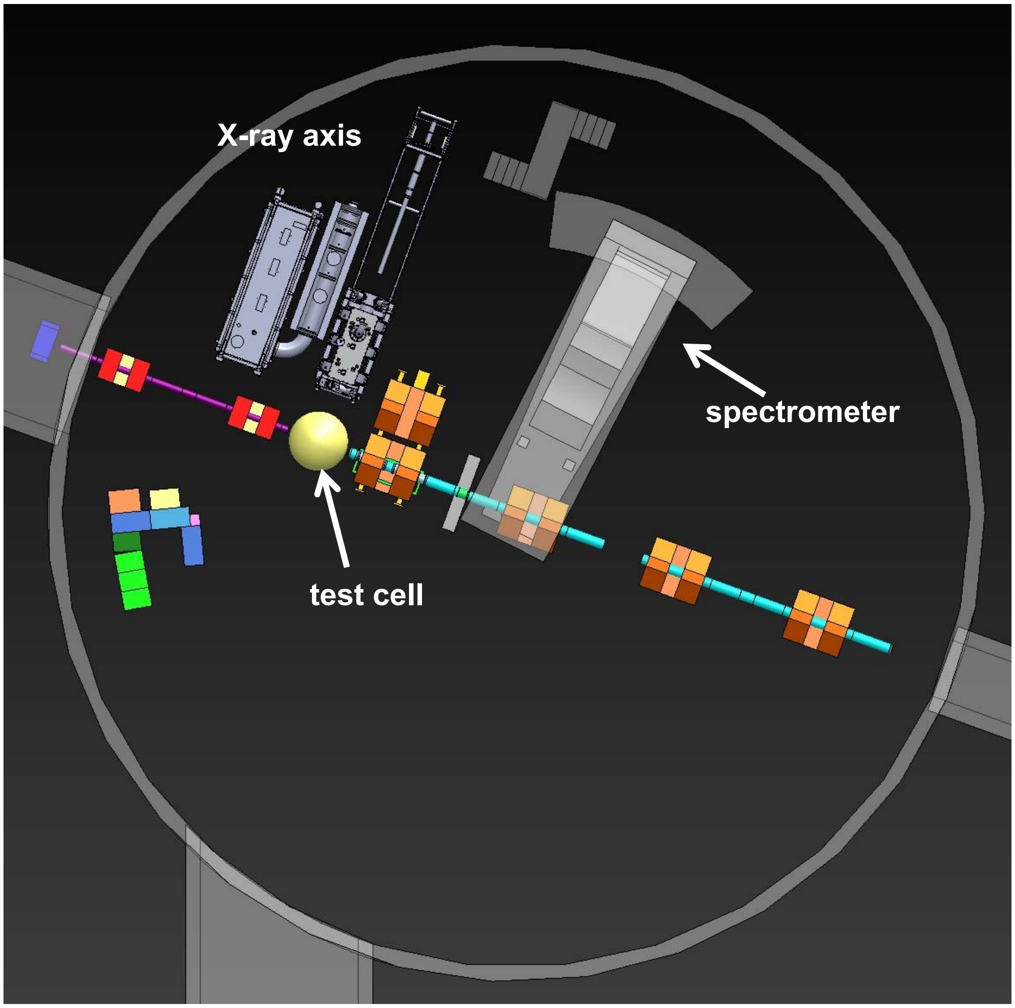


Figure 3. pRad facility in area C with the Cygnus machine located orthogonal to the test cell.

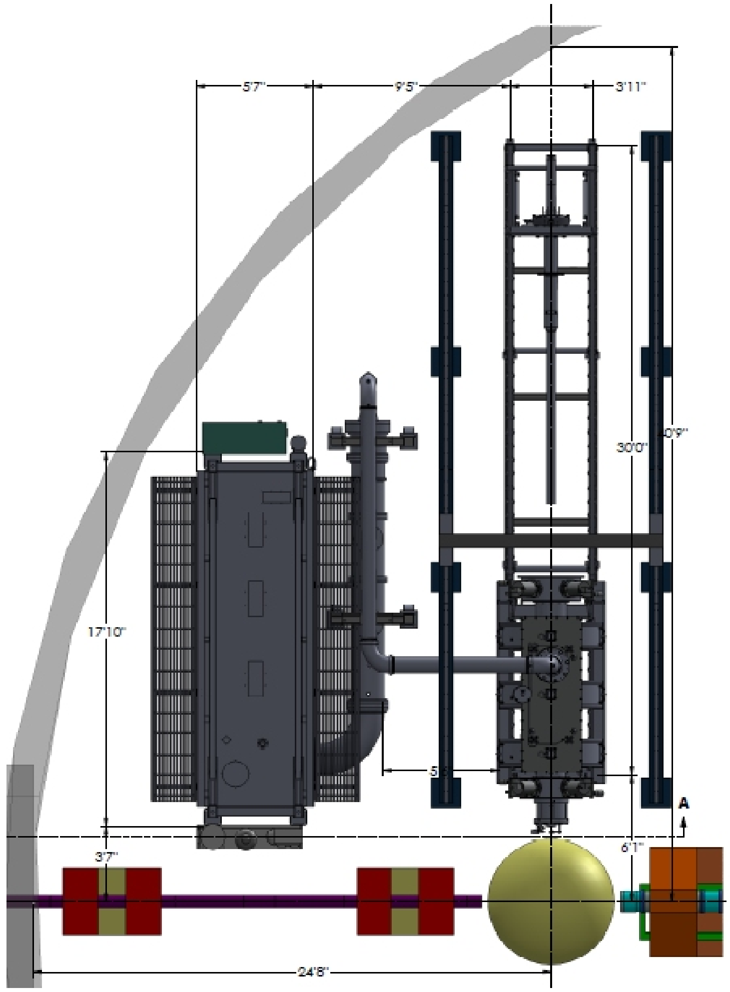


Figure 4. Detailed layout of the Cygnus machine in the pRad facility.

IIb. Required Changes to LANSCE Area C to accommodate Cygnus

Several facility changes will be required to accommodate the installation and maintenance of a Cygnus-like accelerator. The layout in Figure 4 requires that the large cable tray near the outer wall be removed. This space is required for the Marx tank and is also needed for full extraction of the VITL center conductor. An overhead crane would be installed to aid in the installation and servicing of the IVA cells. The crane is not required for normal daily operations, but is required for assembly and for some maintenance activities. The crane shown in Figure 4 covers the IVA cells and the extracted VITL. The crane design can be modified if coverage over the pRad experimental chamber or other equipment is deemed beneficial. During machine assembly, the pRad experimental chamber and some of the beamline equipment shown in Figure 4 would be removed. A fork lift can be used to transport large items into the Area C facility and to position the Marx generator tank and PFL. The new crane can be used in assembling the VITL and IVA cells.

The Marx tank contains approximately 2000 gallons of transformer oil for insulation. The IVA cells and manifold contain 1900 gallons of transform oil. Neither the Marx tank nor the cells are normally drained under routine operation and maintenance of the machine. However, a secondary containment system for the oil will have to be provided to meet environmental and safety requirements. Ancillary systems which are included in the design and cost estimate include: deionized water system for the PFL, compressed air to the Marx switches, hydraulic pumps for raising and lowering the Marx, and vacuum pumps for the vacuum transmission line and diode.

IIc. Costing and Schedule for the Cygnus-like Option

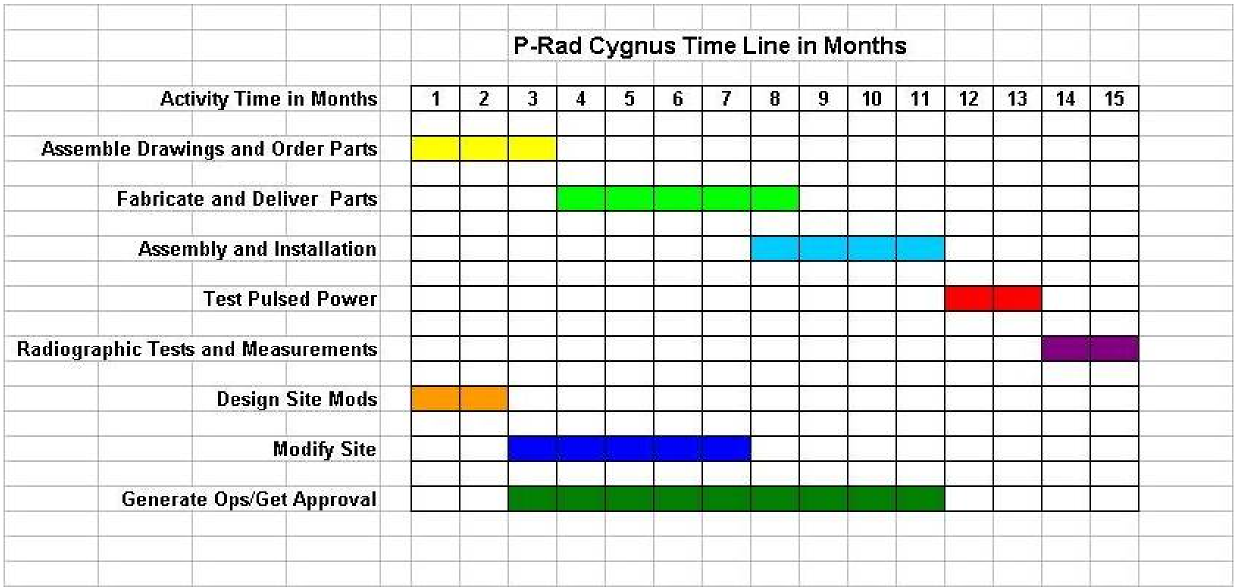
Table 2. Cygnus option cost estimate contains the cost estimates for the Cygnus machine option. The estimates are determined with information from a number of sources and based on some simplifying assumptions. First, the actual parts costs from the U1a Cygnus machines are escalated by 5% per year over 8 years (originally procured in 2002). Updated labor and costing estimates were also provided by L-3 Pulse Sciences, San Leandro (the original designer and fabricator of some Cygnus parts). Finally, estimates by Sandia personnel based on experience in assembly and testing of various IVA accelerators are also included. Two major machine components are assumed available at no cost to the project: the IVA cells from SABRE on hand at Sandia and the Marx tank that was built for Cygnus at Los Alamos but never used in U1a. As with the original Cygnus machines, the SABRE cells require some modification to reduce electric field stress and these costs are included. Some minor design changes, most notably the length and shape of the water transmission line, will be necessary for this version of Cygnus to accommodate placement at pRad and have been included in the cost and schedule. Costs to modify the Area C facility (power drops, guide rails, overhead crane, removal/repositioning of facility components, etc.) are not included. Oil containment and storage equipment are also not included in the cost estimate. These will have to be determined by LANL personnel. Loading for purchasing and requisitions was set at 14%, the standard Sandia procurement rate. The total estimated cost with 15% contingency is ~$3.7M. If the assumed available parts (IVA cells and Marx tank) are purchased new, the cost will escalate by ~$1.0 to $1.5M.

Table 3 shows an estimated timeline for procurement, assembly, and testing of a Cygnus-like accelerator in Area C at LANSCE. The schedule allots three months to assembling the drawings and placing orders. Assembly of the drawing package would involve locating the final version of drawings and modifying drawings where changes are desired. The design incorporates few changes from the existing Cygnus accelerators and most parts can be ordered without modification to drawings. Manpower estimates for accelerator assembly and testing in Table 2 and Table 3 assume all personnel are trained, competent, and familiar with pulsed power accelerator operation and maintenance. Estimates of the time required for site modifications are based on the limited modifications outlined in this report. This time estimate would not be sufficient if more extensive modifications were undertaken such as the removal of the large spectrometer. Operating procedures will be similar to existing procedures for Cygnus, but will need to be adapted to the requirements of the LANSCE facility. Time is also included for obtaining approval for radiation shielding, oil handling, and other aspects of the accelerator operation that will change the current safety documentation in the Area C laboratory. A Cygnus-like capability could be ready to field on experiments at Area C about 15 months after a decision is made to fund the project. An artists rendition of the accelerator is shown in Figure 5

Table 2. Cygnus option cost estimate

Machine sub ass'ys	**Cost (k$)**	
Marx Tank	20	Old R306 tank on hand at NTS
Oil Storage System	40	Secondary containment for oil must be included in site modifications and prep
Marx Generator	450	
PFL	100	
Water Line	190	Estimate based on U1a configuration
Adder Skid Ass'y	450	Three Cobra IVA's available at Sandia (Mods Required)
Oil Manifold	120	
VITL & Diode	150	
Control System	150	
DAS	100	~40 channels of digitizers
Diagnostics	35	Monitors and integrators
Gas System	10	
Oil System	25	
Vacuum System	100	4 8" cryos and 4 mechanical pumps used on each U1a Cygnus + 4 gate valves
Core Reset	15	
Sub Total (k$)	**1955**	(No loading applied for procurement)
Procurement Loading	274	Assumes 14% Loading
15% contingency	334	
Total (k$)	**2563**	
FTE's		
Drawing Prep	0.25	1 Person - 3 mons
Procurement	0.25	1 Person - 3 mons
QC	0.35	1 Person - 4 mons
Assembly	2.00	Machine ass'y, DAS, Command & Control (6 Persons - 4 mons)
Testing	1.35	4 Persons - 4 mons
Total (FTE's)	**4.20**	
Total Labor Cost ($k)	**1155**	$275k per FTE Assumed (PP Engineer and Techs)
Total Machine Cost ($k)	**3718**	LANL costs for Site Mod design and Mods not included

Table 3. Estimated schedule for assembly and testing of the Cygnus option.



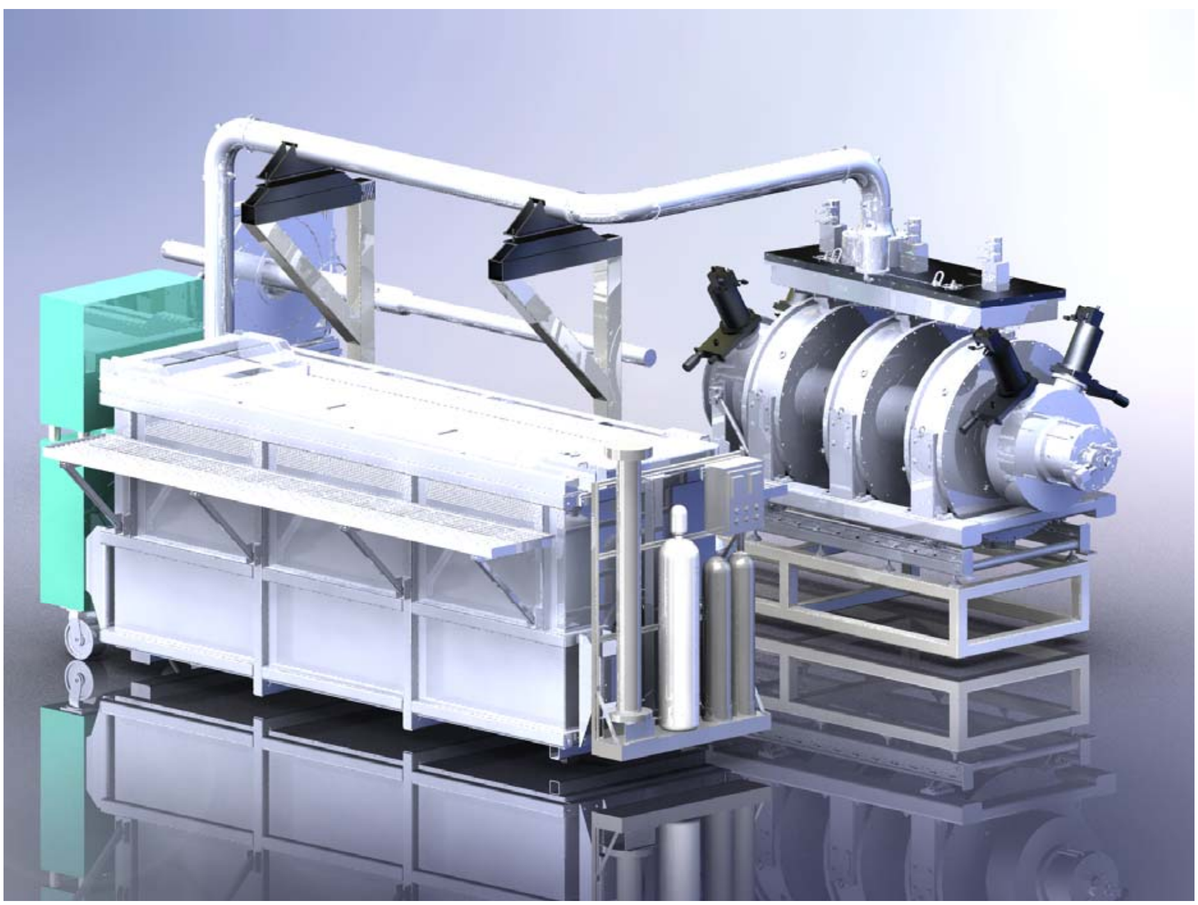


Figure 5. Artist rendition of the Cygnus accelerator configuration at pRad.

III. Option 2: Linear Transformer Driver

The Linear Transformer Driver (LTD) is a relatively new pulsed power architecture based on the induction voltage adder (IVA) [6-8]. In both systems (IVA or LTD) voltage adder cells are stacked in series and voltage is added along a coaxial vacuum transmission line. The fundamental difference is that in the case of the LTD, all energy storage and pulse forming circuitry is contained in the adder cell or cavity. In the traditional IVA, like Cygnus, the energy storage and pulse forming circuits are external to the cavity. The LTD lacks a traditional marx capacitor bank and accompanying oil tank which can occupy significant lab space. Since the LTD cavities contain energy storage circuitry, the output voltage per cavity is typically lower than is achievable with a traditional IVA resulting in the need for many more series cavities.

The LTD architecture is being studied by several institutions for various applications. The radiographic LTD (LTDR) at Sandia National Labs was moved from the High Current Electronics Institute in Russia to Sandia in 2004 and originally consisted of seven series cavities. The system is currently being upgraded to 21 series cavities and will generate pulses of 2-2.5 MV at the diode. Two other LTD labs exist at Sandia which are testing LTD circuits with similar cavity architecture. One is a 1/2-MA cavity called LTDII or LTDIII which has been tested at repetition rates up to 0.1 Hz to investigate circuit lifetime [9]. The other is a high current LTD lab named Mykonos which when completed will contain 10 series cavities and will generate pulses of 1-MV and 1-MA [10]. The University of Michigan has a single 1-MA LTD cavity that is being used to study high current plasma physics environments [11]. The CEA in France has begun testing a 10-cavity radiographic LTD which produces a 1-MV pulse.

Over the next year significant information will be gathered on the various LTD systems that will help validate LTD modeling. The upgraded 2.5-MV LTDR will be used to study vacuum electron effects and coupling to a radiographic diode. Testing at the CEA and on LTDIII at Sandia will provide additional lifetime and reliability data. This testing will also help elevate the technical readiness of the LTD technology.

IIIa. Physical Layout of the LTD Option

The LTD design proposed in this report is based on the design of the cavities in the Sandia 2.5-MV LTDR and the CEA 1-MV LTD. Each cavity is 55.4" outer diameter with a 16" inner diameter and 8.7" long. The accelerator contains 24 of these series cavities assembled in two groups of 12 cavities each, Figure 6. The cavities are typically separated into groups to reduce the force required to compress the cavities together and form a vacuum seal. The Sandia LTDR contains three groups of seven cavities each and the CEA LTD contains one group of 10 cavities. A 16-18" long spacer is required between groups of cavities. The design considered here uses two groups to minimize the total accelerator length. The LTD option is significantly longer than the three IVA cavities of a Cygnus machine, but the accelerator does not require additional lab space adjacent to the cavities for a Marx tank or PFL. The total oil volume is less than 1000 gallons, less than one fourth of the oil required in the Cygnus option.

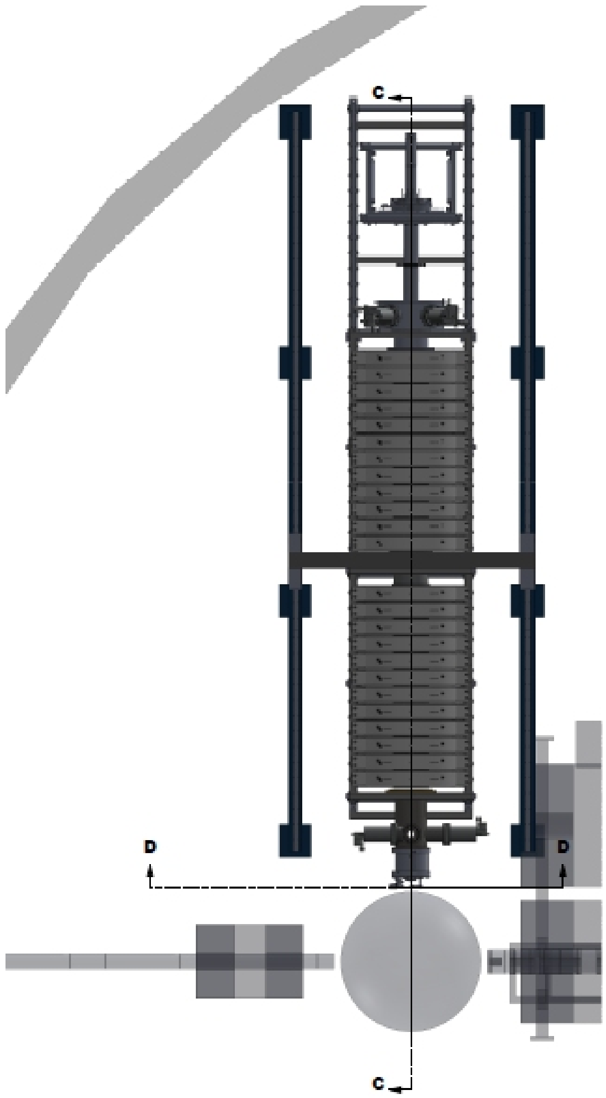


Figure 6. Layout of the 24-cavity LTD design shown in the area C pRad facility at LANSCE.

IIIb. Electrical Design of the LTD Option

The LTD option is intended to provide similar radiographic capability as Cygnus. Many of the Cygnus design specifications were applied to the design of the LTD option. Some of these are listed in Table 1. Cygnus was designed to provide the desired performance with low probability of failure, less than one failure in 200. The LTD system is designed using components rated for 100 kV charge and could be operated at this level. However, to improve reliability, we have assumed that the system will be charged to 90 kV and is designed to meet the above voltage and current requirements at this lower charge level.

The design was developed in several steps. First, the load voltage and current requirements were used to estimate the number of cavities and number of bricks per cavity. Second, circuit simulations were used to fine tune the design. Third, electrostatic field calculations of the entire output transmission line were performed to design the vacuum interface of the cavities and the impedance of the transmission line. Fourth, these vacuum line impedances were fed back into the circuit simulations. A couple iterations of steps three and four were used to arrive at a final design which gives the desired output voltage and maintains the field stress in the vacuum line below the stated design limits. The load voltage from circuit simulations of the final design is shown in Figure 7.

The output vacuum transmission line in Cygnus was designed as a 60-Ω line. In a coaxial vacuum line, 60 Ω is the impedance that minimizes the electric field stress on the outer conductor. In the design of Cygnus it was shown that with a relatively short transmission line with no electron emission, the exact impedance of the transmission line had little effect on the diode voltage [1]. In the Cygnus design, the PFL is connected to the cavities through a long transmission line. When the pulse arrives at the cavities and the output transmission line, a mismatch in impedance will result in increase or decrease in voltage, but little change in pulse shape. The same occurs at the diode.

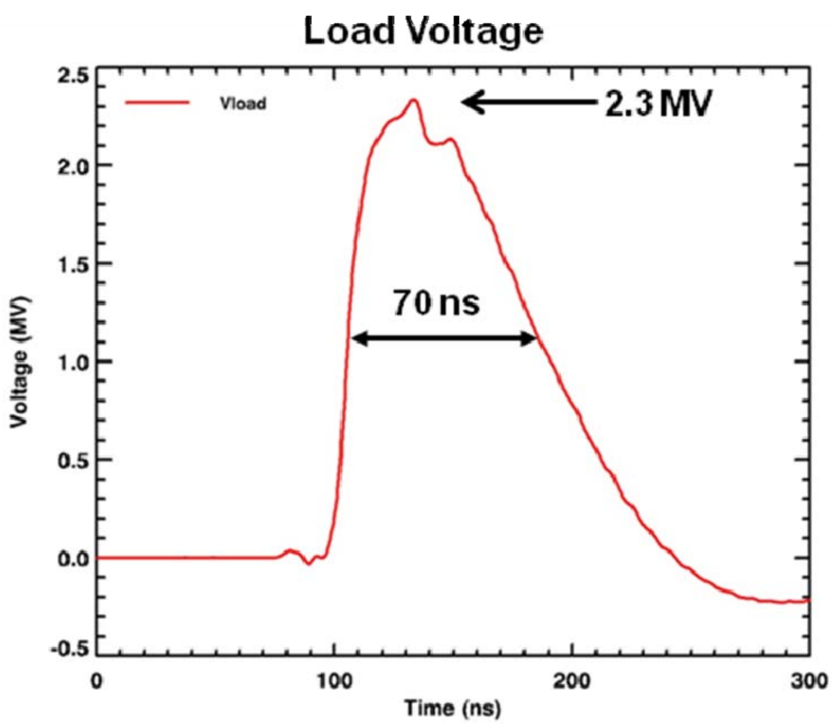


Figure 7. Simulated load voltage of the LTD option. The diode impedance in the simulation is 40 Ω.

The interaction of the LTD with the output transmission line and diode is significantly different. The impedance of the output transmission line relative to the impedance of the cavities determines the discharge rate of the capacitors and will not only change the peak output voltage, but also the pulse shape. If for example, the LTD is designed to produce a 70-ns voltage pulse when coupled to a 40-Ω load and the transmission line is changed to 60 Ω, then the output pulse will be higher peak amplitude but longer pulse width. Coupling the 60-Ω transmission line to a 40-Ω diode will decrease the peak voltage without significantly changing the pulse shape. A compromise must be designed where the transmission line is well matched to the LTD and diode impedances but also has low electric field stress on the cathode surfaces. The design considered here has a 45-Ω vacuum transmission line with a slightly larger diameter outer conductor than the Cygnus design (16" for the LTD compared to 15" diameter for Cygnus). This design produces the desired pulse shape shown in Figure 7 and low electric field stress shown in Figure 8.

The X-ray dose production of an electron beam diode can be estimated using the appropriate radiographer's equation derived from radiation transport calculations. For the rod-pinch diode used on Cygnus the radiographers equation is [3]

$$D = 0.61\, IV^{1.25}.$$

where: D = dose rate (Rad@1m / ns), I = Current (MA), and V = Voltage (MV)[we note that this is used in the model calculation of Figure 2 b.]. Applying this equation to the results of the circuit simulations of the LTD design gives the result shown in Figure 9. The integral of the dose rate gives the total X-ray dose per shot and is predicted to be about 5 Rad as measured at 1m.

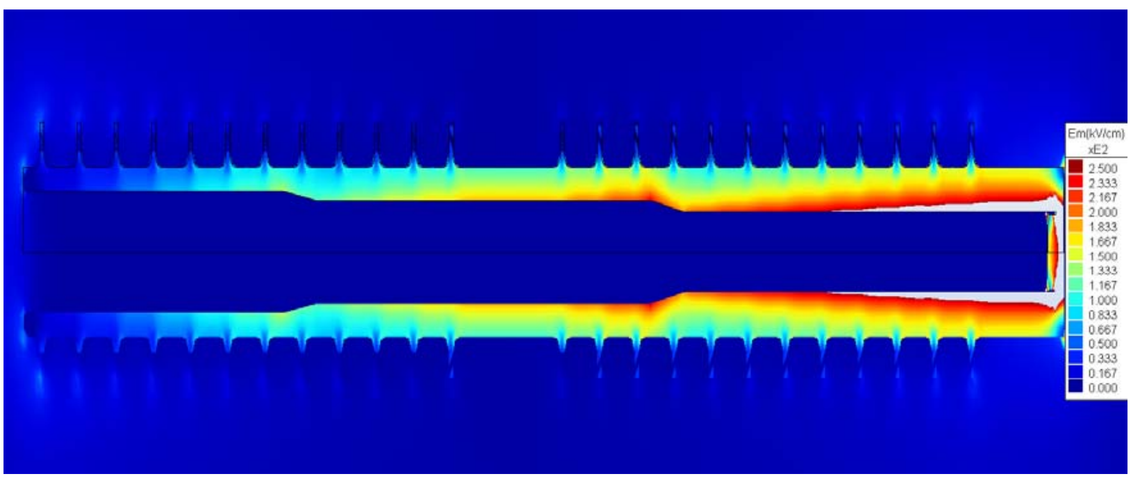


Figure 8. Electric field simulations of the vacuum section of the LTD option were used to design the vacuum transmission line impedance and verify that field stress on all cathode surfaces is below 200 kV/cm.

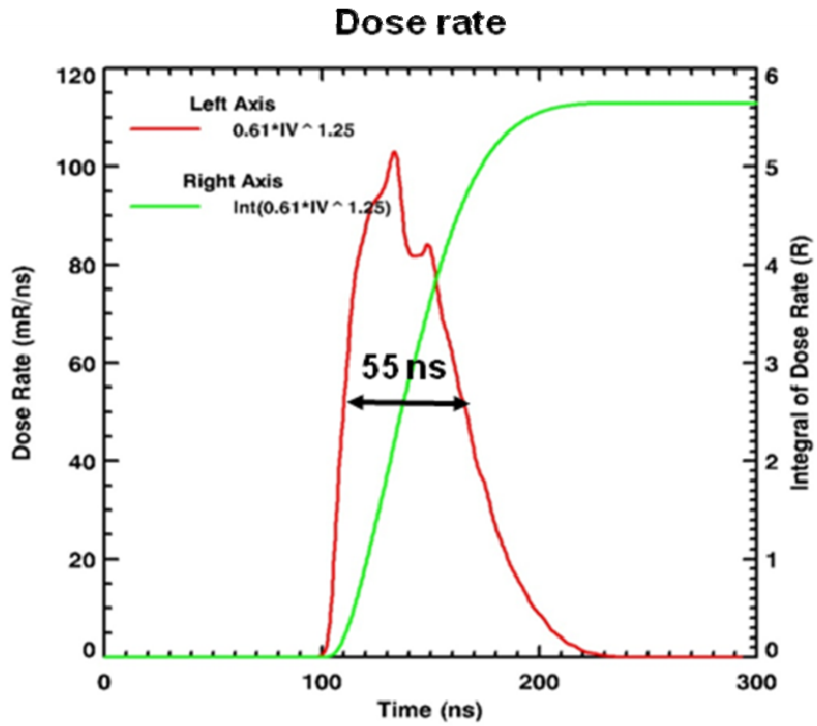


Figure 9. The voltage and current from the circuit simulations were used to predict the x-ray dose production using the radiographers equation $0.61*I*V^{1.25}$ (see ref. 3).

IIIc. Costing and Schedule for the LTD Option

The cost estimate for the LTD option is shown in Table 4. Like the Cygnus option cost estimate, the LTD option cost is estimated based on several factors. The cost of LTD parts is based on recent information gathered by Sandia for the cost of materials purchased during the expansion of the Sandia LTDR from seven cavities to 21 cavities during FY10. Estimates were escalated where appropriate for differences in size of machined hardware. The cost estimates for support systems such as vacuum hardware, control systems, and data acquisition were assumed to be the same as Cygnus.

Manpower estimates for the LTD are slightly higher than the estimates for Cygnus. The LTD design would use the drawings generated for the expansion of the Sandia LTDR, but would require significant update and modification for this new application. The modifications would require a larger effort than the modifications to the Cygnus design. Procurement estimates are also increased somewhat due to lead time for manufacturing large numbers of each component. The assembly time of the LTD is increased because LTD assembly will require assembling each cavity and performing high voltage test of each cavity to verify all capacitors and switches are functioning properly. The total predicted cost of the LTD is about 45% higher than the Cygnus option. However, the Cygnus cost estimate assumes that some of the most expensive parts are available at no cost. As with the Cygnus cost estimate, Area C facility modifications would need to be estimated by LANL personnel and are not included.

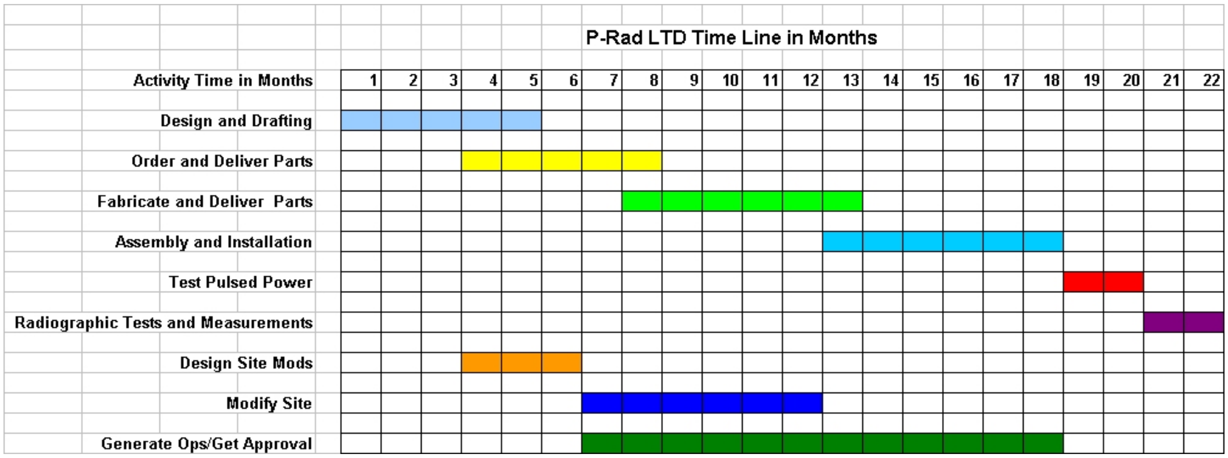
Again procurement loading of 14% is assumed. Total cost with 15% contingency is ~ $5.2M.

Table 5 shows an estimated timeline for design modifications, procurement, and testing of the LTD option. The LTD option would require about seven months longer for this process. As mentioned before, the LTD design will require a few months of design and drafting to modify and prepare the drawings, a step not required for the Cygnus option. It is also assumed that the procurement and manufacturing will require more time than the Cygnus option. An artists rendition of the LTD accelerator is shown in Figure 10.

Table 4. LTD Option Cost Estimate

Machine sub ass'ys	Cost (k$)	
Cavity Housings	1027	Based on NSTech machining cost for LTDR expansion
Cavity Internal Parts	1032	Includes capacitors, switches, cores, connectors, etc
Charging & Triggering	118	
Stands	75	Based on NSTech machining cost for LTDR expansion
Oil Storage System	40	Secondary containment for oil must be included in site modifications and prep
VITL & Diode	150	
Control System	150	
DAS	100	~40 channels of digitizers
Diagnostics	35	Monitors and integrators
Gas System	10	
Oil System	25	
Vacuum System	100	4 8" cryos and 4 mechanical pumps used on each U1a Cygnus + 4 gate valves
Core Reset	15	
Sub Total (k$)	**2877**	(No loading applied for procurement)
Procurement Loading	403	Assumes 14% Loading
15% contingency	492	
Total (k$)	**3772**	
FTE's		
Drawing Prep	0.60	2 Person @ ~3/4 time each - 4.5 mons
Procurement	0.20	1 Person @ ~1/2 time - 5 mons
QC	0.25	1 Person @ ~1/2 time - 6 mons
Assembly	3.00	Machine ass'y, DAS, Command & Control (6 Persons - 6 mons)
Testing	1.35	4 Persons - 4 mons
Total (FTE's)	**5.40**	
Total Labor Cost ($k)	**1485**	$275k per FTE Assumed (PP Engineer and Techs)
Total Machine Cost ($k)	**5257**	LANL costs for Site Mod design and Mods not included

Table 5. Estimated schedule for design and deployment of the LTD option



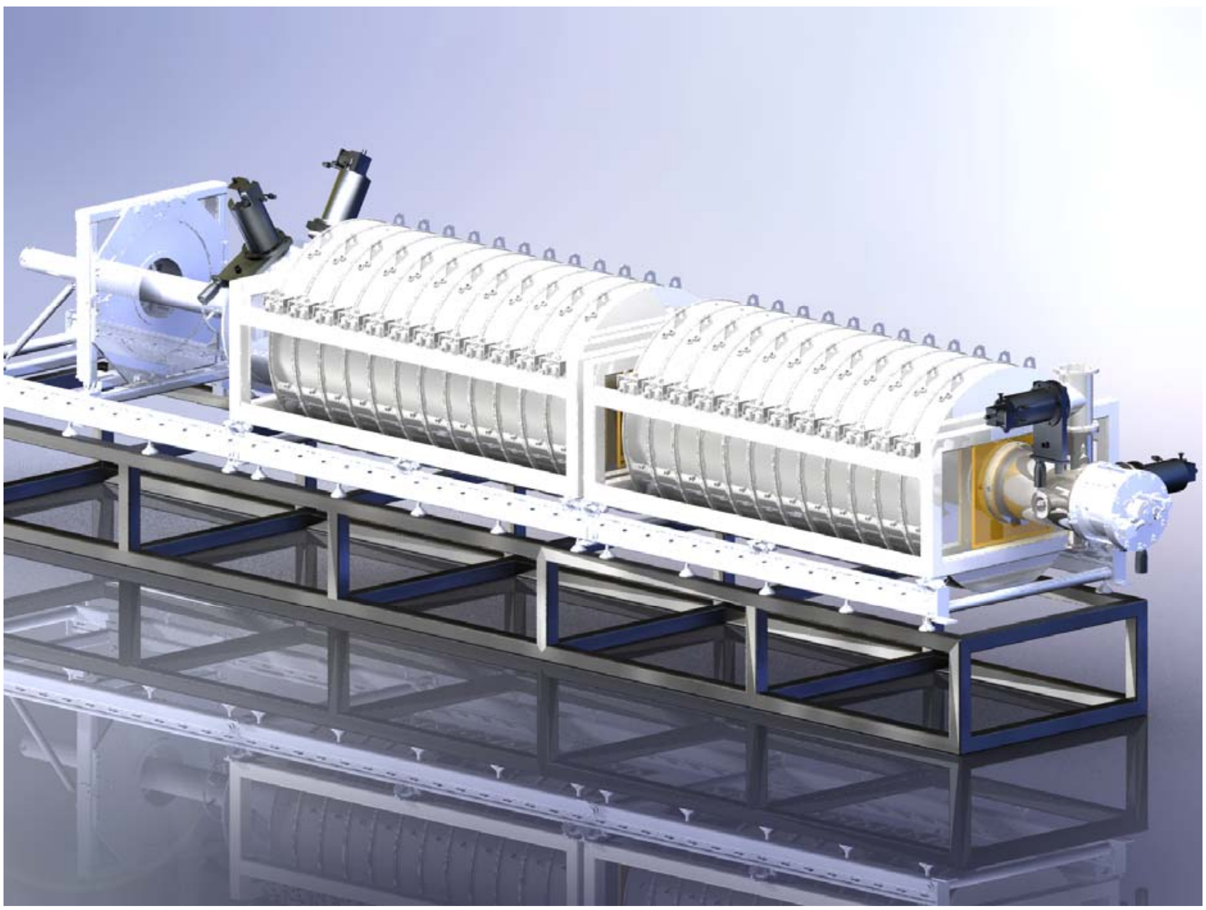


Figure 10. Artist rendition of the LTD accelerator for pRad

IV. Conclusions

Two option studies for the deployment of Cygnus-like x-ray radiography capability at pRad have been presented, A Cygnus replica can be modified to exist within a relevant footprint with minor changes to the existing architecture. The estimated cost is $3.7 M with a manufacture and deployment time of 15 months. An LTD based option design is also feasible at an estimated cost of $5.2M with an engineering design, manufacture and deployment time of 22 months. All things being equal, we consider the Cygnus replica the lowest risk option, however the LTD option will allow for the opportunity of pushing new technology with potentially more favorable output.

References

[1] D. Weidenheimer, P. Corcoran, R. Altes, J. Douglas, H Nishimoto, I. Smith, J. Gustwiller, J. E. Maenchen, P. Menge, R. Carlson, R. D. Fulton, G. Cooperstein, D. Droemer, and E. Hunt, “Design of a driver for the Cygnus X-ray source”, in Proc. 13th IEEE Int. Pulsed Power Conf., Jun 2001, pp 591-595.

[2] V. Carboni, P. Corcoran, J. Douglas, I. Smith, D. Johnson, R. White, B. Altes, R. Stevens, H. Nishimoto, R. Carlson, J. Smith, P. Ortega, J. Chavez, J. Maenchen, E. Ormond, D. Nelson, D. Henderson, T. Helvin, V. Mitton, and B. Anderson, “Pulsed power performance of the Cygnus 1 and 2 radiographic sources,” in Proc. 14th IEEE Int. Pulsed Power Conf., Jun 2003, pp. 905-908.

[3] D. V. Rose, D. R. Welch, B. V. Oliver, R. E. Clark, D. L. Johnson, J. E. Maenchen, P. R. Menge, C. L. Olson, and D. C. Rovang, “Coupled particle-in-cell and Monte Carlo transport modeling of intense radiographic sources”, J. Appl. Phys., vol. 91, no. 5, pp. 3328-3335, 2002.

[4] J. Smith, D. Nelson, E. Ormond, S. Cordova, I. Molina, G. Corrow, M. Hansen, D. Henderson, S. Lutz, and C. Mitton, “Cygnus performance in subcritical experiments,” in Proc. 16th IEEE Int. Pulsed Power Conf., Jun 2007, pp. 1089-1094.

[5] B. V. Oliver, M. Berninger, G. Cooperstein, S. Cordova, D. Crain, D. Droemer, T. Haines, D. Hinshelwood, N. King, S. Lutz, C. L. Miller, I. Molina, D. Mosher, D. Nelson, E. Ormond, S. Portillo, J. Smith, T. Webb, D. R. Welch, W. Wood, and D. Ziska, “Characterization of the Rod-pinch diode x-ray source on Cygnus,” in Proc. 17th IEEE Int. Pulsed Power Conf., Jun 2009, pp. 11-16.

[6] D. V. Rose, D. R. Welch, B. V. Oliver, J. J. Leckbee, J. E. Maenchen, D. L. Johnson, Alexandre A. Kim, Boris M. Kovalchuk, and Vadim A. Sinebryukhov, “Numerical analysis of a pulsed compact LTD system for electron beam-driven radiography,” IEEE Trans. Plasma Sci., vol. 34, pp 1879-1887, 2006.

[7] J. Leckbee, S. Cordova, B. Oliver, D. L. Johnson, M. Toury, R. Rosol, and B. Bui, “Testing of a 1-MV linear transformer driver (LTD) for radiographic applications,” in Proc. 17th IEEE Int. Pulsed Power Conf., Jun 2009, pp. 156-160.

[8] I. D. Smith, “Induction voltage adders and the induction accelerator family,” Phys. Rev. Special Topics – Accel. And Beams, vol. 7, no. 064801, 2004.

[9] M. G. Mazarakis, W. E. Fowler, A. A. Kim, V. A. Sinebryukhov, S. T. Rogowski, R. A. Sharpe, D. H. McDaniel, C. L. Olson, J. L. Porter, K. W. Struve, W. A. Stygar, and J. R. Woodworth, “Higher current, 0.5-MA, fast, 100-ns, linear transformer driver experiments,” Phys. Rev. Special Topics – Accel. and Beams, vol. 12, no. 050401, 2009.

[10] M. G. Mazarakis, W. E. Fowler, K. R. LeChien, F. W. Long, M. K. Matzen, D. H. McDaniel, R. G. McKee, C. L. Olson, J. L. Porter, S. T. Rogowski, K. W. Struve, W. A. Stygar, J. R. Woodworth, A. A. Kim, V. A. Sinebryukhov, R. M. Gilgenbach, M. R. Gomez, D. M, French, Y. Y. Lau, J. C. Zier, D. M. VanDevalde, R. A. Sharpe, and K. Ward, “High-current linear transformer driver development at Sandia National Laboratories,” IEEE Trans. Plasma Sci. vol. 38, no. 4, pp. 704-713, 2010.

[11] M. R. Gomez, R. M. Gilgenbach, Y. Y. Lau, W. Tang, J. C. Zier, M. G. Mazarakis, M. E. Cuneo, T. A. Mehlhorn, and W. A. Stygar, “Design of a MITL for a 1 MA LTD driving a wire array Z-pinch load,” in Proc. 16th IEEE Int. Pulsed Power Conf., Jun 2007, pp. 152-155.

Distribution:

5	Cris W. Barnes P-DO MS-H847 Los Alamos National Laboratory Los Alamos, NM 87545		
2	Voss Scientific Attn: D. R. Welch and D. V. Rose 418 Washington SE Albuquerque, NM 87108		
1	Dept. of Electrical & Computer Engineering Attn: Edl Schamiloglu MSC01 1100 1 University of New Mexico Albuquerque, NM 87131-001		
1	MS 1181	L. X. Schneider	1650
3	MS 1178	P. A. Jones	1655
1	MS 1195	S. R. Cordova	1656
1	MS 1195	M. D. Crain	016561
1	MS 1195	D. W. Droemer	016561
1	MS 1195	D. L. Johnson	1656
1	MS 1195	M. D. Johnston	1656
3	MS 1195	J. J. Leckbee	1656
1	MS 1195	I. Molina	1656
3	MS 1195	B. V. Oliver	1656
1	MS 1195	T. J. Webb	1656
1	MS0899	Technical Library	9536 (electronic copy)

Sandia National Laboratories