Lawrence Livermore Laboratory

RTNS-II TECHNICAL DEVELOPMENT PLAN

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MASTER

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RTNS-II SOURCE

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ABSTRACT

The goal of the RTNS-II (Rotating Target Neutron Source) project at the Lawrence Livermore Laboratory is to provide a dedicated facility for investigation of 14-MeV neutron damage processes in materials to be used in controlled thermonuclear fusion reactors. LLL will operate the RTNS-II facility for ERDA as a national materials damage center. This Technical Development Plan describes the need for 14-MeV neutron sources, the physics and engineering design basis for the beam-target sources to be built for the RTNS-II facility, and the research support equipment included in the facility. Fiscal and manpower schedules for construction and operation of the facility are included. Finally, the accelerator and target research program directed at raising the strength of these sources from the design goal of 4×10^{13} n/s to higher levels is described.

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INTRODUCTION

PROPOSED LIVERMORE NEUTRON SOURCE FACILITY

This report describes the development and construction program to build intense sources of T(d,n) neutrons at the Lawrence Livermore Laboratory. This neutron source facility will be referred to as the Rotating Target Neutron Source II (RTNS-II). The 14-MeV neutron source now in operation at Livermore (RTNS-I) is described in Appendix A. The new facility will be a national facility operated by LLL under the auspices of the Division of Controlled Thermonuclear Research of the United States Energy Research and Development Administration. Development of the data base on 14-MeV neutron-induced radiation damage processes required for fusion reactor construction will be the research goal of the facility. Access to the facility by all qualified U.S. and non-U.S. experimenters in the materials effects field will be provided through a user's group structure.

Artists' conceptions of two views of the RTNS-II facility are shown in Figs. 1 and 2. The facility will contain two neutron sources with source strengths 4×10^{13} n/s each. A small sample 14-MeV neutron flux of $\sim 1.4 \times 10^{13}$ n/cm²s will be available from each source. Experiments requiring simultaneous neutron, ion, and photon irradiations to investigate synergistic effects will be possible. Complete facilities for handling, repair, and storage of radioactive equipment will be provided. Control and data logging services for in-situ experiments will be provided, as well as office and laboratory space for users.

The cost of the building, neutron sources, and equipment required to support the experimental program is \$5M (FY'76). Time required to construct the facility and begin initial operation is approximately two years.

14 MEV ROTATING TARGET NEUTRON FACILITY
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ARCHITECTS ENGINEERS PLANNERS

01-2-76

Figure 1 - Artist's conception of RTNS-II Facility. View toward control and support area.

Figure 2 - View of RTNS-II Facility toward irradiation area.

Detailed technical discussions of the neutron sources and building subsystems are given in the following sections of this report. Also given are manpower, fiscal, and task schedules for the construction and development plan. The effect of delay in the authorization of this project is discussed in Appendix B. An update to Title I status is given in Appendix C.

NEED FOR INTENSE 14-MeV NEUTRON SOURCES

Conceptual designs of fusion power reactors indicate that the first wall of the vessel containing the plasma will be exposed to a 14-MeV flux of $0.5 - 1.0 \times 10^{14}$ n/cm²s. Additionally, there will be a return flux of backscattered neutrons across the wall that is perhaps eight times as large. It is assumed that the lifetime of the first wall will be limited by neutron-induced damage processes. This lifetime is a crucial factor in determining scientific, engineering, and economic feasibility of fusion power. Periodic replacement of the wall involves not only shutting down the reactor for some time, but also handling large quantities of highly activated material. One conceptual Tokamak reactor design forecasts biennial change of a wall having a mass of 10^5 kg with a residual activity of 10^9 Ci. In addition to radiation damage to the first wall, other reactor components such as superconducting magnets, structural members, and tritium and heat removal systems must have satisfactory performance and lifetime at relatively high 14-MeV neutron fluxes.

Although much has been learned about neutron induced damage processes in the fission power program, radiation damage produced by 14-MeV neutrons from T + D fusion has not been studied sufficiently to allow reliable prediction of material behavior in fusion reactors. Two differences between the effects of 14-MeV neutrons and fission neutrons of average energy of 1 MeV prevent confident predictions from being made based on fission reactor

experience. The energy transferred by 14-MeV neutrons colliding with atoms in materials is much higher, producing cascades which result in different recombination probabilities for interstitial atoms and vacancies in lattices. Also, the higher neutron energy results in much higher transmutation cross sections, producing more hydrogen, helium, and isotopes different from the host material.

For purposes of the CTR program, radiation damage processes are divided into two categories: surface and bulk effects. Surface effects entail change in macroscopic surface properties of materials due to neutron-induced microscopic processes such as sputtering, blistering, and erosion. Examples relevant to reactor design are contamination of the plasma by impurity atoms sputtered from the first wall or released from it, failure of insulating components due to surface modification, and kinematic recoil of activated species into cooling lines.

Bulk effects include modification of properties such as strength, ductility, or hardness due to hydrogen or helium produced in materials, or aggregation of voids or interstitials produced in ordered lattices. Relevant examples of these effects are loss of strength or embrittlement of first wall or structural materials, distortion of components by swelling or failure of superconductors from cumulative damage to the lattice structure.

Because of the effect of these damage processes upon the lifetime and performance of reactor subsystems, adequate information about them is required for the choice of reactor materials and design of these subsystems. For the near term program to obtain materials information, construction of accelerator-based neutron sources is preferred to construction of confinement devices capable of producing reactor flux levels because the accelerator-based sources are less expensive and can be built in less time.

TIME SCHEDULE FOR MATERIALS DECISIONS

Construction and operation of intense neutron sources must be related to the time schedule upon which materials decisions must be made for the major milestones of the CTR program. These milestones are operation of the Engineering Power Reactor I (EPR-I) in 1985, operation of EPR-II in 1990, and operation of a Demonstration Power Reactor in 1998. EPR-I will be the first attempt to demonstrate the engineering feasibility of fusion power under the conditions anticipated in power reactors. Materials decisions for the EPR-I will be made by 1980, although some review of these decisions will be possible during the detailed engineering design phase. RTNS-II will be the only intense neutron source in operation before 1980, allowing two years operation for input to these decisions.

The experimental program envisioned for the facility will combine fundamental study of damage processes with verification testing of materials selected for EPR-I. Surface damage studies will investigate synergistic effects of combined neutron, ion, and photon bombardment of surfaces. The Laboratory will conduct an ongoing source development program with the goal of increasing source strength to 1×10^{14} n/s or higher by 1980. Construction of more neutron sources of the RTNS-II type will depend upon the viability of alternative neutron source concepts. These sources should contribute to materials damage investigations up to the availability of the Fusion Engineering Research Facility (FERF) in the mid-to-late 1980s.

PROJECT SUMMARY

Construction and operation of neutron sources at source strengths a factor of ten higher than that of RTNS-I, currently the most intense DC 14-MeV source available, will require the solution of many interesting problems. Accelerator and target technology must be further developed and considerable problems of radiation containment and materials handling solved. A brief description of the proposed facility, neutron sources, and ancillary equipment is given in this section. Detailed discussion of technical difficulties anticipated, proposed solutions, and schedules is deferred to subsequent sections.

PHYSICAL PLANT

A floor plan of the proposed facility is given in Fig. 3. There are two distinct areas. The control, support, and office area is a general access, radioactively cold area for control, experimental setup, and accelerator development work. Both laboratory and office space are available for facility users. The portion of the structure containing accelerators, target cells, Van de Graaff, hot work area, and hot cell is designed for radiation containment and will be a controlled access area for safety purposes.

Overall floor area of the facility is approximately 1600 m^2 , with 500 m^2 inside the heavy concrete walls of the neutron shielding and 1000 m^2 of standard light frame construction. Estimated cost of the building if bid for construction in January 1976 is \$2300K.

NEUTRON SOURCES

The two neutron sources will be based upon the RTNS-I beam-target

Figure 3 - Floor plan of RTNS-II Facility produced by conceptual design study of building.

source now in operation at Livermore. Near and long term source strength, flux, and other parameters are listed in Table 1. The accelerators will be air insulated, producing 150 mA of 400 keV D^+ beam which will be focused to a 1 cm diameter spot on a rotating tritium in titanium target. Power supplies, vacuum equipment, and beam transport systems are designed to allow upgrading to 400 mA beam current to produce 1×10^{14} n/s. Shielding will be designed for that source strength.

Lifetime of the tritium target has been predicted by computer modeling of the target system now in use on RTNS-I. A 100 hour useful target life is expected. Although the present tritium-titanium target is adequate for operation at 4×10^{13} n/s if its speed can be increased tenfold new target materials will be required to produce a target capable of 1×10^{14} n/s operation with flux above 2×10^{13} n/cm²s.

A plot of the flux field near the target for 4×10^{13} n/s operation is shown in Fig. 4.

Cost of the neutron sources was estimated for FY '76 budgetary purposes as \$2100K.

SYNERGISTIC EQUIPMENT

Because the early concerns of the experimental program will center on surface effects, the ability to simulate more than one component of the radiation field to which the first wall is exposed is important. The facility will include a 3.75 MV Van de Graaff generator capable of producing 100 μ A ion beams of H^+ , D^+ , $^3He^+$, and $^4He^+$ as well as a variety of low energy ion sources and a 10 keV x-ray source. Development of multi-component irradiation experiments will be an interactive process between the users and the operating staff of the facility.

Figure 4 - Flux plot near source.
Flux is plotted as a
fraction of source
strength

ADVANCED SOURCE DEVELOPMENT

Livermore will conduct a program of accelerator and target development with the neutron sources of the RTNS-II facility to upgrade both the source strength and target performance. There are two justifications for this effort. Any significant increase in source strength will accelerate the process of accumulating damage information and thus provide a better data base for EPR-I materials decisions in the near term. Second, the long term value of these sources compared to other neutron source concepts can be better determined when the limits of the rotating target technology are clearly defined.

TASK, MANPOWER, AND COST

For each major subsection of the project, detailed quarterly schedules have been prepared outlining the subtasks, manpower, and costs involved in completion of the relevant subsection. Distinctions have been made between construction of the facility and ongoing development work essential for design of facility components or subsequent upgrading of source performance. While these schedules are given in terms of months after project authorization, they were made under the assumption of project authorization on 1 October 1975. The effects upon both schedules and costs of slippage of the date of project authorization are discussed in Appendix B.

It should be realized that these schedules are estimates of the time required. While checkpoints for design evaluation are provided by construction and operation of prototype devices, the risk of schedule slippage due to failure of items and subsequent redesign and reconstruction must be accepted. Similar uncertainty in costs exists. Although careful estimates

have been made, the actual costs of successful construction of new hardware cannot always be predicted with certainty. The review process for this project will update task and cost schedules as the work is in progress.

TECHNICAL PLAN

PHYSICAL PLANT

The lead time required for design and construction of the building to house the neutron sources is such that the physical plant is the first item on the critical path to project completion. To determine crucial design problems and possible cost-benefit tradeoffs, an outside architectural-engineering firm performed a conceptual design study of the facility. Simpson, Stratta and Associates of San Francisco were retained to take LLL's design criteria for the facility and to determine the most cost effective design meeting research and operating requirements and starting with several alternate layouts of the building. This two month study was iterative in nature, requiring careful re-examination of source utility, space, and shielding requirements by laboratory staff, and occasional closure of options held open till this point. The building layout given in this section differs from earlier versions in that it reflects the results of such decisions. With minor changes, the facility built will be the one described in this section.

Irradiation Area

The heavily shielded portion of the building containing the accelerator rooms and target pits is the irradiation area proper. This definition is extended somewhat to include all areas to which access is limited because of prompt or residual radiation or reasons of industrial safety. The power supply room, Van de Graaff room, and work and storage areas for hot equipment thus are grouped together with the accelerator and target rooms.

The major design problems for this portion of the facility are to provide containment of both the prompt and residual radiation from the neutron

sources and to provide the support systems required for handling, modifying, and repairing activated experimental assemblies and neutron producing targets. Another consideration is to provide work and storage space for equipment which is cooling off after irradiation.

Prompt radiation confinement is provided by 2.5 m thick concrete walls and roofs on the target cells. This thickness of concrete reduces the neutron dose outside the cells to 0.2 mrem/hr for source operation at the 10^{14} n/s level. While one source is in operation, access to the other portions of the irradiation area will be possible. Radiation resulting from neutron activation of air and dust in the target cells will be handled by passing the air exhausted from the cells through HEPA filters and a delaying loop before exhausting it through a stack. Radiation monitors on the stack will insure that the level of activity released is safe. The radiation hazard caused by outgassing of tritium from the targets into the vacuum systems of the sources is discussed under the subsection on target systems.

Residual activation poses several of the most difficult problems in facility design. Scaling data from the present source suggests that the concrete walls of the target pits may have activity as high as 1 rem/hr 10 hours after source shutdown. A study of low activation liners (gypsum, polyethylene, etc.) revealed that they were not cost effective or posed unacceptable industrial hazards. Design of source components and experimental equipment must be such that no routine access to the target pits is required.

Activated equipment and target systems will be removed from the target pits by a remote-controlled prime mover capable of moving 2700 kg. Umbilical systems for utilities and control of this equipment will couple automatically in the target pits, hot cell, and hot work area. The hot cell will contain

a turntable and manipulators to allow work on all portions of the activated assembly. Hot equipment can also be stored in this area with proximity shielding until the radiation level has dropped sufficiently to allow return to the support area.

The Van de Graaff room will provide space and shielding for a 4 MV machine to be added for synergistic effect studies. The ion beam from this machine will be transported through the shield wall into one source room for these experiments. There will also be some provision for carrying out separate experiments with the Van de Graaff, i.e. pre-irradiation loading of samples with hydrogen or helium or using nuclear analytic techniques to examine samples.

Control and Support Area

General access will be allowed to the portion of the facility where radiation or industrial hazards are negligible or easily controlled. This portion of the facility will be standard frame construction used for office and light laboratory space. No particular design difficulties or technical constraints are imposed in this area.

In addition to the control room and accelerator laboratory for the neutron sources, a setup laboratory and counting room will be provided for outside users. The former will contain a duplicate target assembly for initial experiment alignment and checkout, while the latter will be available for post-irradiation dosimetry measurements. Office and conference room space are provided for off-site users. The electrical and mechanical shops of the facility will support the users' experimental programs as well as the neutron sources. More sophisticated shop and support facilities are available elsewhere at the Laboratory.

Task, Manpower, and Cost Schedules

Initiation of the contracting sequence for design and construction of a line item project depends upon passage of the federal budget. The task schedules for completion of subsystems of the neutron source facility reflect this dependence: all milestones are relative to the authorization of the project. The schedules assume that the time required to accomplish tasks is independent of the date of authorization. Effects upon this assumption of the actual date of authorization, seasonal weather, and inflation are discussed in Appendix B.

Operation of the RTNS-II facility on schedule depends upon completion of a parallel research and development program in accelerator and target technology. This program provides an opportunity to check design decisions before initial operation of the sources. As these activities are funded by the ERDA operating budget they are not as directly tied to passage of the budget authorization. Schedules for these activities are thus presented on a fiscal year basis and kept separate construction schedules throughout this report.

Major steps in the construction process for the RTNS-II building are shown in Table 2. Selection of the architectural-engineering firm and a conceptual design study for the building were done in early FY '76 on operating funds. Title I design cannot be begun until the project is authorized. Design criteria for the Title I design were fixed by the conceptual design study. Title I fixes all major building details and produces a firm cost estimate. Title II produces the detailed engineering drawings required for actual construction.

Construction of the building will be via the construction-management

Table 2 Building Construction Sequence

Major Subtasks	Quarters after Authorization							
	1	2	3	4	5	6	7	8
Title I Design	XXX							
Title II Design								
Phase I	XX	XX						
Phase II		XXXXX	X					
Construction								
Bid Award - Phase I		XXX	X					
Construction - Phase I			XXXXX	XXXXX				
Bid Award - Phase II			XXXXX	XX				
Construction - Phase II				XXXXX	XXXXX	XXXXX		
Activation							XX	
Source Installation							XX	XXXXX

technique with LLL letting a variety of contracts to several contractors. While this method introduces more cost uncertainty than a conventional lump-sum contract with a single contractor, it offers substantial savings in time which may actually result in lower costs. The final decision upon the contracting procedure to be used will be deferred until actual project authorization.

Actual construction time for the building is estimated to be 9-10 months. This is followed by a 6-8 week activation period. After this time the installation of the neutron sources will begin. Initial operation of the first source is scheduled to commence 24 months after project authorization.

The cost estimate for the building is given in Table 3. This estimate is the result of the conceptual design study and gives the cost of the building shown in Fig. 3 if bid in May 1976. Differences between this cost and that of the Schedule 44 estimate are the result of programmatic changes in size of rooms, particularly the accelerator rooms, and more detailed estimates of building costs. Paving, landscape, and utility connection costs were estimated for the actual building site. Engineering costs (including design, supervision, and inspection) are included at the average level for comparable construction at the Laboratory. The \$300K entry for standard equipment includes items readily available from commercial suppliers which may be installed with little or no engineering or systems integration effort. This item is reduced from \$440K in the Schedule 44 submittal due to inclusion of cranes and hot cell shielding in the building estimate. Escalation of the calendar year 1975 price is calculated at 0.75% per month. A contingency of 15% on equipment and construction and 10% on engineering is included to cover unanticipated

costs.

A commitment and cost schedule for construction of the building is given in Table 4. Overall management of the project is included under building construction. The manpower forecast for management, engineering and construction effort are given in Fig. 5. The assumptions made in preparing these projections are that labor represents 65% of the construction cost of the heavily shielded area and 60% of the cost of the support area. Engineering effort is divided into 30% for Title I, 65% for Title II, and 5% for Title III (contractor supervision during construction).

Table 3 Building Cost Estimate (\$K)

1. Site work		35
2. Landscaping		22
3. Structures		
Support Building	180	
Machine and Target Rooms	510	
Hot Cell	21	
Tritium Storage Vaults	14	
Van de Graaff Cell	<u>89</u>	
		814
4. Mechanical		
Heating, Ventillation, & Air Conditioning	118	
Piping Systems	91	
Plumbing	34	
Fire Protection	17	
Diagnostic Penetrations	<u>6</u>	
		266
5. Electrical		195
6. Shielding Doors and Windows		
Target Rooms	150	
Machine Rooms	116	
Hot Cell Door	40	
Hot Cell Window	22	
Van de Graaff Door	<u>40</u>	
		373
7. Cranes		<u>40</u>
		1745
Contractor Field Overhead (6%)		<u>105</u>
		1850
Contractor Office Overhead and Profit (5%)		<u>100</u>
Cost if bid during Calendar 1975		1950
Engineering (14%)		<u>280</u>
		2230
Standard Equipment		<u>300</u>
		2530
Escalation to May 1976 (3/4% per month)		<u>95</u>
		2625
Contingency (15% on Construction and Equipment, 10% on Engineering)		<u>325</u>
		2950

Table 4 RTNS-II Building Commitment/Cost Schedule (K\$)

	1	2	3	4	5	6	7	8	TOTAL
1. Engineering	192 124	12 71	12 13	9 10	10 11	14 15	17 19	14 12	280 280
Title I	54 54								54 54
Title II	117 58								117 117
Title III	9 9								9 9
Project Management	12 12	12 12	12 12	9 9	10 10	14 14	17 17	14 14	100 100
2. Construction			550 185	1385 642		130 554	188 188	47 177	2300 2300
Phase I			500 175						500 500
Phase II				1385 277					1385 1385
Activation			10 10				58 58	47 47	115 115
Equipment			40 40			130 130	130 130		300 300
3. Contingency	20 10	5 10	80 50	200 80	5 100	20 20	30 50	10 50	370 370
TOTAL	212 134	17 81	642 248	1594 732	15 665	164 584	235 257	71 244	2950 2950

Figure 5 - Quarterly manpower forecast for building design and construction.

ACCELERATORS

To meet the source strength goal of 4×10^{13} n/s, an accelerator capable of producing a DC beam of 150 mA of 400 keV atomic deuterons (D^+) must be built. Most accelerators which operate with comparable current and energy serve as injectors for linacs or synchrotrons which are low duty factor machines; typically for 2% of the time or less. The injectors are thus able to operate in a pulsed mode as well to avoid the power dissipation problems of DC operation. The RTNS-II accelerators must overcome those problems.

To meet the flux goal of 1×10^{13} n/cm²s or greater, the beam transport system must take the D^+ beam from the accelerator and focus it to a 1 cm diameter spot on the target. The design of the accelerator thus reflects primarily the characteristics of the ion source used. One must meet the power, cooling, and pumping speed requirements of the source while insuring that the source emittance is sufficiently good that the transport system can produce the spot size desired on the target.

Other parameters of the accelerator are important if the neutron source is to be used for carefully characterized irradiation experiments. The position and area of the beam spot must be stable or controllable within known limits for reasonable variations of accelerating voltage or beam current. Diagnostic equipment capable of providing real time flux and source strength information is needed. Finally, the accelerator must be sufficiently reliable that users can expect a neutron source availability of 85-95% of scheduled time.

The accelerator design presented in this section is a conservative approach to meeting these requirements. An attempt has been made to

decouple the components of the accelerator to the maximum extent so that failure of one component does not require redesign of the entire system. Similarly, the degree of flexibility thus produced allows advantage to be taken of unexpected hardware developments.

Ion Source

As explained above, most of the 50-100 mA ion sources used in high energy physics accelerators operate in pulsed mode. The CTR program, has produced multi-ampere sources capable of operation for a few seconds. However, the MATS-III source (multiple aperture test source) at Livermore has produced 1.5 A of beam in DC operation with a lifetime in excess of 1000 hours. The D^+ fraction of the source output is 65-75%.

Preliminary accelerator and beam transport studies suggested that an ion source producing a total current of 300 mA (nominally 70% D^+) with a normalized emittance of 2 mm-mrad was required. As these requirements can easily be met by a scaled down version of MATS-III it has been chosen as the ion source for the accelerator design.

The features of the MATS-III source are shown in Fig. 6. The magnetically confined plasma source is of the reflex arc type. An oxide coated cathode with a lifetime of several hundred hours is used. The multiple extraction electrode set (accel-decel) is water cooled and can operate for several months before replacement is required. Although use of multiple apertures results in a larger emittance than a single aperture duoplasmatron, the shorter extraction gap and resulting lower extraction voltage required are attractive design features.

The ion beam will be extracted from the source at 20 kV, bent through 90° by a double focusing magnet to remove the D_2^+ and D_3^+ components which we do not wish to accelerate, and then focused again by a solenoid lens

Figure 6 - Assembly drawing of LLL MATS-III ion source.

to match the acceptance of the high voltage acceleration tube. The layout of these components in the high voltage terminal of the accelerator is shown in Fig. 7. A significant advantage of magnetic selection of the D^+ component is that the acceleration tube and transport system may be optimized for that species only with no concern about heating or radiation due to the D_2^+ or D_3^+ striking the vacuum pipe.

Use of the MATS-III source insures that this portion of the accelerator can meet the upgrade requirement of 400 mA of D^+ . The ion source has already demonstrated the capability to produce more than sufficient beam to meet that goal.

High Voltage Power Supply

The power to accelerate the D^+ beam to the desired energy of 400 keV is supplied by a high voltage power supply capable of producing at least 300 mA of current at 400 kV. The design of the supply must be such that it can be upgraded to 500 mA at some future date.

Several basic design requirements must be met by the supply. Most components should be air insulated for ease of service. Regulation and ripple of the output voltage must be sufficiently good that the beam spot is stable on target. However, the stored energy in the supply should be low to minimize the potential damage to accelerator components in the event of a spark-down. Also, the supply should have a crowbar capability so its output can be clamped to ground quickly if a discharge is sensed in the acceleration tube.

The only power supply capable of meeting these requirements is the Cockcroft-Walton or voltage multiplier supply. Two sources have been identified which can meet the design requirements. The Laboratory's

Figure 7 - Layout of major optical components of accelerator.

ION SOURCE AND ACCELERATION SECTION

Electrical Engineering group has designed a supply which is driven at 10 kHz by a Colpitts circuit oscillator. The high frequency design minimizes stored energy while meeting the fast crowbar requirement. The regulation and ripple are 0.1%, better than required by our initial beam transport design.

Alternatively, a motor-generator driven Cockcroft-Walton supply from Emile Haefely and Co., Ltd.* will meet our requirements. The 2 kHz output of the motor-generator is stepped up to 150 kV by a high voltage transformer and then applied to the rectifier stack. Stored energy problems are minimized by decoupling the supply from the high voltage terminal with a damping resistor. Fast crowbar capability is provided by a sparkgap switch which can short the accelerator terminal to ground in less than one microsecond. Regulation and ripple are adequate to meet our needs. Upgrading to 500 mA output is done by adding another high voltage transformer, rectifier stack, and smoothing capacitor. Cost of the supply and upgrade options are well established and are within budgetary limits.

Acceleration Tube

After the ion source and associated optical components (mass separation magnet and solenoid lens) have produced a low energy D^+ beam of the proper current and emittance, the beam must then be accelerated to its final energy.

*Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U. S. Energy Research and Development Administration to the exclusion of others that may be suitable.

The electrode structure across which the high potential is held is the acceleration tube. Several design problems must be solved if the tube is to operate properly. Unfortunately, the solutions of these problems are not always compatible.

The high electric fields (10-40 kV/cm) within the acceleration tube will remove all electrons from the region near the beam. In the tube the beam experiences the full effect of its own space charge and will expand rapidly. The beam tube must operate at as high a gradient as possible to minimize this blow up. Commercially available acceleration tubes for electrostatic generators operate at gradients up to 20 kV/cm quite reliably. Although this gradient can be supported in vacuum, it cannot be easily sustained in air at one atmosphere. The beam tube must either be of a re-entrant design to reduce the gradient on the outside or be surrounded with gas such as SF_6 at one or two atmospheres to increase the breakdown strength on the outside of the tube.

Acceleration tubes can be built which balance the space charge force on the beam by careful electrode shaping, the so-called "Pierce geometry." However, these Pierce geometry tubes have several disadvantages for the present application. For maximum advantage the ion source must look directly into the acceleration tube. In this geometry it is not possible to separate the D_2^+ and D_3^+ components from the ion source from the D^+ component. One must accelerate both unwanted components to full energy before separation. This causes power dissipation and background radiation problems. The optics of the acceleration tube are not optimized for the D^+ beam but rather for the mixture of beams. Also, the tube is designed for only one current. For proper operation the electrodes must approach

very closely the edge of the beam. Operation at currents other than the design current may be difficult because of radiation and electron multiplication which occur when small amounts of the beam strike these electrodes.

Because of the small electrode openings in a Pierce tube the tube has a relatively low conductance for pumping. The neutral gas load from the ion source at the tube entrance must be pumped through a conical manifold with large pumps. The cantilevered position of the ion source inside the tube makes it difficult to service in position or to remove for maintenance. A great disadvantage is that the source can be let to air only by letting the tube to air as well, ruining the conditioned state of the electrode surfaces.

Given these disadvantages, we have picked an accelerator design which decouples the ion source from the tube. The tube can then be of a simple uniform gradient, large aperture design. As only D^+ will be accelerated through the tube, the optical properties of the tube and the following transport system can be optimized for that ion species alone. The electrode apertures are 10 cm in diameter, providing excellent pumping speed through the tube. To compensate for the variation in space charge force at different beam currents, a solenoid lens is inserted before the tube so the focusing effect of the lens plus tube can be held constant. The divergence of the D^+ beam delivered to the transport system is thus the same over a wide range of beam current.

The tube will be built with ceramic insulators bonded to titanium alloy rings. The electrodes will be coupled to the rings for mechanical support and cooling. Removal of the electrodes for replacement or modification will be possible. LLL has experience with construction of beam

tubes of this type; similar tubes were built for the Astron electron injector.

Beam Transport

Once accelerated to the final energy, the D^+ beam must be transported through the shield wall between the accelerator room and the target vault and then focused to a 1 cm FWHM spot size. In addition to the quadrupole lenses and magnets required to focus and steer the beam, the transport system includes the diagnostic equipment to monitor beam position and the pumping equipment necessary to maintain proper vacuum in the beam line.

The initial design for the beam transport system is such that the only optical elements in the system are quadrupole triplets. All beam pipe in the system has been chosen to have 10 cm aperture. The triplets have outer pole tips 10 cm long and inner pole tips 17.5 cm long. Such lenses are standard items and can produce 3 kG fields at the pole tips with 500 watt power supplies.

A beam envelope calculation for the accelerator plus transport system is shown in Fig. 8. This calculation was run for a 150 mA D^+ beam with input emittance expected for the MATS-III ion source. Field strength in each optical element is shown below the element. The beam spot size produced at the target ($2\sigma = 0.80$ cm, FWHM = 0.94 cm) is that required. Only two of the quadrupole triplets are running at appreciable fractions of their maximum field strength.

The sensitivity of the spot size on target to changes in beam energy was investigated for this system. All lens parameters were held fixed while the voltage on the accelerator was varied. For this system a 1%

Figure 8 - Beam envelope (2σ radius) of 150 mA D^+ beam in transport system.

variation in energy produced only a 5% change in area of the target spot. As the high voltage supply can be regulated to better than 0.5%, this sensitivity is acceptable. No trim magnets are included in this calculation although they would be installed on a working system to correct for slight misalignment of elements.

A major uncertainty in the design of the transport system is the degree of neutralization of the beam's space charge. Experience with high current beams at 10-20 keV indicates that the beam is neutralized to better than 1% in drift spaces when the background pressure is 10^{-5} torr or greater. Measurements with pulsed beams from linac injectors suggest neutralization of the beam due to electron buildup after the beam has been on for 300 μ s. We plan to measure the degree of neutralization of the 20 mA, 400 keV D^+ beam from the ICT accelerator. The final design of the transport system will include elements with sufficient field strength to overcome the degree of residual space charge. Discussion of these measurements is included in the section on development.

The exceptionally high power level of the beam from these accelerators will make it impossible to use conventional diagnostic tools such as rotating wire scanners or quartz viewers. Well cooled tapered apertures which are split to provide directional information will be used to locate the beam. Currents from these apertures will be processed by the monitor computer system to provide the most effective tuning aid for the accelerator operators. Spot size on target will be monitored with a neutron pinhole camera.

Gas loads in the beam transport system will be relatively modest. The contribution to the load from ion source gas will be on the order of 5-10 atm cm³/min. Tritium and deuterium outgassing from the target should total no more than 1-2 atm cm³/min. To maintain the entire system at pressures in the 10⁻⁵ torr range, a delivered pumping speed of only 2000-4000 l/s is needed. Readily available turbomolecular and ion pumps can meet these requirements.

Control and Monitoring

The conceptual design for the neutron source control system has as its main purpose the combination of the advantages of two quite different control systems. One would like to have the simplicity, reliability, and stand alone capability of hardwired, manually operated systems. However, the high speed decision-making capabilities and large data-handling capacity of a computer offer real advantages in the operation of equipment containing many complex subsystems.

The control system for the neutron sources will be based upon manual operation of the sources with a computer running in a supervisory and backup mode for the operators. Controls for all accelerator, target, and radiation interlock systems will be hardwired for manual operation or verification from individual control consoles for each source. The operator will be able to set all operating parameters freely. However, important equipment in critical subsystems (power supplies, ion source, transport system, etc.) will provide analog outputs suitable for conversion to digital signals so the computer can monitor system performance. With a relatively modest computer and interface system hundreds of operating parameters can be checked against predetermined levels at a high rate.

Using an operating system with a stacked interrupt scheme, the computer can respond to excursions of one or more parameters beyond these limits with actions ranging from calling the operator's attention to the problem to shutting down major portions of the neutron source. This graded response capability cannot easily be provided by a hardwired interlock and protective system alone.

During debugging or maintenance operations, one frequently needs to change or override protective limits. Having both a hardwired and a computer based system allows this to be done easily, with considerable flexibility, and with a system which inherently keeps a record of the act.

The data logging function of the computer system can be extended to the irradiation experiments to provide the same control and monitoring functions to users. Experimental conditions such as pressure, temperature, etc., can both be recorded and acted upon as desired. The parameters of the neutron source which are of most interest to the user (source strength as a function of time, dose, percentage down-time, etc.) can be included with the experimental data.

Task, Manpower, and Cost Schedules

The design, construction, and assembly effort for the accelerators is an integral portion of the line item program and, like building design and construction, cannot be started until the project is authorized. Because of the need for speed in bringing this facility on line for materials damage work however, we do not wish to delay assembly and initial operation (thus testing of the entire source concept) until the new building is complete. To avoid this delay, construction of a prototype source will be begun in an existing building at LLL. This work will run in parallel with building construction. Once complete, the prototype accelerator will be run for debugging, training, and development until completion of the first neutron source in the new facility. Because of shielding limitations in existing building, the prototype accelerator cannot produce neutrons. However, it will provide a test of all source components and concepts from ion source through to target within 14 months of project authorization.

When the first neutron source in the new facility is complete, the prototype accelerator will be shut down and moved to the new facility to become the second neutron source. The schedule for the construction of these two accelerators is shown in Table 5. The cost estimate for the two proposed accelerators plus the computer monitoring system is given in Table 6. A quarterly commitment and cost schedule for accelerator design and construction is given in Table 7. The manpower forecast for design and assembly is given in Fig. 9. Neither of these projections include the manpower or costs of installation, debugging or research with the prototype accelerator. Those figures are included in the section on source development.

Table 5 Accelerator Construction Sequence

Major Subtask	1	2	3	4	5	6	7	8
Prototype Accelerator								
Design	XXXXX	XXXXX						
HV Supply Fabrication		XXXXX	XXXXX					
Ion Source Fabrication		XX	XXXXX					
Terminal Fabrication			XXXXX					
Control System Fabrication			XXX	X				
Beam Transport Fabrication			XX	XX				
Assembly				XXX	XX			
Initial Operation					XXXXX			
Accelerator & Target						XXXXX	XXXXX	
Research Operation								
Second Accelerator								
Design Review					XXX			
Component Fabrication					XXX	XXX		
Assemble Computer						XXX		
Interface								
Program Computer							XXX	
Assembly							XXX	XX
Initial Operation								XXX
Prototype Relocation								
Disassemble								XXX
Assemble								XXX

Table 6 Accelerator Cost Estimate (Conceptual Design - FY '76)
(K\$)

A. Cockcroft-Walton HV Supply		
Rectifier Stack	16	
Oscillator	32	
Modulator	55	
Plate Supply	65	
Variable Transformer	19	
Precision Divider	5	
Reference	<u>3</u>	
		195
B. Ion Source/HV Terminal		
Source	10	
Vacuum System	15	
Power Supplies	15	
Alternator and Drive	20	
Beam Tube	10	
Housing and Supports	10	
Cooling Equipment	<u>10</u>	
		90
C. Beam Transport System		
Quadrupole Lenses and Supplies	20	
Beam Tube and Supports	10	
Vacuum System	20	
Diagnostic Equipment	<u>10</u>	
		60
D. Controls and Monitoring		
		<u>75</u>
		420
TOTAL FOR TWO ACCELERATORS		
		<u>840</u>
E. Monitor Computer and Interface		
		<u>100</u>
		940
F. Engineering (18% of costs)		
		<u>170</u>
		1110
G. Contingency (10% on Engineering, 15% on Equipment)		
		<u>160</u>
TOTAL ACCELERATOR COSTS		
		1270

Figure 9 - Quarterly manpower forecast for accelerator design and construction.

Table 7 Accelerator Commitment/Cost Schedule
(K\$)

	Quarters After Authorization								TOTAL
	1	2	3	4	5	6	7	9	
Design	20 20	25 25	40 40	55 55	15 15	15 15			170 170
Procurement & Installation	75 25	150 70	200 270	275 300	150 100	60 100	30 45	30	940 940
Contingency	10 5	15 10	30 10	40 30	10 30	20 15	10 30	25 30	160 160
Total	105 50	190 105	270 320	370 385	175 145	95 130	40 75	25 60	1270 1270

TARGETS

During initial operation the RTNS-II sources will use titanium tritide targets similar to those in use on the present source. This section of the report details the developments undertaken to insure that the present target material can operate at the higher power density it will experience on the new sources. The section of the plan on advanced source development discusses the program to develop target materials with improved properties.

The neutron yield from a target decreases with use because the tritide layer is subject to intense radiation damage, deuterium implantation, and heating by the incident deuteron beam. These processes contribute to the flushing of tritium from the region of the target in which neutron production occurs. The depth profile of tritium in the titanium layer on an unused target is shown in Fig. 10. The tritium distribution throughout the target is essentially uniform. Scatter in the points results from the measurement technique used. The depth profile of tritium in a target for which the neutron yield has dropped to 70% of its initial value is shown in Fig. 11. Maximum depletion of tritium has occurred at the end of the 1.6 mg/cm^2 range of the 400 keV deuteron beam. The depth profile of deuterium retained in the target is also shown in Fig. 11.

The peak temperature to which the beam drives the tritide layer, and hence the rate of diffusion of displaced tritium, depends upon the power density of the incident deuteron beam and the linear velocity of the target past the beam spot. Diffusion calculations of mass transport with the one dimensional code TRUMP have been performed to determine the linear velocity

Figure 10 - Depth profile of tritium in unused target.

Figure 11 - Depth profiles of tritium and deuterium in a target after use on RTNS-I.

required to keep the RTNS-II targets within the temperature excursion experienced by the targets on the present source. This condition can be met if the RTNS-II targets move past the beam at ten times the speed of the present targets. This will be accomplished by doubling the diameter of the targets to 46 cm and increasing the rotation rate from the present 1000 rpm to 5000 rpm. However, the present rotating assembly is unable to operate with the larger target or at such speeds. The engineering considerations and the prototype testing required to produce such a rotating assembly are detailed below.

Rotating Seal

Any moving target system requires the use of a sliding or rotating vacuum seal between the moving portions and the stationary beam line of the accelerator. On the present target system (shown in Fig. A1 in the appendix) this seal is a rotating Rulon ring (loaded teflon) which is pressed against a stationary stainless steel surface. Because the sliding contact causes heating and wear, seal lifetime decreases rapidly at speeds above the present 1000 rpm. Failure would be almost instantaneous if 5000 rpm operation were attempted with this seal.

The new target system will use a differentially pumped air bearing for the rotating seal. Details of the bearing assembly are shown in Fig. 12. Clean, compressed air at ~100 psig is supplied through tiny passages to the gap between rotating and stationary parts. The air cushion produced prevents contact between metal parts serving as both a lubricant and coolant. On the side of the seal towards the accelerator vacuum system, two differential pumping ports separate the exhaust line from accelerator vacuum. The final sealing region runs with the same clearance as the air

Figure 12 - Schematic view of air bearing target and cutaway detail.

cushioned portion but with air pressure in the micron range. Gas leakage into the accelerator vacuum is reduced at high rotation rates by turbine pumping grooves machined into the final seal region. The bearing is shown disassembled in Fig. 13.

Three complete prototype bearing assemblies have been built. The first has operated on a test stand at speeds up to 10,000 rpm with uncooled dummy targets and at 5000 rpm with dummy targets incorporating the internal cooling system discussed in the following section. A test stand with monitoring and control instrumentation suitable for lifetime testing is being built. The bearing assemblies will be given long-term tests under simulated operational conditions, then disassembled and inspected. As the only metal erosion or wear results from moving air, bearing and seal lifetime are expected to be very long in routine operation.

Following successful bench tests, the air bearing system will replace the present target system on RTNS-I. This will provide experience with 23 cm tritium targets. When the prototype accelerator has produced H^+ beams at the target position, tests of 46 cm targets loaded with hydrogen or deuterium may be carried out. This sequence will provide a rotating seal system with fully determined performance characteristics before the sources in the new facility are ready for operation.

Internal Coolant Flow

The present target is cooled by water flow between the rear surface of the target and a stationary matching surface behind the target. The target rotation insures turbulent flow between the moving and stationary surfaces and thus high heat transfer coefficients are obtained. However, with this arrangement the power required to overcome the viscous drag of

Figure 13 - Major components of air bearing disassembled.

the coolant scales as the cube of the angular velocity and the fifth power of the target radius. To cool the targets with the speed and size of the RTNS-II targets with this system would require a prohibitively large motor to drive the rotating system.

To decouple the flow and efficiency of the coolant from the target rotation, a design has been developed in which the water circulates within the target in turbulent flow. Water is supplied through a central hub assembly, flows out radially through etched channels in a sandwich target, and then returns to the hub through radial channels. The pattern of the channels is shown in Fig. 14. The curving or wiggly pattern results in heat transfer coefficients approximately twice those obtained in turbulent flow in straight channels.

Prototype targets with internal coolant flow have been operated at 5000 rpm on the air bearing test stand. Lifetime tests of various rotating systems which couple water into the target are now in progress.

Fabrication and Loading

The conditions under which the RTNS-II targets will operate and the processes through which the substrate materials go during fabrication and loading impose stringent requirements on the properties of target materials. Heat conduction and specific heat of the substrate material must be as high as possible for good cooling. However, because of the tensile load imposed by the high speed of rotation, the material must have a high yield strength. The backing must remain ductile after the bonding process which makes the sandwich to allow hydroforming to the proper shape. Finally, all the above properties must survive the thermal cycles required to deposit titanium on the front surface of the target and then load it with tritium.

Figure 14 - Channel patterns for internal coolant flow in targets.
Photographic mask on right, etched target blank on left.

An alloy which appears more suitable than the Cu-Zr alloy now used is one which contains a dispersed second phase of alumina in a copper matrix. The matrix retains the thermal and ductile properties of copper while the alumina provides barriers against dislocation motion. A contract for a special mill run of this material with low oxygen content has been signed. Evaluation of the material will begin shortly. Production of prototype bonded targets will start within six months.

The present bonding system for the internally cooled targets uses a gold-diffusion technique. While the process works adequately and could be used for production targets, it would be desirable because of cost and residual activation considerations to reduce or omit the use of gold. Other bonding techniques are being explored.

The present facility for tritium loading of targets is limited to target diameters of 23 cm or less. Development of the internally cooled targets will proceed with this diameter to maintain compatibility with this system. Demonstration targets for the prototype accelerator will be hydrogen or deuterium-filled and thus may be produced in conventional evaporation systems without tritium capability. The decision to develop the tritium-loading facility for 46 cm targets and where to locate it will be based upon considerations of source construction schedules, shipping regulations, and environmental impact assessments.

Remote Changeout System

The need for precise alignment of experimental apparatus with respect to the target requires that the remote handling and positioning systems for the target and experimental assemblies be designed with high compatibility. Additionally, during target change operations, power and control functions must be maintained for the experimental equipment.

One task given the A-E firm during the conceptual design study was to determine what was available commercially in remote controlled equipment capable of precise handling of delicate but heavy assemblies. After reviewing several systems, the A-E recommended a heavy duty battery powered forklift that can operate manually, under radio control, or by following a buried wire. In its wire following mode, this unit can place a mass of 2700 kg within 3 mm of a preselected location. Use of such a unit decouples the handling problem into two portions: gross movement (10-100 m) of equipment which is placed with low tolerance on accuracy, i.e. ~ 1 cm, and the final small movements (1-2 cm) which must be carried out with accuracy of better than 1 mm. We plan to purchase the prime mover for the gross movement and design and fabricate in-house the system for small movement and final alignment. Division of the system into two portions in this manner avoids producing a large number of self-powered, remote controlled carts which spend most of their time stationary.

For some complex experiments (e.g. simultaneous sample irradiation with neutrons and charged particles) it may be more appropriate to design the remote positioning and support capabilities into the experimental equipment itself than to meet these needs with a general purpose facility system. Further investigation with potential facility users will determine whether or not there are such break points.

Safety and Control Systems

Although tritium and induced radioactivity make the targets items which must be handled with some care, the major hazards associated with the target system are industrial. In particular, the stored energy in several kilograms of metal rotating at 5000 rpm presents a somewhat unique hazard for an accelerator facility. The target assembly will be coupled

with the accelerator interlock system so target operation is limited to low speed test work with the pit door open. Sensors on the target assembly which measure rotational speed, vibration, air supply pressure, coolant flow and temperature, and roughing and high vacuum pressures will be used to monitor target operation. As in the case of accelerator subsystems the supervisory computer will have some discretionary responses when nominal operating limits are exceeded.

Many of these control and sensor systems will be built in prototype form for the target test stand. By the time the prototype accelerator is available for target testing final versions of most systems can be specified.

Task, Manpower, and Cost Schedules

The task schedule for design, construction, and fabrication of the target system and the related tritium scrubbing and remote handling systems is given in Table 8. Note that final design of the target system is delayed until the second year of the project to allow input of experience gained with the prototype targets. The schedule and funding of this prototype work is discussed in the section on Supporting Development. The cost estimate for construction and assembly of the target related systems is given in Table 9.

Because of the specialized nature of the target components it is anticipated that most of the fabrication of the target system will be done within the Laboratory. The scrubbing system for removing tritium from pump and vent system exhausts is available from commercial suppliers. This equipment may be purchased as a complete system with minor LLL engineering effort required to couple it to the facility exhaust systems.

A commitment and cost schedule for the target and related systems is given in Table 10. The manpower projection for this work is shown in Fig. 15.

Table 8 Target System Construction Schedule

Major Subtasks	Quarters After Authorization							
	1	2	3	4	5	6	7	8
Rotating Target								
Preliminary Design		XXX						
Final Design					XXX			
Fabrication						XXX	XXX	
Installation								XXX
Tritium Scrubber								
Design/Specify		XXX	XXX					
Fabrication				XXX	XXX	XXX		
Installation								XXX
Remote Handling System								
Specify Prime Mover	XXX							
Order		XXX						
Fabrication			XXX	XXX	XX			
Design Coupling System			XXX					
Fabrication				XXX	XXX			
Test							XXX	
Installation								XXX

Table 9 Target System Costs
(K\$)

Rotating System Fabrication		
Air Bearings	60	
Mounting Brackets	20	
Utility Interconnects	15	
Collimators	10	
Controls and Diagnostics	30	
Cooling	<u>65</u>	200
Tritium Scrubber		
Acquisition of Scrubbers	150	
Monitoring	15	
Controls	<u>25</u>	190
Remote Positioning Equipment		
Prime Mover System	65	
Coupling Heads	60	
Secondary Systems	50	
Controls	<u>25</u>	<u>200</u>
		590
Engineering		95
Contingency		<u>95</u>
		780

Table 10 Target System: Commitment/Cost Schedule
(K\$)

	1	2	3	4	5	6	7	8	TOTAL
Design	15	25	10	25	20				95
	15	25	10	25	20				95
Procurement and Installation	20	25	100	175	70	40	100	60	590
	5	15	20	50	170	150	80	100	590
Contingency	5	10	15	20	20	10	10	5	95
	2	5	5	10	25	20	10	18	95
TOTAL	40	60	125	220	110	50	110	65	780
	22	45	35	85	215	170	90	118	780

Figure 15 - Quarterly manpower forecast for target design and construction.

OPERATIONS

Operating Philosophy

The neutron sources and associated equipment will be operated subject to the Laboratory's basic safety policy that all operations be planned in a manner that will prevent injury to personnel or damage to property. As this facility will be a national research facility and the majority of users will not be Laboratory employees, the operating staff will provide both support and guidance to users as well as ensuring source operation at the highest levels consistent with safety and equipment capability. Guidelines for operation and experimental procedures established by the Facility Director and advisory committees representing DCTR and the users will be enforced by the operating staff.

Access to the sources, priority and compatibility of experiments, and other aspects of the experimental program will be determined by a users group to be established by DCTR. Details of organization of and representation on this group will not be discussed in this report. This section discusses the personnel requirements for the operations group and the program to meet these requirements.

Operator Training

Two features which distinguish the accelerators for these sources from others at the Laboratory will require special training for operators. The beam power is so high that operator error or inattention during minor perturbations of operating conditions could cause extensive damage to accelerator components. Also, the high residual activity of experimental equipment puts special responsibility on the operators. At the Laboratory's other accelerators, the experimenter is responsible for the activation

hazards associated with his own equipment. As most users of the neutron source facility will not be Laboratory employees, the responsibility for guarding against accidental exposure due to activated equipment will fall upon the operations group. Accordingly, at least the chief operator for each shift shall have the training given to the Laboratory's Hazards Control technicians.

To provide an operations crew for these state-of-the-art accelerators, the hiring and training of operators must proceed in parallel with construction of the accelerators. Three groups of operators will go through a training sequence on an operational accelerator, assist in the assembly of an accelerator, and then debug the accelerator which they have put together. This sequence will provide operators fully familiar with the sources, their subsystems, and the operating system as the sources come into production operation.

Initial and Routine Operation Schedules

During the debugging and initial operating periods the sources will run only a single shift. Experience with the initial operation of other Laboratory accelerators suggests that trial operation on swing shift with days reserved for correcting problems, making repairs, etc. is most productive. As the sources move toward production operation, swing and owl shifts will run with days left unscheduled. The integrated dose delivered to the target pits will be fairly low during this phase of operations, making reasonable access to them possible. Finally, when the reliability of all components of the sources has been demonstrated, when normal operating parameters have been determined, and the sequences for scheduled maintenance and target changes established, the sources will go into twenty-four-hour-a-day operation.

Safety

The overall responsibility for safe operation of this facility rests with the E-Division Leader. During the construction and initial operation stages, the Project Manager shall be responsible for recognizing and dealing with any industrial or radiation hazards associated with the sources. Once the sources are in production operation, the Facility Director shall have this responsibility. Before an experiment is placed on the source for irradiation, a hazards evaluation prepared by the experimenter must be submitted for review by the facility staff as well as representatives of the Laboratory's Hazards Control Department. Changes in the experiment may be suggested as a result of this review.

The facility will operate according to the rules of an operating safety procedure developed by the staff and the Hazards Control Department. This procedure will detail all hazards associated with operation of the sources and their support equipment, the safety systems in the building, and the responsibilities of staff members and users. Guidelines for the design of experiments will be included (based upon operating experience with the present source) and explicit limitations on kinds or amounts of potentially hazardous materials stated. All users of the facility will be required to familiarize themselves with the contents of this safety procedure.

Task, Manpower, and Cost Schedules

The schedule of manpower required by the neutron source facility is given in Table 11. Because of the time required to train operators they must be hired during the construction phase of the project. In addition to the operators themselves, administrative, clerical, and support personnel will be required as the program changes from construction and assembly to initial operation to routine operation. By the third year after project authorization the experimental program will be fully developed and the operating staff will be at its full strength.

The operating cost projection for the facility is given in Table 12. Manpower costs are calculated at 45K\$ per FTE and shift differential have been applied for the accelerator operators. Tritium target costs are indeterminate at this time but are estimated to be at least 125K\$ annually for each source. The cost of equipment replacement is estimated to be 50K\$ per source per year. During the initial year or two of operation, these funds would be expended for modification or upgrade of initial equipment. After operation becomes routine, this money will be used to replace equipment which is lifetime limited.

Operating and maintenance costs for Livermore buildings averages \$2.06 per square foot (\$1.01 utilities and \$1.05 maintenance). This figure is given for a 15,000 square foot building to present a general cost picture. Electrical power required by research equipment is estimated to total 4K\$ annually.

Table 11 RTNS-II Operating Staff

Manpower (FTE)	Years After Project Authorization			
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>
Administration	-	1	2	2
Scientific Staff	-	-	2	2
Operating Staff	3	6	9	9
Engineering	-	-	2	2
Technicians	-	-	4	4
Hazards Control	-	1	1	1
	<u> </u>	<u> </u>	<u> </u>	<u> </u>
TOTAL	3	8	20	20

Table 12 Operating Costs Summary (K\$)

	Years After Project Authorization			
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>
Manpower	135	300	980	980
Maintenance & Utilities	-	-	35	35
Equipment Replacement	-	-	75	100
Accelerator Power	-	10	50	50
Target Costs	-	-	200	250
TOTAL	135	310	1340	1415

SUPPORTING RESEARCH

In addition to the funds required to design and construct the neutron source facility, operating funds are required for further support of development work on this source concept. The effort can be divided into two categories: work essential to operation of the neutron sources at their design strength on schedule, and work directed toward upgrading the sources to higher source strengths. Examples of the first category are the construction of prototype targets or ion sources to check designs, operation of a prototype accelerator to determine beam quality and component lifetimes, and similar efforts to obtain early experience with all state-of-the-art equipment. This would allow design modification if necessary. Work on upgrading would be more general in nature, concentrating on fundamental questions of isotope balance in target materials, development of new target concepts, and study of production and transport of high current beams. Although there are gray areas in the division of work between these two categories, all supporting research is discussed in this section in terms of Engineering (essential to take the sources from 1×10^{13} n/s at turn on to 4×10^{13} n/s in six months) and Development (directed to upgrade to 1×10^{14} n/s within 18-24 months).

Accelerator Engineering

The goal of this work is to determine as early as possible the characteristics, performance and limitations of the accelerator which we have designed. As construction of the sources will proceed in a staged manner (with the second one built being the first to produce neutrons) it is important that this characterization effort begin as early as possible. As soon as line item funds are available we will begin construction of the

ion source test stand included in the proposal. Measurement of the emittance and quantity of beam to be delivered to the acceleration tube are expected to be possible within six months of project authorization.

Construction of a prototype accelerator should be complete within one year of project authorization. With these two pieces of equipment, complete demonstration of the accelerator properties will be possible.

Although all funds required for construction or purchase of this equipment are covered by the line item appropriation, installation costs (in an existing building) and operating costs for them must be provided from operating funds.

Target Engineering

This effort will address the mechanical and electrical engineering problems of fabricating the 46 cm, 5000 rpm targets for the new sources. A test stand will be built for lifetime tests of rotating seals, water feed throughs, and development of control and safety electronics. Coupled with tests of tritium loaded prototype targets on the RTNS-I source, the engineering design and test of 23 cm, 31 cm, and then 46 cm targets will be accomplished. By the time the hardware for the prototype 46 cm target has been developed, it should be possible to test hydrogen-loaded versions of this target on the prototype accelerator.

Accelerator Development

To produce accelerators capable of operation at currents of 0.5 A or higher several fundamental questions of beam production, acceleration, and transport must be investigated. Two important series of measurements are possible. In the near term the 25 mA 400 keV D^+ beam from the ICT accelerator of the RTNS-I source is available. This beam can be used to

investigate the degree of neutralization of the beam's charge in drift spaces. The effects of time structure of the beam upon neutralization can also be measured. Accurate measurements under a variety of focal conditions and background gas pressures in the drift spaces will allow much more accurate prediction of ion beam characteristics (and correspondingly more cost effective design of transport systems) than is now possible. When the prototype accelerator is assembled, it will be possible to measure typical emittances of the ion source, injection optics, and accelerator as a whole in short duration runs at currents above the design current. This will be possible even though the component lifetime problems associated with high current operation have not been solved. These measurements will provide information needed for the design of an acceleration tube for higher current operations.

Target Development

The demonstration of whether or not a source strength of 1×10^{14} n/s with useful flux of $2 - 3 \times 10^{13}$ n/cm² s can be produced using a rotating tritiated target depends upon better understanding of the processes which limit target lifetime. In particular, we wish to measure and parameterize the hydrogen isotope transport processes in the tritiated layer.

The beam pulsing capability of the ICT accelerator of RTNS-I allows the temperature cycle of the surface of a rotating target to be duplicated on small stationary targets. By varying the pulse length and repetition rate it is possible to run small samples through a variety of temperature cycles. Neutron yield, lifetime, and gas output from these small targets will provide normalization for the transport code calculations of tritium diffusion.

Once the present target system is well characterized, systematic work to develop a target material capable of withstanding the power levels of 10^{14} n/s operation will be undertaken. Materials whose hydrides have greater thermal stability than titanium hydride will be investigated. Initial candidates are yttrium, erbium, and scandium hydrides. It may be possible to improve target performance through use of multilayered targets which incorporate diffusion barriers on the surface to inhibit tritium release and/or palladium underlayers to provide a dumping zone for deuterium.

Small samples of alternate target materials will be tested in pulsed beam simulation experiments with the ICT accelerator. Performance will be measured relative to the benchmarks established for titanium-tritide. If promising results are obtained, full-sized targets will be fabricated for testing in DC operation on the ICT. The simulation capability is particularly valuable as preliminary target evaluation can be done with small samples with no risk to performance of the RTNS-I source during production runs.

Task, Manpower, and Cost Schedules

The time schedule of tasks in engineering and development work for the RTNS-II sources is given in Table 13. To reiterate, engineering work is necessary to guarantee successful early operation and to raise the source strength from 1×10^{13} n/s at turn on to 4×10^{13} n/s within six months. Development work is directed toward eventual operation at source strengths of 1×10^{14} n/s with fluxes of $2 - 3 \times 10^{13}$ n/cm² s or higher.

Manpower and cost estimates for this work are given in Tables 14 and 15 respectively. Engineering and Development programs are tabulated separately.

Table 13 Supporting Research: Engineering and Development

Major Subtasks	FY 76	FY 77	FY 78	FY 79
Accelerator Engineering				
Source Tests - 20 kV	X X X			
Source Tests - 50 kV		X X X		
Assemble Prototype		X		
Operating Parameter Study-Prototype		X X X		
Prototype Relocation			X	
Target Engineering				
Bearing & Water Feed Design	X X			
23 cm Target Tests on Stand		X X		
23 cm Target Tests on ICT		X X X		
31 cm Target Design		X		
31 cm Target Tests on Stand		X X		
46 cm Target Design		X		
46 cm Target Tests on Stand		X X		
46 cm Target Tests on Prototype			X X	
Accelerator Development				
Space Charge Studies - ICT	X X			
Source Development - High Current		X X X		
Prototype Space Charge Studies		X X X		
Prototype Studies - High Current		X X		
Upgrade Studies - RTNS-II Sources			X X X X	
Target Development				
Small Target Parameter Studies - TiT	X X			
Advanced Materials Studies		X X X X	X X X X	
Prototype Tests - ICT		X X		
Tests on Prototype Accelerator			X X	
Tests on RTNS-II Sources			X X X X X X	

Table 4. Supporting Research Manpower

	<u>FY 76</u>	<u>76 T</u>	<u>FY 77</u>	<u>FY 78</u>	<u>FY 79</u>
Accelerator & Target Engineering					
Administration	0.5	0.5	0.5	0.5	--
Scientific & Engineering	4.0	4.0	6.0	3.5	--
Technicians, Fab, Installation	6.5	6.5	8.5	5.0	--
Accelerator & Target Development					
Administration	0.5	0.5	0.5	0.5	0.5
Scientific & Engineering	2.0	2.5	1.75	2.5	4.0
Technicians, Fab, Installation	3.0	4.0	2.5	2.5	3.0

Table 15. Supporting Research Cost Estimate
(K\$)

	<u>FY 76</u>	<u>76 T</u>	<u>FY 77</u>	<u>FY 78</u>	<u>FY 79</u>
Accelerator & Target Engineering					
Manpower	410	115	645	435	--
Materials	70	25	60	40	--
Capital Equipment	50	--	60	60	--
	<u>530</u>	<u>140</u>	<u>765</u>	<u>535</u>	<u>--</u>
Accelerator & Target Development					
Manpower	210	75	250	265	380
Materials	15	--	25	30	50
Capital Equipment	--	--	--	20	50
	<u>235</u>	<u>215</u>	<u>275</u>	<u>315</u>	<u>480</u>

FACILITY UPGRADE

Maximum contribution to the CTR materials program can be made by the RTNS-II sources only if the experimental program utilizing them is able to progress to experiments which more nearly simulate fusion reactor conditions than simple neutron irradiation, and if it is possible to steadily increase the dose available from these sources. This section outlines the modifications to the basic facility which should make such progress possible. To some extent the priority and value of these modifications depend upon the results obtained in early operation, thus this program is subject to revision.

Synergistic Effects Equipment

With the flux available from the RTNS-II sources in early operation, the earliest experiments will probably concentrate upon surface effects of neutron bombardment. The effects of multiple component irradiation of materials must be investigated to determine if there are significant synergistic effects resulting in shortened lifetimes of first wall material. Sufficient space and utility capacity is included in the RTNS-II facility to accomodate an electrostatic accelerator, specialized ion sources, and an x-ray generator for such studies. The Lawrence Livermore Laboratory has acquired a surplus electrostatic accelerator suitable for this program. However, the costs of modification, installation, and auxiliary equipment required to operate this machine must be met from operating funds. Similarly, the ion sources and x-ray generator are readily available items but the acquisition costs of this equipment and the engineering required to integrate it into experimental packages must be supported by operating funds. With adequate support in FY 77, some portions of this equipment could be available

for use during early operation of the facility.

Source Upgrade

By mid FY 78 the information available from operation of the prototype accelerator, ion source development work, and target development studies should indicate the best approach to upgrading the neutron source strength to 1×10^{14} n/s from each source. Modification of or replacement of the ion source and acceleration tube on each source may be necessary. The high voltage power supplies will be modified to raise the maximum current available from 300 mA to 500 mA. Changes in some beam transport components and modifications to target cooling loops will probably be required. Funds for these changes in the sources will be requested for FY 79.

Second Increment to Facility

A last step in increasing facility capabilities would be to build more neutron sources. This step would require Congressional approval of a new line item. The decision to proceed with this increment should be based upon the performance of the prototype accelerator and the availability of other neutron sources. Within eighteen months of project authorization the prototype should have operated for six months. A decision to request funding in the FY 80 budget would be appropriate. Because much engineering design work done for the original facility will not have to be repeated, the construction of cells for three new sources would be very rapid. Cost of the building is estimated to be 3M\$. Accelerator design will benefit from experience gained on the prototype and the source test stand and with the RTNS-II sources. The cost of the accelerators and target systems for 1×10^{14} sources is estimated to be 2M\$. Initial operation within 18 months

of the funding decision should be possible. The operating costs for manpower, utilities, and supplies for this addition should be about 1M\$ per year.

Any consideration of increments to the program beyond this expansion depends strongly upon the success of other source systems. Starting from the technology of a target capable of 1×10^{14} operation with a spot area of 1 cm^2 , several variants are possible. One can build sources capable of producing fluxes of $1 \times 10^{13} \text{ n/cm}^2 \text{ s}$ over areas of several square centimeters with flux uniformity of better than 10%. One could also produce high fluxes (i.e. $4 \times 10^{13} \text{ n/cm}^2 \text{ s}$) for small volume experiments. Finally, the cost of 1×10^{14} sources and shielding might be reduced to approximately 1M\$ each by standardization and optimization of design. All the needs of the materials damage program could then be met in a manner combining cost effectiveness and versatility by building large numbers of the sources. A decision point for proceeding with this approach should probably be placed in the FY 80-81 period when other sources are scheduled to be in operation.

Cost Schedule

A schedule of costs associated with progressive upgrading of the RTNS-II facility is given in Table 16. These costs are broken down into engineering fabrication, equipment purchase, installation, and incremental effect upon operating costs to the extent possible at this time. Break-downs of equipment costs for the synergistic equipment and source upgrade equipment are given in Table 17.

Table 16 Cost Schedule for Facility Upgrade
(K\$)

<u>Item</u>	<u>FY 76</u>	<u>FY 77</u>	<u>FY 78</u>	<u>FY 79</u>	<u>FY 80</u>
Synergistic Equipment					
Engineering	--	100	--		
Fab	--	50	100		
Equipment Purchase	--	400	--		
Installation	--	100	--		
Operating Costs	--	--	150	150	150
Source Upgrade					
Engineering	--	--	100	100	--
Fab	--	--	--	200	--
Equipment Purchase	--	--	--	475	--
Installation	--	--	--	100	--
Operating Costs	--	--	--	--	--
Second Increment					
Engineering	--	--	--	--	1000
Construction	--	--	--	--	2500
Purchase/Fab	--	--	--	--	1500
Operating Costs	--	--	--	--	--

Table 17 Upgrade Equipment Costs
(K\$)

Synergistic Equipment	
Electrostatic Accelerator Gas Handling System	50
Voltage Upgrade Equipment	40
Beam Transport Equipment	50
Terminal Ion Source	25
Vacuum Systems	35
X-Ray Generator	100
Ion Sources	75
Special Experimental Assemblies	25
Neutron Source Upgrade	
Power Supply Conversion	100
Vacuum System Components	75
Beam Transport Modifications	50
Target Cooling Refrigerators	150
Isolation Transformers	100

PROGRAM ADMINISTRATION

MANAGEMENT

Lawrence Livermore Laboratory is organized to plan and execute large complex applied scientific tasks. Planning and construction of the facility will be aided by the large support organizations provided by the Laboratory's matrix form of organization. Engineering support is available as needs arise.

Figure 16 shows the organization responsible for the design and construction of the facility. The direction of the effort is in E (Experimental Physics) Division. The Project Manager is responsible to the Division Leader of E Division. Many of the activities will, however, be carried out by other parts of the Laboratory. In particular the planning of the building, the coordination with the San Francisco Operations Office and the negotiations with the architectural engineering firm are the responsibility of the Plant Engineering Department. The Project Manager and the E Division Leader will advise the Plant Engineering Department to assure that the building will satisfy the needs of the facility and experimental program.

The design of the ion source and accelerator will be carried out by a design team from E and M Divisions. The production and acceleration of large ion beams is an area in which M Division personnel have outstanding expertise. Preliminary design of an ion source, acceleration system, high voltage power supply, and beam transport system have been completed.

The present target system was originally developed by Rex Booth of E Division. He will continue to have a major responsibility for the

Figure 16 - Management structure for RTNS-II design and construction.

development of a target for higher current. His effort will be supported by the design and construction facilities available in the Mechanical Engineering Department.

On the basis of the development work done in both E and M Division the Electrical Engineering and Mechanical Engineering Departments will, under the guidance of the Project Manager, develop the integrated facility.

Once the facility is completed and experimental work using the neutron source begins, the organization will change. The responsibility for the operation of the facility will remain in E Division. It will be under the control of a Facility Director, who will receive advice on the operation and the experimental program from a users group to be established by DCTR. Under the director of the facility there will be an Operations Manager who will supervise the operators who actually operate the facility and the technical support staff which is responsible for the maintenance and development of the facility. Under the Facility Director there will also be a coordinator of the scientific effort who will supervise the scientific staff associated with the facility.

Safety

LLL maintains a strict and comprehensive procedure regarding design and fabrication of potentially hazardous equipment. This procedure includes provisions for design, responsibility, approval, and preparation of rules that have to be followed with respect to the fabrication and operation of potentially hazardous equipment.

Particular attention will be paid in the design and operation to the radiation hazards. In the Laboratory organization both general safety and radiation safety are the responsibility of the Hazards Control Department. During the design and construction of the facility, repre-

representatives of the Hazards Control Department will advise the Project Manager on matters pertaining to radiation safety. Personnel from the Hazards Control Department will be assigned to the facility once it is in operation to ascertain that no radiation hazards exist.

Reliability

The Project Manager will ascertain that tests are carried out on components of the accelerator and target assembly to assure reliability of all parts of the facility. He will supervise the preparation of instruction for maintenance and periodic tests to reduce the probability of breakdowns of the operating facility as much as possible.

The same staff which will originally assemble the accelerator and associated controls will later on continue to operate the facility and will therefore be thoroughly acquainted with the equipment.

REVIEWS AND MILESTONES

Planned reviews of design and construction work are needed to assure that the program progresses as rapidly as possible. These reviews provide an opportunity to evaluate work completed and to update the program. Informal weekly meetings will be held to keep all personnel in the design team abreast of the status of all portions of the project. More formal local reviews will be held at monthly intervals. Minutes of these meetings will be kept and distributed to both local participants and other interested parties.

Occasions may arise when program changes or redirections may be required. Should this occur a special review will be convened with LLL, DCTR, and users' representatives present to discuss the courses of action possible. Program progress can be measured by whether or not the program milestones are met on time. Major milestones for the construction of the RTNS-II facility are listed in Table 18.

Table 18 RTNS-II Project Milestones

Building Milestones	Months After Authorization
Title I Start	1
Title II Start	2
Title II, Phase I Complete	4
Phase I Construction Start	5
Title II, Phase II Complete	6
Phase II Construction Start	9
Phase I Construction Complete	10
Phase II Construction Complete	18
Activation Complete	20
Source Milestones	
Prototype Accelerator Design Complete	4
Tritium System Design Complete	8
Prototype Accelerator Operational	11
Design Review, Second Accelerator	13
Final Target System Design Complete	13
Remote Handling System Design Complete	13
Fabrication Start, Second Accelerator	14
Assembly, Second Accelerator	21
Prototype Relocation Starts	23
Initial Operation, First Neutron Source	24
Initial Operation, Second Neutron Source	26

FISCAL SUMMARY

The total cost for the RTNS-II facility is itemized in Table 19. The distribution costs differs from the itemization in the Schedule 44 submittal for this project as a result of the conceptual design study for the building and more detailed study of the source systems. A quarterly commitment/cost schedule for the construction of the facility is given in Table 20.

An overall cost projection for the entire Livermore Neutron Source Program is given in Table 21. This projection assumes that all development research is funded at the levels requested and that all options such as synergistic equipment addition, source upgrade, and facility duplication are exercised. Incremental operating costs for the additions are included separately.

Table 19 RTNS-II Facility Cost
(K\$)

Engineering	545
Construction Buildings	2000
Neutron Sources	1530
Standard Equipment	300
Contingency	<u>625</u>
TOTAL	5000

Table 20 RTNS-II Facility Commitment/Cost Schedule

Quarter After Authorization

	1	2	3	4	5	6	7	8	TOTAL
Engineering	227 159	62 121	62 63	89 90	45 46	29 30	17 19	14 17	545 545
Building			510 185	1385 602		554 554	58 58	47 47	2000 2000
Neutron Sources	95 30	175 85	300 290	450 350	220 270	100 250	130 125	60 130	1530 1530
Standard Equipment			40			130	130		300 300
Contingency	35 17	30 25	125 65	260 120	35 155	50 55	50 90	40 98	625 625
TOTAL	357 206	267 231	1037 603	2184 1202	300 1025	309 889	385 422	161 422	5000 5000

Table 21 Livermore Neutron Source Program

Overall Cost Projection
(K\$)

	<u>FY 76</u>	<u>76 T</u>	<u>FY 77</u>	<u>FY 78</u>	<u>FY 79</u>	<u>FY 80</u>	<u>FY 81</u>
Research and Development	765	355	1040	850	480	--	--
RTNS-II Facility	2500	--	2500	--	--	--	--
Operating Costs	135	--	370	1340	1415	1450	1450
Synergistic Program							
Equipment	--	--	650	100	--	--	--
Operating Costs	--	--	--	150	150	150	150
Source Upgrade	--	--	--	100	875	--	--
Second Facility							
Construction Costs	--	--	--	--	--	2500	2500
Operating Costs	--	--	--	--	--	--	500

APPENDIX A PRESENT LLL SOURCE

THE DT REACTION

In all current designs of fusion reactors almost all the primary neutrons are produced in the DT reaction. These neutrons have an average energy of 14.1 MeV with a small energy spread which depends on the temperature of the plasma and which is not thought to be significant as far as radiation damage is concerned. In addition to these primary neutrons, the inner wall of the reactor is exposed to a flux of neutrons backscattered by the blanket. The flux and spectrum of these backscattered neutrons depends on the details of the design of the blanket, but the total backscattered flux is expected to be about 8 times the uncollided 14 MeV neutron flux incident on the first wall, and the spectrum of the backscattered neutrons is expected to resemble a fission neutron spectrum.

DT neutrons produced in the accelerator have a spectrum which depends on the energy of the bombarding charged particles, on the direction of the observation with respect to the use of the beam and on the thickness of the target. For example, if 400 keV deuterons bombard a thick tritium target the neutrons emitted in the forward direction have a spectrum that extends from 14.1 MeV to 15.6 MeV with an average neutron energy of 15.0 MeV. Although the energy distribution of the neutrons emitted in a direction at right angles to the incident beam is much narrower than in the forward direction, considerations of target design make the use of neutrons in the forward direction much more desirable. Since the samples used for radiation damage studies must be placed close to the source in order to be subjected to a large neutron

flux, they are bombarded not only by neutrons emitted in the forward direction, but also by neutrons emitted at other angles. For all practical purposes the average neutron energy to which a sample is exposed is 14.8 MeV. The difference in energy of the 14.1 MeV thermonuclear neutrons and 14.8 MeV accelerator-produced neutrons may not be negligible, because the cross sections for H and He production which are important for radiation damage may be different at these two energies. Although only very limited experimental results on the variation of the important cross section in this energy region are available, variations in cross section of the order of 20% between these two energies have been reported.

It is difficult to simulate the effect of the neutrons backscattered by the blanket in the proposed facility. In order to obtain adequate neutron fluxes from the accelerator, samples have to be placed as close to the target as possible. This makes it almost impossible to modify the primary spectrum by placing blanket material near the target. The effective source of the neutrons that have collisions in the blanket is of the order of a mean free path inside the blanket. This is of the order of 5 cm, while the sample may be 0.5 cm from the target. Taking into account the inverse square decrease in flux with distance, one can see that the blanket material will not modify the effective primary spectrum substantially. It may be desirable to expose samples both to a fission spectrum in a fission reactor and to DT neutrons to explore the effect of the neutrons reflected by the blanket.

RTNS-I

In 1967 Lawrence Livermore Laboratory purchased from the High Voltage Engineering Corporation an insulated core transformer (ICT) accelerator that could deliver 10 mA of deuterium ions at 500 keV. In 1973 the original ICT power supply was replaced by a new power supply which was capable of delivering 60 mA at 400 keV. In order to take advantage of the higher current capabilities of the power supply, the ion source of the original accelerator was at that time replaced by a new source which could deliver up to 25 mA of atomic deuterons on the target. At the present time the output of this ion source limits the source strength available from the present facility. Most of the recent operating experience is with a deuteron beam between 15 and 25 mA collimated to a diameter of 1.6 cm, with most of the current concentrated within less than half this diameter.

This accelerator has been used in recent years as a high-intensity neutron source. 15-MeV neutrons are produced by deuteron bombardment of tritium which is absorbed in titanium. In order to dissipate the large amount of power in the deuteron beam without destroying the target, the target is rotated at high speed and is cooled with water.

Experiments carried out at this laboratory in 1971 showed that the lifetime of the titanium-tritium target was an order of magnitude longer if only one species of deuterium ions bombarded the target than if a mixture of atomic and molecular ions was used. This is due to the fact that molecular ions stop in a shorter distance in the target than the

atomic ions and displace tritium at that distance. The depth at which the molecular ions replace tritons is the same depth at which the atomic ions produce the largest number of neutrons. The LLL source therefore uses only atomic deuterium ions. Present experience is that typically the source strength decreases from $4 \times 10^{12}/s$ to $3.4 \times 10^{12}/s$ in a hundred hours of operation. This is an order of magnitude longer lifetime of tritiated targets than has been reported in similar facilities elsewhere.

Although different targets vary in their neutron yield, a good fresh target produces approximately 2.6×10^{11} n/mC incident on the target. The yield gradually decreases as deuterons replace tritons in the target. The rate of decrease of the yield with time depends on the beam current used, the size of the target spot, and on the characteristics of the particular target used. The highest source strength observed to date is $6 \times 10^{12}/s$.

Experiments carried out at LLL have shown that the lifetime of the target is strongly affected by the rotation speed of the target, i.e., by the length of time during which the beam heats a given target area. By increasing the target diameter or by increasing the angular velocity this time can be reduced. The target design in present use is shown in Figure A-1. The section to the right of the bearing and seal rotates at 1100 rpm. The 22-cm diameter tritium-loaded target is held with an O-ring at the end of the accelerator vacuum system. In order to take advantage of the entire tritiated target surface the section to the right of the bellows can be moved up and down so that all parts of the target can be used. This motion can be programmed or the operator can move the target from the

Figure A1 - Engineering drawing of 1100 rpm RTNS-I target.

control console when the neutron intensity at a given radius has decreased below a prescribed level.

The titanium layer has an areal density of about 4 mg/cm^2 and is evaporated onto a 1-mm thick copper backing. Tritium is absorbed in the titanium to an average concentration of about 1.2 tritium atoms to 1 titanium atom. To increase the mechanical strength of the backing a copper alloy containing 0.15% Zr (amzirk) is employed.

An important feature of the system is that the neutron source remains fixed in space even though the target moves. The target design aims to permit as close access to the neutron source as possible and to minimize the material near the source to reduce scattering and absorption of the neutrons.

The thin copper backing of the target permits rapid heat flow to the outer surface. This outer surface is cooled by water flowing at a rate of 7 l/min in a closed circulating system. A 0.2-mm thick sheet of stainless steel serves as a water spreader and is placed parallel to the copper target so that the water is confined to a 0.3-mm wide gap covering the entire target backing. The waterflow is aided by the strong centrifugal force exerted on it by the rotating target. Because of the large velocity gradient between the rotating target and the stationary spreader, strong shearing forces are exerted on the waterflow and the flow is turbulent, which increases the heat dissipation. The target is surrounded by a stainless steel cover 0.1-mm thick to catch the cooling water.

The neutron yield from the source is measured by observing proton recoils originating in a polyethylene foil and detected CsI scintillator. This counter is placed 1 m from the source at an angle of 120° with respect to the incident deuterons. The efficiency of the detector is calculated from the geometry and the well-known neutron-proton scattering cross section. Since slightly fewer neutrons are emitted at 120° than in the forward direction where the sample is placed, a small correction for this anisotropy is applied when the flux on the sample is calculated. If samples are placed very close to the target, the proton recoil monitor placed 1 m from the target is not a good flux monitor, because the flux near the target depends both on the size of the target spot and the size of the sample. In this case foils of niobium are placed near the sample and the induced radioactivity in ^{92}Nb is observed in order to determine the flux on the sample. The half life of this activity is approximately 10 days, which makes niobium a useful dosimeter substance for irradiations lasting less than a week.

RADIATION DAMAGE STUDIES WITH PRESENT FACILITY

The neutron source described in the preceding section was acquired by LLL under the auspices of the Division of Military Applications. Until 1973 the facility was used primarily for experiments in pure and applied nuclear physics, especially for measurements of interest to the weapons program of the laboratory. Beginning in 1973 an increasing fraction of the time has been devoted to radiation damage studies of interest to the CTR program. All these experiments take advantage of the high source

strength of 14-MeV neutrons available at the facility. During this period both surface and bulk radiation damage effects have been investigated.

In order to obtain the highest possible flux at the sample in irradiations at the facility, the sample should be placed as close to the target as possible, since the flux decreases rapidly with the distance from the source. Consequently distances of only a few millimeters have to be used if high intensities are desired. Since the flux varies rapidly with the distance, the samples should have a diameter of less than 1 cm, if one wishes to avoid large variations of flux over the sample. For most studies of the bulk effect, samples between 5 and 10 mm in diameter and 0.1-mm thick are used. Samples have been irradiated at temperatures ranging from cryogenic to about 1000° C. Over extended periods of time the average neutron flux, as measured with Nb dosimeters, ranges from 5×10^{11} to $2 \times 10^{12}/\text{cm}^2\text{s}$. In an 80-hour run, fluences between 1.5 and $3 \times 10^{17}/\text{cm}^2$ are usually obtained.

For the study of surface effects the samples are usually irradiated in a vacuum. The need for a vacuum chamber results in larger distances between the sample and the source than for the study of bulk effects. The closest distance at which samples have been irradiated in vacuum has been 6 mm. At this distance the flux is approximately half what can be obtained for samples irradiated at atmospheric pressure and at ambient temperature.

LIMITATIONS OF RTNS-I

The present ICT installation was not designed for the purpose of producing very high neutron intensities. Increasing the neutron source strength much above its present intensity does not appear practical. For example, the acceleration column of the accelerator was designed originally for 10 mA, and the presently used current of about 20 mA tends to produce excessive heating of the acceleration tube. If larger beam currents are to be used, almost the entire acceleration system would have to be replaced.

More serious is the fact that the accelerator building is located at the edge of the laboratory near a public highway. The building containing the source was not designed for housing a neutron source of the intensity currently used. Attempts to increase the shielding on the roof of the building have not substantially reduced the leakage to the outside. During high intensity runs a large water tank is now placed above the neutron source in order to keep the intensity outside the building at an acceptable level. The present arrangement would, however, not be adequate if the intensity of the source were increased substantially. Even with all these precautions, the intensity of radiation at the laboratory fence is high enough to cause substantial concern.

On the basis of these considerations the conclusion was reached that a more intense source should be constructed in a location farther away from the outer boundary of the laboratory in a building specifically designed to house an intense high energy neutron source.

APPENDIX B EFFECTS OF FUNDING DELAY

The delay in authorization of the RTNS-II Facility until January, 1976, may result in some fiscal difficulties with the project. This delay will cause much more of the engineering and construction work to occur in FY 77 than planned in the Schedule 44 submittal for FY 76. Had it been necessary to resubmit the project for the FY 77 budget, an additional \$500K was to be included for escalation of costs due to inflation. Based on that estimate, the delay to date has resulted in cost escalation of perhaps \$250K over the original cost estimate.

The realities of construction work may affect both construction schedules and costs. Unless all heavy foundation work can be done before the start of the 1976 rainy season, a delay of up to six months may be required before the massive footings for the 2.5 m thick shield walls can be poured. This delay may result in cost escalation of perhaps another \$250K.

Finally, the parallel research and development work supporting the neutron source design has been funded at \$500K for FY 76 rather than the \$850K requested. This shortfall, plus the attempt to minimize construction time after authorization by concentrating available manpower on conceptual building design work, has resulted in a slippage in the schedule for preliminary accelerator design. Funding of the research and development effort at the levels suggested in this report for FY 77 will be necessary if early operation of the RTNS-II sources is to be at the desired source strength.

APPENDIX C TITLE I UPDATE

This appendix was written to meet two needs. The main body of this Development Plan was written in January 1976 before authorization of the RTNS-II project. It has become somewhat dated, especially with respect to the description of the neutron sources themselves, because of the design work which has been accomplished since that time. For purposes of technical control of the project, a detailed but concise statement of the content of various neutron source subsystems was clearly required as a technical benchmark. Title I design of the building itself has concentrated upon further development of the layout present in the main body of this plan. As there have been no significant changes, the description provided previously remains adequate.

Completion of Title I design on May 10, 1976 constitutes a checkpoint for financial control of the RTNS-II project. The design work done on both conventional and special facilities since project authorization allows more detailed and more accurate cost estimates for the project to be made. The second half of this appendix contains the estimate of cost to completion for the RTNS-II project as of the close of Title I.

SPECIAL FACILITIES DESCRIPTION

This description of the hardware of the RTNS-II sources is organized into the categories established for financial control of the project at the time of authorization. These categories are Accelerators, Ion Source Systems, Beam Transport Systems, Target Systems, Tritium and Handling Systems, and Controls and Instrumentation. While there may be some

ambiguity in assignment of equipment to these divisions from a technical standpoint, there were significant control advantages to the initial ordering. This system will be maintained throughout the project.

As this listing of components is intended primarily for control purposes, each item is described briefly in terms of most significant design, construction, or performance characteristics. The scientific and engineering considerations used to establish these characteristics are covered in detail in the body of this report and are omitted here.

TITLE I SPECIAL FACILITIES DESCRIPTION

1. Accelerators

1.1 High Voltage Supplies

The high voltage supply for each accelerator will be a motor-generator driven, air-insulated supply of the Cockcroft-Walton type. The supply will have a rating of 300 mA at 400 keV and will be upgradable to 500 mA at a later date. Regulation will be better than $\pm 0.1\%$ for $\pm 10\%$ load change with ripple less than $\pm 0.5\%$ over the operating voltage range.

1.2 High Voltage Terminals

The high voltage terminals to house ion source, low energy beam transport equipment, etc. will be 10 ft. high by 12 ft. wide by 11.5 ft. in length. The surface will be polished and contoured to allow operation at 400 kV. Insulating legs 5 ft. long will support the terminal. A total load of 10,000 lbs. can be installed in the structure. Surface panels will be removable for access to equipment installed inside.

1.3 Isolation Transformers

Electrical power for equipment installed in each high voltage terminal will be provided by a 480 V three-phase isolation transformer rated at 75 kVA. Should future upgrading of the accelerators require more power in the terminal, a second transformer can be added to each accelerator.

1.4 High Voltage Crowbar

To discharge the stored energy in each terminal, an air-insulated multiple switch acting as a fast crowbar circuit may be installed. This device would protect the high voltage acceleration tube from damage due to internal sparkdown. The switch can short the terminal to ground within 1 μ s of initiation. As no previous accelerator has utilized such a device, its need is not demonstrated. Experience with the prototype accelerator will be required to determine the usefulness of this concept.

2. Ion Source Systems

2.1 Ion Sources

The ion source for each accelerator will be a modified version of the LLL MATS-III source. Studies are now in progress to determine the exact extraction electrode and extraction voltage optimum for the RTNS-II application. Nominal performance required is production of 200 mA of D^+ at extraction voltages between 20 kV and 50 kV.

2.2 Acceleration Tube

The high voltage acceleration tubes have a ceramic vacuum envelope with 18" diameter porcelain rings vacuum brazed to copper electrodes. The inner electrode structure through which the D^+ beam will be accelerated to 400 keV will be of molybdenum inserts bolted to the copper electrodes. Present design calls for an inner electrode aperture of 10 cm with an active tube length of 25 cm.

2.3 Low Energy Transport

The 20-50 keV beam from the MATS-III source will be bent through 90° in a 25 cm radius double-focussing magnet to remove the molecular components. A magnetic lens will be used to adjust the size and divergence angle of the beam as it enters the acceleration tube. Peak field required for the lens is below 0.2 T.

2.4 Power Supplies

Power supplies in the HV terminal are all routinely available off-the-shelf items. High current, medium voltage supplies are required for ion source filament and arc power. High current, low voltage supplies will be used on the 90° magnet and lens magnet. As all these supplies have been used on MATS-III for years; performance, cost, and lifetime are well established. The size of the extraction supply has not been fixed at this time pending cost-benefit study of ion optics, isolation difficulties, upgrade potential, and cost and space requirements of the supply itself.

2.5 Vacuum System

The vacuum system must remove the 10 cc/min D_2 gas flow from the ion source. A combination of 2000 μ /s (air) turbo-molecular pump, mechanical booster pump, and two-stage 130 cfm fore pump will be used. In a test setup, this pumping system delivered 1500 μ /s (deuterium) pumping speed, holding the test chamber at a pressure of 7×10^{-5} torr indicated with an input load of 19 cc/min. The turbo pump will be bolted directly to the stainless steel tank of the 90° magnet for maximum pumping speed. An isolation valve will be used to allow ion source removal without letting the acceleration tube to air.

2.6 Telemetry Equipment

Two-way transmission of signal and control information between the high voltage terminal and ground will be via a multiplexed light link system using optical fibers. The optical and multiplexing equipment are commercially available. Design of the analog-to-digital conversion equipment to go in the terminal remains to be done.

3. Beam Transport Systems

3.1 Optical Elements

Two kinds of active elements will be used on the ~ 7 m transport from the accelerator to the target: magnetic quadrupole triplets to focus the beam and air core trim magnets to steer the beam. The quadrupole triplets will have iron poles, 10 cm aperture, and peak field capability of 0.25 T on the pole tips. Outer pole tips will

be 10 cm long, inner pole tips 17 cm long. Three triplets will be used on each accelerator. The trim magnets are duplicates of those used for 5 years on the LLL Cyclograaff.

3.2 Beam Line and Supports

The 10 cm diameter beam line will be of stainless steel except near the target where aluminum may be used to minimize residual radiation problems. Metal gaskets will be used at joints exposed to beam heating. In the machine rooms the beam line will be supported on a steel mezzanine while in the target rooms floor mounted supports will be used.

3.3 Vacuum System

The beam transport vacuum system must pump the excess gas from the accelerator, the deuterium and tritium outgassed from the target, and the residual gas load from outgassing, leaks, etc. in the beam lines themselves. Two 2000 ℓ/s turbo molecular pumps will be installed on a plenum at the exit of the acceleration tube and two 1000 ℓ/s turbo pumps will be placed on a plenum near the target. The exhaust of these high vacuum pumps will be collected and fed to a high speed backing system consisting of a blower pump and a pair of two-stage mechanical pumps. Output of the mechanical pumps will go to the tritium scrubber.

4. Target Systems

4.1 Rotating Assemblies

Basis of the rotating portion of the target is the differentially pumped air bearing tested during FY 76. The bearing uses a stainless steel rotor floating on compressed air between brass surfaces. An

air turbine is used to drive the target which is connected to the rotor up to speeds of 10,000 rpm. Cooling water is supplied to the target by another rotating seal at its center. The present bearing appears adequate for targets up to 46 cm in diameter. Extensive tests will be performed before the design is frozen. Alternate materials may be considered to reduce the residual activation of bearing components.

Tests of the bonded, internally cooled target will begin on RTNS-I in the 76T quarter. Research on backing materials and bonding techniques will continue to select the optimum materials and fabrication procedures for the RTNS-II targets.

Five complete rotating assembly packages will be built for RTNS-II. This will provide two for operation while three are available for target change, repair, etc. Each assembly will be mounted on a skid which the remote handling system can position at the end of the beam line.

4.2 Coupling System Components

The coupling system is the interface between the end of the accelerator beam line and the removable skid containing the rotating target assembly. All utility, signal, and control connections for both the target and routine experimental packages will be made through these couplings when the handling system places the skid in the target room. The toggling and connecting systems are now being designed.

4.3 Cooling System

To remove the 60 KW of energy deposited in each target by the deuteron beam a large cooling capacity is required. Because of the possibility of tritium contamination of the cooling water the system must be a closed loop within the RTNS-II facility. A large chiller coupled to a pump to raise the water pressure to 300 psi will be used.

4.4 Electronics and Interlocks

To protect building personnel, the accelerator, and the target system itself, a variety of controls and protective devices are required. Target speed must be measured and regulated; rotation, vibration, air and coolant flow sensed to prevent damage to the target, and only low speed operation allowed when personnel are exposed to the target. Prototypes of all required equipment have been built for operation of the 5000 rpm target on RTNS-I.

5. Tritium and Handling Systems

5.1 Tritium Scrubber

Approximately 9 Ci/hr will outgas from each target in use on an accelerator. This tritium must be removed from the fore pump exhausts rather than simply vented to the air. The system presently envisioned will use freon traps and a molecular sieve to remove pump oil and contaminants, a rate metal catalyst to oxidize all tritium and deuterium to water, and another molecular sieve trap to catch the water. Total flow rate of air and hydrogen through the system will be ≈ 1 l/min. The final molecular sieve trap will saturate and begin to pass water after about a week. Multiple final

traps will be used to minimize personnel exposure during trap replacement. All components of the system will have backup elements.

5.2 Remote Positioning System

Remote changeout of targets and alignment of experimental packages with respect to the target requires a handling system with large capacity capable of placing its load with some accuracy. The system is divided into two parts: a commercially available remote controlled forklift capable of placing 500 kg with an accuracy of 0.5 cm and a fine adjustment capability provided by using self-aligning fixtures into which the forklift slowly pushes the target assembly in the target room. Experimental packages will ride in with the target assembly initially but will be off loaded onto a holding pad in the target room to maintain utility and control during target changeout. After the target assembly has been changed the experimental package will be replaced and realigned with respect to it.

6. Controls and Instrumentation

6.1 Diagnostic Equipment

Equipment to monitor both the deuteron beam and the neutron source are required. Non-interfering optical and magnetic systems will be used to measure beam current, size, and divergence. Neutron source strength will be measured with a proton recoil telescope while source size may be observed with an array of partially shielded scintillators. Prototype equipment is now being constructed for test on RTNS-I and the 50 kV ion source test stand.

6.2 Hard-wired Controls

Many subsystems of the sources come with control chasses. Examples are the HV power supplies, quadrupole triplets, and some of the turbo pumps. However, control circuitry for beam diagnostics, vacuum systems, radiation monitors, etc. must be fabricated and integrated into a control console for each source to provide all necessary operational and safety control functions. Such control consoles are routinely constructed for many of LLL's experimental areas in nuclear and plasma physics.

6.3 Digital Interface

Eventually, all vital information from both the neutron sources and experimental assemblies will be digitized and presented to a small computer operating in a process-control mode for monitoring purposes. Several commercial packages are available which can handle analog to digital conversion at the modest speed required for this application. Standard components can also be assembled to provide the 100 - 200 channels of data conversion needed. Design will begin on the interface after some experience has been obtained with the data telemetry system selected for the accelerators.

6.4 Computer

Several small computer systems available for ~ 50K\$ have the speed, memory, and software available for the monitoring and control functions planned. Computer selection will be deferred until design of the digital interface has begun.

6.5 Personnel Interlocks

Protection of personnel within the facility and on the LLL site requires a variety of interlocks. Standard industrial hazards such as high voltage and rotating equipment must be controlled. Monitors for prompt and residual radiation and access controls such as door locks, watchman stations, etc. will be installed to prevent radiation exposure. A prescribed sequence of interlock checks, pit inspection and closure, and warning operations will be required before source operation will be possible. Computer backup of the interlock system will also be used.

TITLE I SPECIAL FACILITIES COST ESTIMATE

The following cost estimate is based upon an item by item estimate of base costs of each major subsystem of the RTNS-II sources. Base cost includes either the purchase or fabrication cost of individual items and the manpower required to assemble individual components to the subsystem level. Installation in the building housing the RTNS-II sources has been estimated on a man-week basis for each item. In the summary, installation is calculated at \$700 per manweek. This value is an average of representative FY 78 wage rates for the appropriate specialties.

Escalation has been included separately in the summary at 6% of base cost. This value represents 8% annual inflation projected from May 1, 1976 to January 31, 1977. The latter date is the midpoint of the project contracting sequence. No escalation has been applied to the Accelerator Category because this item is completely covered by a quotation now in hand..

COST SUMMARY

<u>Item</u>	<u>Base</u>	<u>Escalation</u>	<u>Installation</u>
1. Accelerators	462K\$	- K\$	16K\$
2. Ion Source Systems	279	17	25
3. Beam Transport Systems	210	13	18
4. Target Systems	171	10	15
5. Tritium and Handling Systems	155	9	11
6. Controls and Instrumentation	275	17	35
	<u>1552K\$</u>	<u>66K\$</u>	<u>120K\$</u>

Total Estimate

Base	1552K\$
Escalation	66
Installation	120
Total	<u>1738K\$</u>

<u>Item</u>	<u>Base</u>	<u>Installation</u>
1. <u>Accelerators</u>		
1.1 HV Supplies	269K\$	10 Mnwk
1.2 Terminals	60	8
1.3 Isolation Transformer	87	5
1.4 Crowbar*	57*	4*
1.5 Spare Parts	18	-
1.6 Shipping	<u>28</u>	<u>-</u>
Total	462K\$	23 Mnwk

*Need not established - not included in totals.

2. <u>Ion Source Systems</u>		
2.1 Ion Sources	30K\$	2 Mnwk
2.2 Acceleration Tube	62	2
2.3 Low Energy Transport	30	2
2.4 Power Supplies	87	15
2.5 Vacuum System	60	5
2.6 Telemetry Equipment	<u>10</u>	<u>10</u>
Total	279K\$	36 Mnwk

3. <u>Beam Transport Systems</u>		
3.1.1 Quadrupole Triplets	60K\$	10 Mnwk
3.1.2 Trim Magnets	5	1
3.2 Beam Line & Supports	15	5
3.3 Vacuum System	<u>130</u>	<u>10</u>
Total	210K\$	26 Mnwk

<u>Item</u>	<u>Base</u>	<u>Installation</u>
4. <u>Target Systems</u>		
4.1 Rotating Assemblies	46K\$	5 Mnwk
4.2 Coupling System	40	5
4.3 Cooling System	65	2
4.4 Electronics & Interlocks	<u>20</u>	<u>10</u>
Total	171K\$	22 Mnwk
5. <u>Tritium & Handling Systems</u>		
5.1 Tritium Scrubber	75K\$	5 Mnwk
5.2 Remote Positioning System	<u>80</u>	<u>10</u>
Total	155K\$	15 Mnwk
6. <u>Controls & Instrumentation</u>		
6.1 Diagnostic Equipment	50K\$	10 Mnwk
6.2 Hard-wired Controls	75	10
6.3 Digital Interface	40	5
6.4 Computer	60	5
6.5 Personnel Interlocks	<u>50</u>	<u>20</u>
Total	275K\$	50 Mnwk

TITLE I CONVENTIONAL FACILITIES COST ESTIMATE

Detailed description of the basis for the Title I Conventional Facilities Cost Estimate is provided by the Title I report from Simpson, Stratta and Associates. The cost breakdown for the major construction subcontracts of the approximately 18,000 sq. ft. building are as follows. Estimates include escalation calculated to the middle of the contracting sequence. The cost estimate was developed in April and May of 1976.

Phase I

1. Excavation, Rough Grading Backfill Required Compaction	74K\$	
2. Footings & Foundation Walls (To elevation noted on the drawings) underground mechanical and electrical	129	
3. Shielded Doors	281	
Total Phase I Construction		484K\$

Phase II

1. Building	798K\$	
2. Mechanical, Plumbing & Sheet Metal	250	
3. Electrical	232	
4. Roofing	49	
5. Automatic Fire Sprinkler System	12	
6. Cranes	34	
7. Fence	6	
8. Paving	36	
9. Finish Grading & Landscaping	31	
10. Hot Cell Windows	21	
Total Phase II Construction		1469K\$

Total Conventional Facilities	1953K\$
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TITLE I COST SUMMARY

Overall allocation of funds for the RTNS-II project as of the close of Title I is given below.

Engineering, Design and Administration

Title I, II, III	200K\$	
Project Management	109	
Special Facilities Design	275	
		584K\$

Construction

Conventional Facilities	1953K\$	
Standard Equipment	340	
Special Facilities	1738	
		4031K\$

Contingency		385K\$
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Total Project Cost		5000K\$
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Distribution

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D. C. Sewell	L-1
T. K. Fowler	L-382
C. E. Taylor	L-386
A. C. Haussmann	L-28
J. D. Anderson	L-75
R. W. Bauer	L-313
J. E. Osher	L-386
J. C. Davis (80)	L-327

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Technical Information Department

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