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# National Biomedical Tracer Facility Project Definition Study


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## *EXECUTIVE SUMMARY*

The Los Alamos National Laboratory is an ideal institution and New Mexico is an ideal location for siting the National Biomedical Tracer Facility (NBTF). There are compelling reasons for siting the facility at Los Alamos:

- Los Alamos National Laboratory has a demonstrated record in the safe and effective production and distribution of radioisotopes.

- In addition, there is a 20 year history at Los Alamos in the research and development of biomedical radioisotopes, both production and application. Qualified staff and facilities are available to satisfy the NBTF objectives.

- Los Alamos National Laboratory is managed by the University of California and has excellent relations with the University of New Mexico and other educational institutions in New Mexico, that will enhance the educational objectives of the NBTF.

- The cooperative management plan for the NBTF is readily accommodated in the new Los Alamos structure. At the present time there are many user facilities at Los Alamos, and operation of the NBTF will be modeled after the successful operation of these facilities.

- Los Alamos facilities and infrastructure minimize both the capital construction costs and the operating costs that are required to satisfy the NBTF objectives. The waste handling and disposal capabilities are unmatched among those institutions interested in siting the NBTF.

- Los Alamos has the academic environment and cultural diversity conducive to the user community and research constituencies that will be attracted to the NBTF.

The essence of the Los Alamos proposal is the development of two complementary irradiation facilities that combined with our existing radiochemical processing hot cell facilities and waste handling and disposal facilities provide a low cost alternative to other proposals that seek to satisfy the objectives of the NBTF. We propose the construction of a 30 MeV cyclotron facility at the site of the radiochemical facilities, and the construction of a 100 MeV target station at LAMPF to satisfy the requirements and objectives of the NBTF. **We do not require any modifications to our existing radiochemical processing hot cell facilities or our waste treatment and disposal facilities to accomplish the objectives of the NBTF.**

The total capital cost for the facility defined by the project definition study is $15.2 M. This cost estimate includes $9.9 M for the cyclotron and associated facility, $2.0 M for the 100 MeV target station at LAMPF, and $3.3 M for design, documentation, project management, and other project costs. The most effective way to satisfy the NBTF objectives is to develop both facilities. Developing the cyclotron facility will insure that 75% of the NBTF objectives will be met. Construction of the 100 MeV target station guarantees that the other 25% of the NBTF objectives will be accomplished. However, each facility can also be considered seperately as the objectives of the NBTF are prioritized.

We have taken a very conservative view of future radioisotope markets and revenues. Our experience in the radioisotope production business suggests that although there is tremendous market potential, it takes a long period of time for this potential to be realized. Currently, we believe that approximately $5 M in revenues can be realized from NBTF-like accelerator isotope production (consistent with recent marketing surveys); the NBTF share of this market will be less than 50%. Hopefully aggressive marketing and ready availability from the NBTF will increase the projected NBTF market share. Also future development of therapeutic radioisotopes could significantly increase these projections. Other revenues, including other research support and fees from intellectual property could become important in the longer-term NBTF operation.

Operating costs for an NBTF sited at Los Alamos have been estimated with certain assumptions concerning the level of radioisotope production, extent of research and development program, and the implementation of the educational objectives of the NBTF. Based on the operating plan described in the project definition study the steady state operating cost of the NBTF is $6.2 M. This cost would support the full capacity of operations capable by the NBTF. It would take several years after commissioning for this level of operation to be realized.

Management of the NBTF is described in section 7 of the project definition study. The Los Alamos National Laboratory has extensive experience in the operation of large multi-user, multi-constituent research entities, such as LAMPF and LANSCE. These will become models for the operation of the NBTF. Siting the NBTF at Los Alamos will insure the greatest access to this user facility by the user community and the research communities interested in accessing the facility.

# 1. ACCELERATORS AND IRRADIATION FACILITIES

The objectives of the NBTF project can best be accomplished by constructing two irradiation facilities: (1) a 30 MeV cyclotron with associated target stations, and (2) a 100 MeV accelerator with target station. In this way the technical capabilities of each facility can be optimized and the construction and operating costs for the project can be minimized. This is especially so for Los Alamos, since the 100 MeV accelerator already exists as the drift tube linac injector at LAMPF. Each of these irradiation facilities is discussed separately below.

## 1.1. Rationale for Two Accelerators.

Table 1.1 lists the various radioisotopes that have appeared in previous NBTF workshops and discussions according to the proton beam energy required for their production. It is clear that the vast majority of these isotopes can be made at 30 MeV or less. In fact all of the production isotopes (see Section 6 of this document) fall into this category with one exception (Strontium-82). Consequently most of the objectives of NBTF can be satisfied with a 30 MeV cyclotron alone; this could be considered as a possible low cost option for the NBTF. Higher beam energies make it possible to produce additional isotopes through (p,xn) reactions, where x is greater than 3, and other more exotic reactions. A few important isotopes, notably Strontium-82, can be produced in this way. Other isotopes can be produced by different methods at higher energies, sometimes at greater efficiencies. Examples include Cadmium-109 and Iodine-123. Nevertheless, it is clear that the emphasis for the NBTF should be placed on efficient and cost effective production of isotopes at relatively low energies.

Satisfying the multiple objectives of the NBTF with a single 100 MeV accelerator is technically difficult. A cyclotron designed to operate at 100 MeV can easily provide beam in the 50 to 100 MeV range. However, extracting beams at less than 40 MeV becomes progressively more difficult as the energy decreases, because the beam extractor is so far into the cyclotron and the beam must travel so far before exiting the magnetic field in the cyclotron. In addition, operating such a large accelerator at such a small fraction of its designed output energy is quite inefficient and constitutes a poor allocation of resources.

**Table 1.1**

**Proton Energies Required for Producing Radioisotopes**

| Less than 30 MeV | | More than 30 MeV Less than 45 MeV | More than 45 MeV Less than 100 MeV | More than 100 MeV |
|---|---|---|---|---|
| Be-7 | Tc-95m | Fe-52 | Sr-82 | Mg-28 |
| F-18 | Tc-96 | Se-72 | Xe-122 | Si-32 |
| Na-22 | Ru-97 | Te-118 | Ba-128 | Ca-47 |
| Al-26 | Pd-103 | Gd-148 | | |
| Sc-47 | Ag-105 | W-178 | | |
| Ti-44 | Cd-109 | Hg-194 | | |
| V-48 | In-114m | | | |
| V-49 | Sb-119 | | | |
| Cr-51 | I-123 | | | |
| Mn-52 | I-124 | | | |
| Fe-55 | Xe-127 | | | |
| Co-55 | Ce-139 | | | |
| Co-56 | Pr-142 | | | |
| Co-57 | Gd-153 | | | |
| Cu-61 | Ho-163 | | | |
| Cu-67 | Lu-172 | | | |
| Zn-62 | Lu-173 | | | |
| Zn-65 | Ta-179 | | | |
| Ga-67 | Re-186 | | | |
| Ge-68 | Ir-192 | | | |
| As-73 | Hg-195 | | | |
| As-74 | Au-195 | | | |
| Se-75 | Au-199 | | | |
| Br-75 | Hg-197 | | | |
| Br-76 | Tl-201 | | | |
| Br-77 | Pb-203 | | | |
| Rb-81 | Bi-205 | | | |
| Rb-83 | Bi-206 | | | |
| Sr-85 | Bi-207 | | | |
| Y-88 | Np-235 | | | |
| Zr-88 | Np-236 | | | |
| Zr-89 | Pu-237 | | | |

Since most of the isotope production work would be done at 30 MeV or less, it seems logical to focus the design efforts for the facility on that energy range.

Construction costs for accelerator facilities include not only the cost of the accelerators, but also the costs of buildings, target facilities, shielding, and other components that are collectively described as infrastructure. The strong cost drivers are shielding and targetry, which scale non-linearly with accelerator beam energy. Thus, while a 100 MeV cyclotron may cost twice as much as a 30 MeV cyclotron, the cost of the building to house the 100 MeV machine will cost a higher multiple of that for the 30 MeV machine. Substantial unnecessary construction cost may be incurred by building an accelerator facility with more beam energy than is necessary.

Similar considerations apply for operating costs. In the case of a cyclotron, a certain amount of power is required to energize the magnet. Once this is accomplished, the incremental power needed to accelerate the beam is relatively small. Since the magnet for a 100 MeV machine is much larger than that for a 30 MeV machine, considerable unnecessary cost is incurred by operating the larger machine at low beam energies. Power costs for linear accelerators (linacs) scale more directly with beam energy, and one can, in principle, operate a high energy linac at low power by not energizing all of the RF tanks. However, these tanks and the beam lines must still be maintained, so that operating such a machine in this way constitutes a poor allocation of resources.

In the discussions below we describe two accelerator facilities. The first is a 30 MeV negative ion cyclotron with associated beam lines and target stations that will satisfy the low-energy irradiation requirements for the NBTF. The second is a targeting facility that would accept a 100 MeV proton beam from the drift tube linac portion of the LAMPF accelerator. This would satisfy all of the remaining irradiation requirements of NBTF. These target irradiation facilities, when combined with the already existing chemical processing, and waste handling facilities at Los Alamos, provide the optimal configuration for the NBTF at an extremely low cost.

## 1.2. Low Energy Irradiation Facility.

1.2.1. Accelerator Description. Table 1.1 clearly shows that the major objectives of the NBTF can be satisfied with a low energy (30 MeV) accelerator. Therefore we submit that the main focus of the NBTF project should be directed toward providing such a capability. Accordingly we propose the construction of a 30 MeV negative ion cyclotron, with capabilities for accelerating both hydrogen and deuterium ions. This machine shall be capable of delivering 1 mA of beam current, and shall be equipped with two beam extractors with associated beam lines for delivering beams to two target caves. Extracted proton beam energies shall be tunable between 10 and 30 MeV, with beam energies reproducible to 1 % and with energy spread less than 1 %.

Cyclotrons of the above description can be purchased from any of several manufacturers. The best known of these include Ion Beam Applications (Louvain La Neuve, Belgium) and EBCO Technologies, Inc. (Vancouver, Canada), although others exist. Our approach to this project will be to solicit quotations from all interested manufacturers and then select the bid package that represents the best value.

An accelerator of this description has the advantage of being based on well tested technology, so that startup and operational difficulties will be minimized. By keeping the design simple and addressing the most useful energy range for isotope production, the benefits derived from the facility can be maximized while minimizing the costs.

1.2.2. Facility Description. The design and location of the building to house the accelerator are just as important as the accelerator itself. The building must accommodate the following major functions:

- Cyclotron
- Cyclotron mechanical and support areas
- Target caves
- Mechanical and electrical equipment spaces
- Communication and data equipment spaces
- Office and support space

The cyclotron and target caves will require thick concrete shielding. This can be reduced somewhat by locating the facility below grade and using earthen shielding. Even though the cyclotron itself is not expected to become highly activated, the cyclotron vault must be shielded to nearly the same extent as the target caves.

While the detailed design of the accelerator building and associated services must be done in concert with the accelerator manufacturer, it is possible to do a generic design, based on published specifications, which can be used to generate preliminary cost estimates. Such a design is shown in Figs. 1.1 through 1.3. This revolves around a cyclotron vault with internal dimensions of 20 ft. by 36 ft. This should provide adequate room for the cyclotron, beam extractors, and beam line optics, including bending magnets to direct the beams to multiple target stations. There are two target caves, each with internal dimensions of 14 ft. by 16 ft. These are large enough to allow for great flexibility in operation. Ports are provided for delivering beam to several locations within each cave. Target caves are shown with 8 ft. of concrete shielding (except for the west side which is

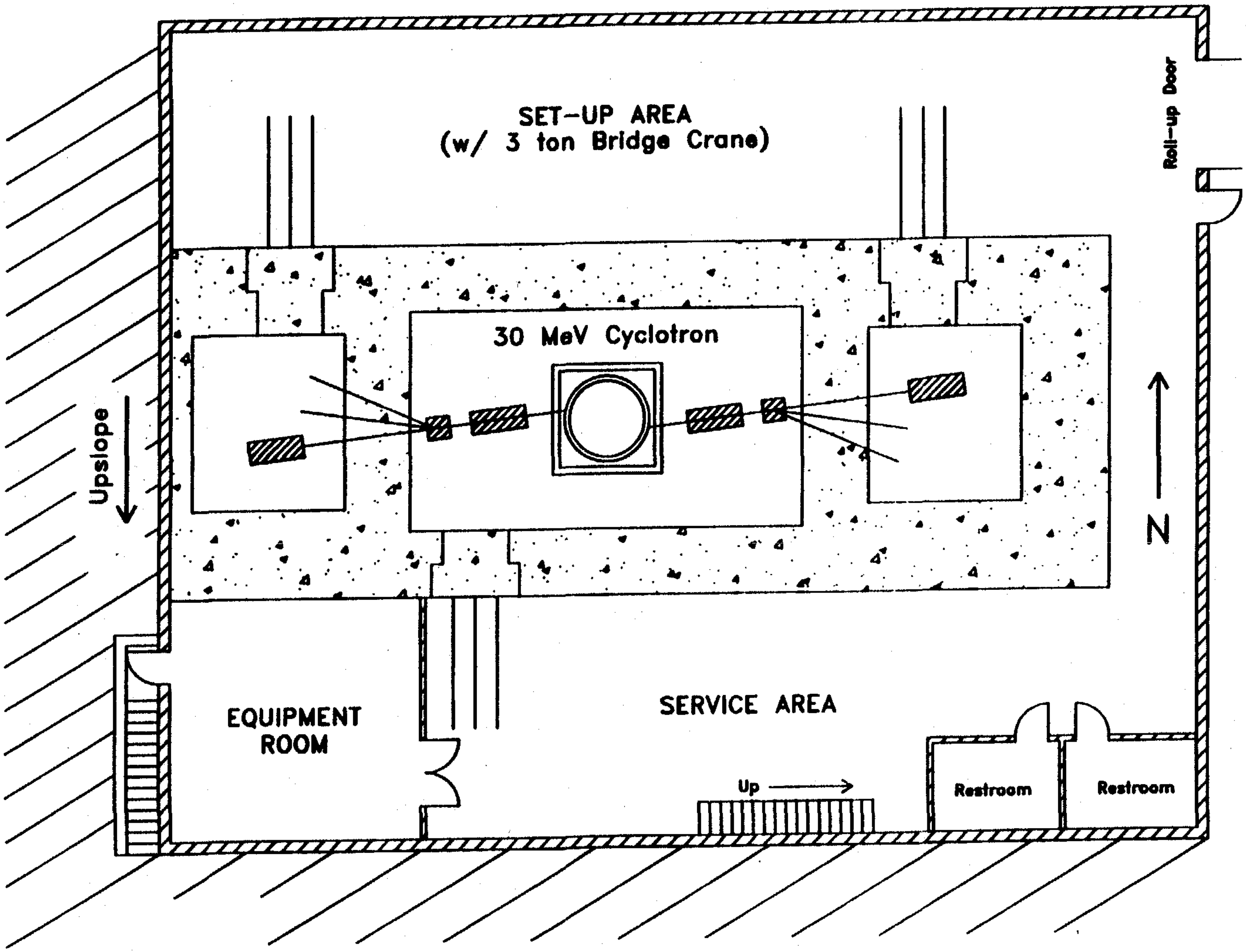


**Fig. 1.1**
**Lower Level Floor Plan for the Proposed NBTF Cyclotron Facility**

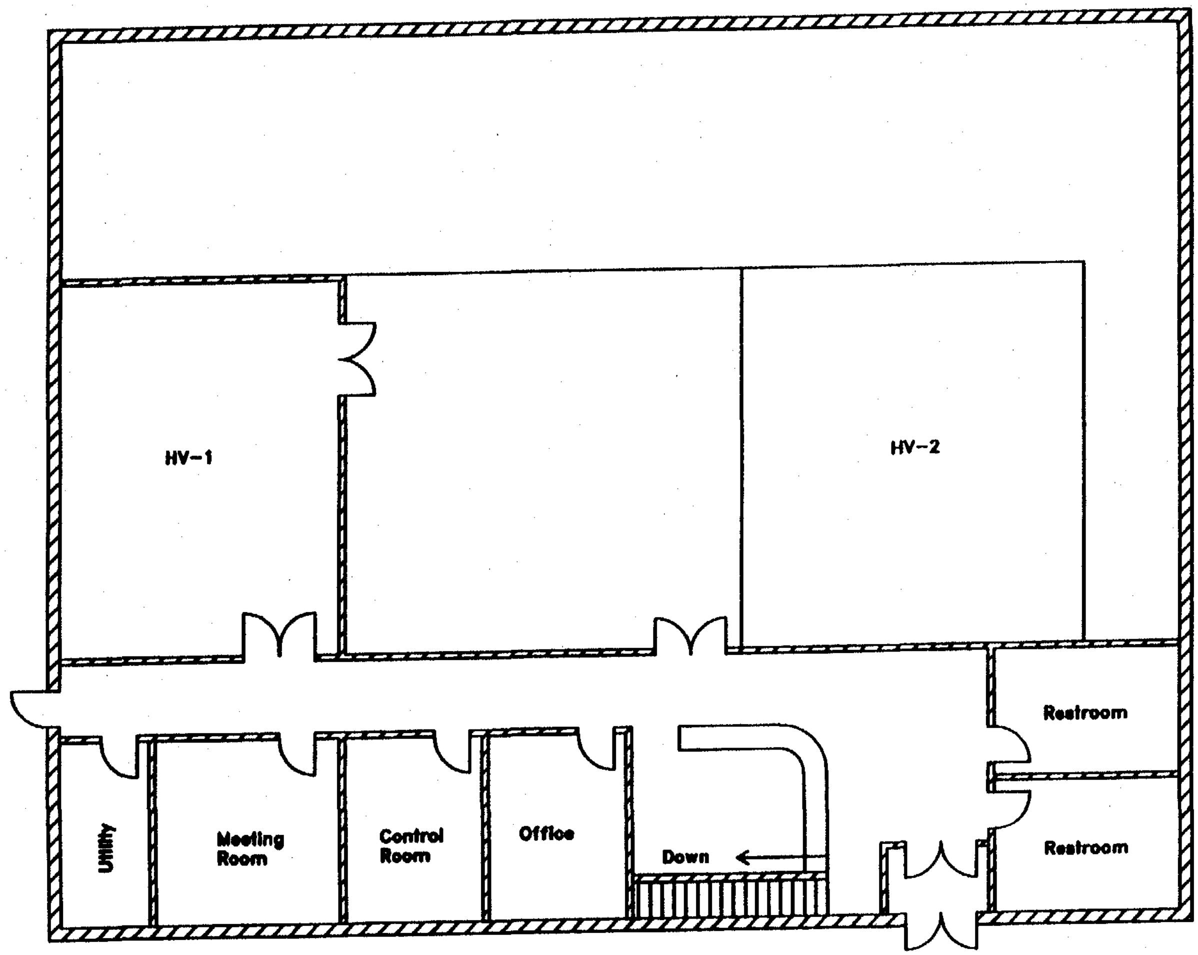


**Fig. 1.2**
**Upper Level Floor Plan for the Proposed NBTF Cyclotron Facility**

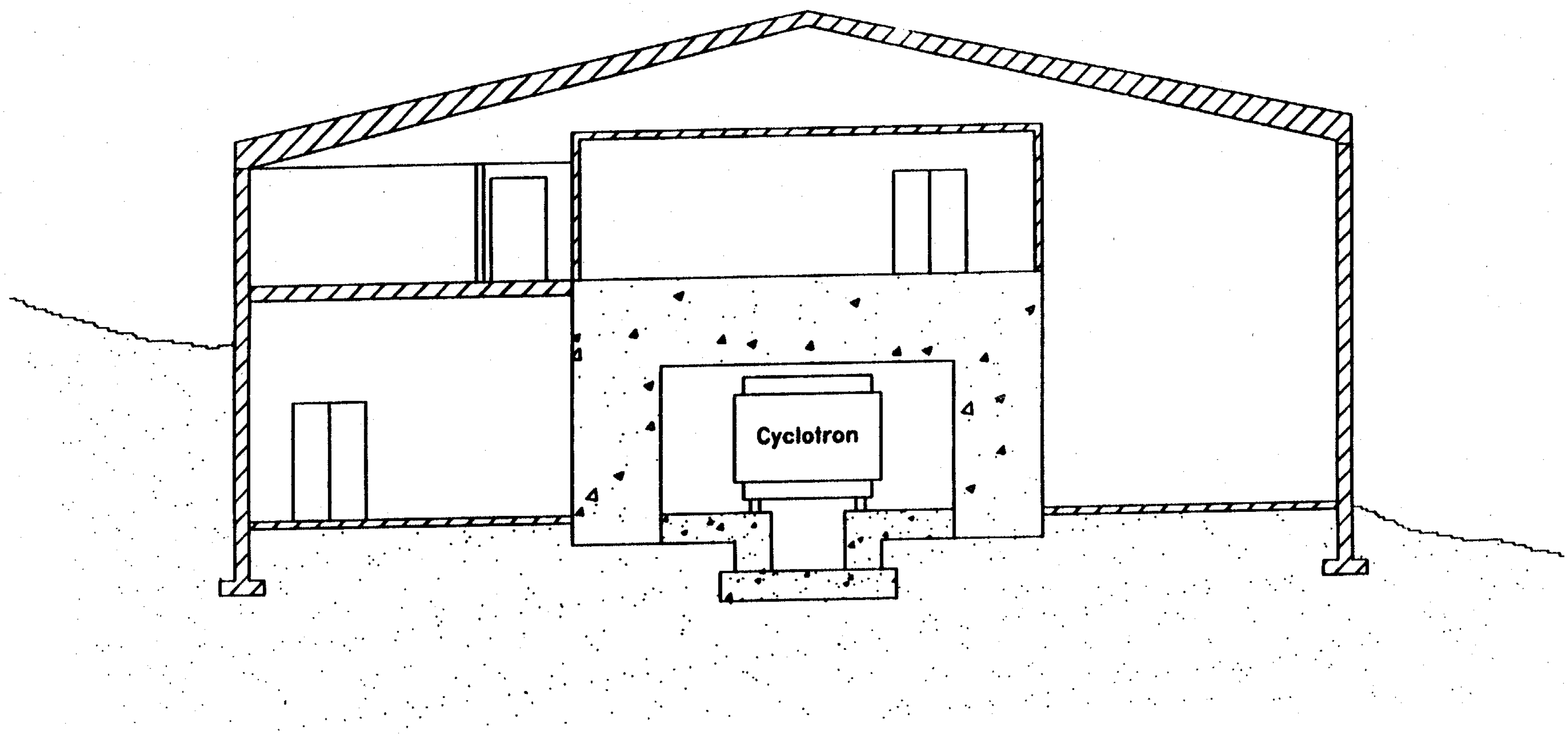


**Fig. 1.3**
**Building Section for the Proposed NBTF Cyclotron Facility**

Los Alamos

underground) while the cyclotron vault is shown with 6 feet of concrete shielding. The actual size and shape of the cyclotron vault and target caves will be optimized during the detailed design phase of the project to allow for the desired operating characteristics at minimum cost.

Service and equipment areas are shown adjacent to the vault. These will contain the electrical and mechanical support equipment for the cyclotron. The entrance to the cyclotron vault is placed in this area to facilitate maintenance activities. Entrances to the target caves are placed on the other side of the facility, so that radioactive and potentially contaminated objects do not have to pass through the service areas when retrieving targets. This design assumes that targets will be retrieved by entering the target caves and placing the targets in shielded casks, which will then be transported on a cart or small fork lift. However, more elaborate target retrieval mechanisms are not precluded and provisions for such systems may be included in the detailed design phase of the project.

A large setup area will be located on the north side of the vault to accommodate future experiments. Fully equipped machine shops are located in an adjacent building and are not needed as part of this project.

Office areas, the accelerator control room, and HVAC equipment will be located on an upper level above the service areas for the cyclotron (Fig. 1.2). The entire facility will be located on a north-facing slope, so that the ground level entrance on the south will be into the upper level, while that on the north side will be into the lower level.

1.2.3. Targetry. The accelerator will be capable of delivering 1 mA of beam to either of two beam lines. With both beam lines operating this means that each beam line will handle 500 μA. For this reason most of the production yields discussed in Section 6 of this document assume 500 μA beam currents. In fact, building targets that can handle that much current will be challenging in many cases, so that we do not expect the cyclotron to be the limiting factor for production.

We have shown one target cave for each beam line, although the design allows for delivery of beam to several locations in each cave. This approach allows the beam line optics to be simple (and low cost) while still allowing for either production or research applications in each cave. Changing between production and research modes will be no more complicated than retrieving and loading the appropriate targets. While it is possible to provide for simultaneous irradiations at more than one target station within a single cave, we have not provided for this in our preliminary design.

There are many designs for cyclotron targets, target stations, and target recovery systems available. At least two such systems can be purchased commercially, although they are expensive and unnecessarily complicated. In addition there are a number of private companies that produce radioisotopes commercially, who have expertise in high current targetry. We believe that acceptable production targets can be developed rapidly and at modest cost for this facility. Development of targets for more esoteric applications is an appropriate research topic for the NBTF, and we anticipate that the NBTF will contribute significantly in this area once it becomes operational.

1.2.4. Accelerator Site. We propose to locate the accelerator building at Los Alamos Technical Area 48, immediately to the west of the main radiochemistry building. The proposed site is sufficiently close to the existing medical radioisotope chemical processing facility that targets can be transported between the two facilities without using public roads and without crossing a perimeter fence.

The proposed location has already gone through a preliminary site approval process, and it was determined that the site is compatible with the Laboratory's Site Development Plan and does not present any other significant planning concerns.

All necessary utilities and services are available in close proximity to the site. These include electrical power, water (fire and domestic), gas, sanitary sewer, radioactive liquid waste, telephone and data lines, parking, and vehicle access. These services can be accessed and sized to meet the facility demand at minimum cost.

The proposed site is currently occupied by two temporary office structures; these will be relocated. The relocation is part of the proposed project, and costs are included.

1.2.5. Facility Classification. We anticipate that the proposed accelerator will be classified as a Radiological Facility, since the expected radioisotope inventories fall well below the category 3 values listed in DOE Standard 1027. As such it will be exempt from the requirements of DOE Order 5480.23, which applies to Nuclear Facilities. The facility will be subject to the requirements of 10 CFR 835 and it will be necessary to prepare an Authorization Document, which will essentially consist of a safety assessment. Since it will be an accelerator facility it will also be covered by DOE Order 5480.25. For additional information on permits and regulatory requirements see Section 4 of this document.

## 1.3. High Energy (100 MeV) Irradiation Facility.

One difficulty inherent in any NBTF proposal is satisfying the requirement for 100 MeV beam energies when there are apparently few isotopes that require these energies, and most of those that do are not likely to generate large revenues. Implementation of this capability can only be justified if the cost of constructing and operating such a facility is extremely low. Fortunately such low costs can be realized by using a portion of the existing LAMPF accelerator to provide the necessary beam. This beam can be provided at low cost regardless of whether the accelerator is operated by other programs.

1.3.1. Description of the Existing 100 MeV Accelerator. The LAMPF accelerator is made up of three components: an injector, which accelerates protons to 750 KeV, a drift-tube linac (DTL), which further accelerates the beam to 100 MeV, and a side-coupled cavity linac (SCCL), which then accelerates the beam to 800 MeV. There is a region between the DTL and the SCCL, known as the transition region, from which 100 MeV protons can be diverted for experimental use. This capability was designed into the LAMPF facility when it was built, but has never been implemented. By installing appropriate magnets in the transition region and building a short beam line out the side of the existing facility, a high-current 100 MeV proton beam can be obtained at extremely low cost.

The DTL at LAMPF is capable of accelerating both positive and negative hydrogen ions ($H^+$ and $H^-$) at beam currents greater than 1 mA. In its present mode of operation (FY 1995) it will accelerate 1 mA of $H^+$ and 100 μA of $H^-$ beam simultaneously; all of this will be injected directly into the SCCL for further acceleration to 800 MeV. If implemented properly, beam currents between 100 μA and 250 μA can be diverted from the transition region for isotope production without interfering with other experimenters in other parts of the facility. Under some circumstances a full mA of beam current could be provided.

Isotope production can be performed with either $H^+$ or $H^-$ beam, depending on which is more readily available. This decision does not have to be made until the design of the beam diverter is finalized. If the primary users of LAMPF require only $H^-$ beam, which seems likely when LANSCE becomes the main focus, then we will choose to use $H^+$ beam, since this can be accelerated simultaneously at virtually no cost to the isotope production program. Conversely, if major experiments in accelerator transmutation get funded, which seems less likely, these would require all the $H^+$ beam available, and we would choose to use $H^-$ beam. $H^+$ can be extracted by installing a simple diverter magnet within the transition region. Extraction of $H^-$ beam will require installation of a pulse (kicker) magnet, which will divert portions of the beam at the desired repetition rate.

1.3.2. Description of the Proposed Targeting Facility. The proposed targeting facility includes a short beam line out the north side of the existing accelerator building, a target station where the irradiations will take place, and a system for loading and retrieving targets. Design of all of these systems depends on the type of targeting station used. There are several examples of target systems for proton beams of the desired energies and intensities. These include systems currently in use at TRIUMF, Brookhaven National Laboratory, and at the Institute for Nuclear Research at Troitsk in Russia. The system proposed here includes features from all of these facilities.

The beam line at LAMPF is located 21 feet below ground level, while the floor of the beam line channel is 27 feet below ground level. Thus the new beam line will also be underground, requiring excavation and construction of a short tunnel and a cave for the target station. Fig. 1.4 shows a possible layout for beam line and target station. The targets themselves will be located in the center of a large shield, 10 feet on a side, constructed of steel, which is in plentiful supply at most large accelerator complexes. This confines the activation to a small volume and provides the maximum amount of shielding around the small target volume. While the beam enters the shield cube horizontally, the targets will be inserted and removed vertically from the top. In this way the targets can be loaded and retrieved without requiring personnel access to the target cave. The target cave will only need to be entered occasionally to perform maintenance on the beam line and the beam line exit window.

After irradiation, targets will be pulled vertically into a hot cell located at ground level above the target shield (Figs. 1.5 and 1.6). Manipulators will be used to remove the target from its holder and place it in a transport cask. The ground level facility will be equipped with an overhead monorail crane that can be used to load the cask onto a truck for transport to the chemical processing facility. Protocols for transferring irradiated targets between technical areas at Los Alamos already exist and are currently in use.

The beam line itself will be 61.5 feet long from the diverting magnet to the target. A removable beam stop will be provided at the wall of the existing beam transport channel. This is necessary to isolate the isotope production beam line from the rest of the accelerator during maintenance activities. Room is provided for focusing magnets and beam diagnostics, which are needed to control the position and profile of the beam on the targets. Vacuum pumps will be located within the beam line tunnel. Sufficient room is provided within the tunnel so that maintenance activities can be carried out easily and safely. Since most of the activation takes place within the steel target shield, we anticipate that radiation levels within the target cave (with beam off) will be acceptably low for knowledgeable personnel to work within the cave when necessary.

Targets will be cooled by high-pressure recirculating water. This will be a closed system, with water purification and monitoring systems to detect any problems with target

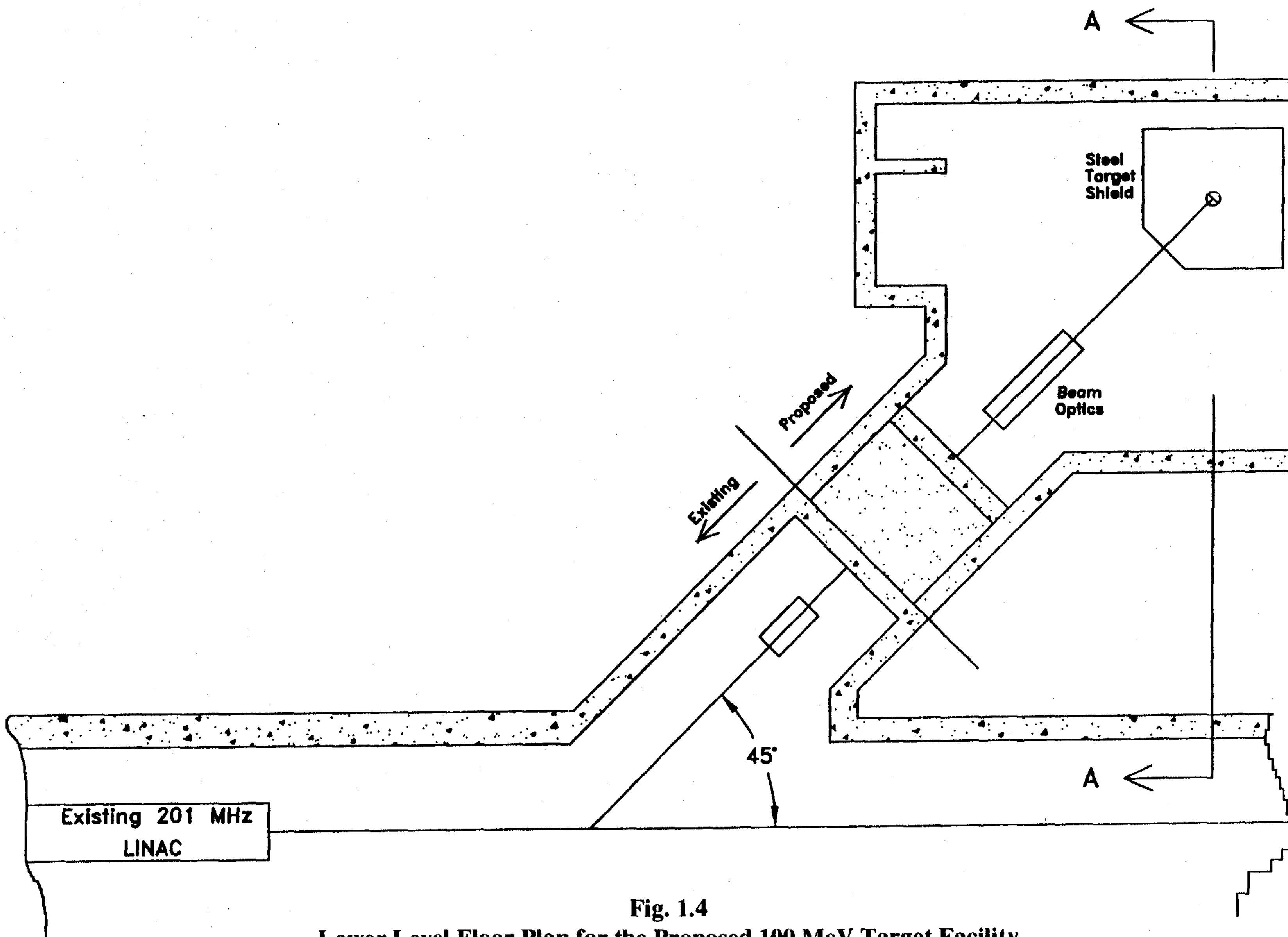


**Fig. 1.4**
**Lower Level Floor Plan for the Proposed 100 MeV Target Facility**

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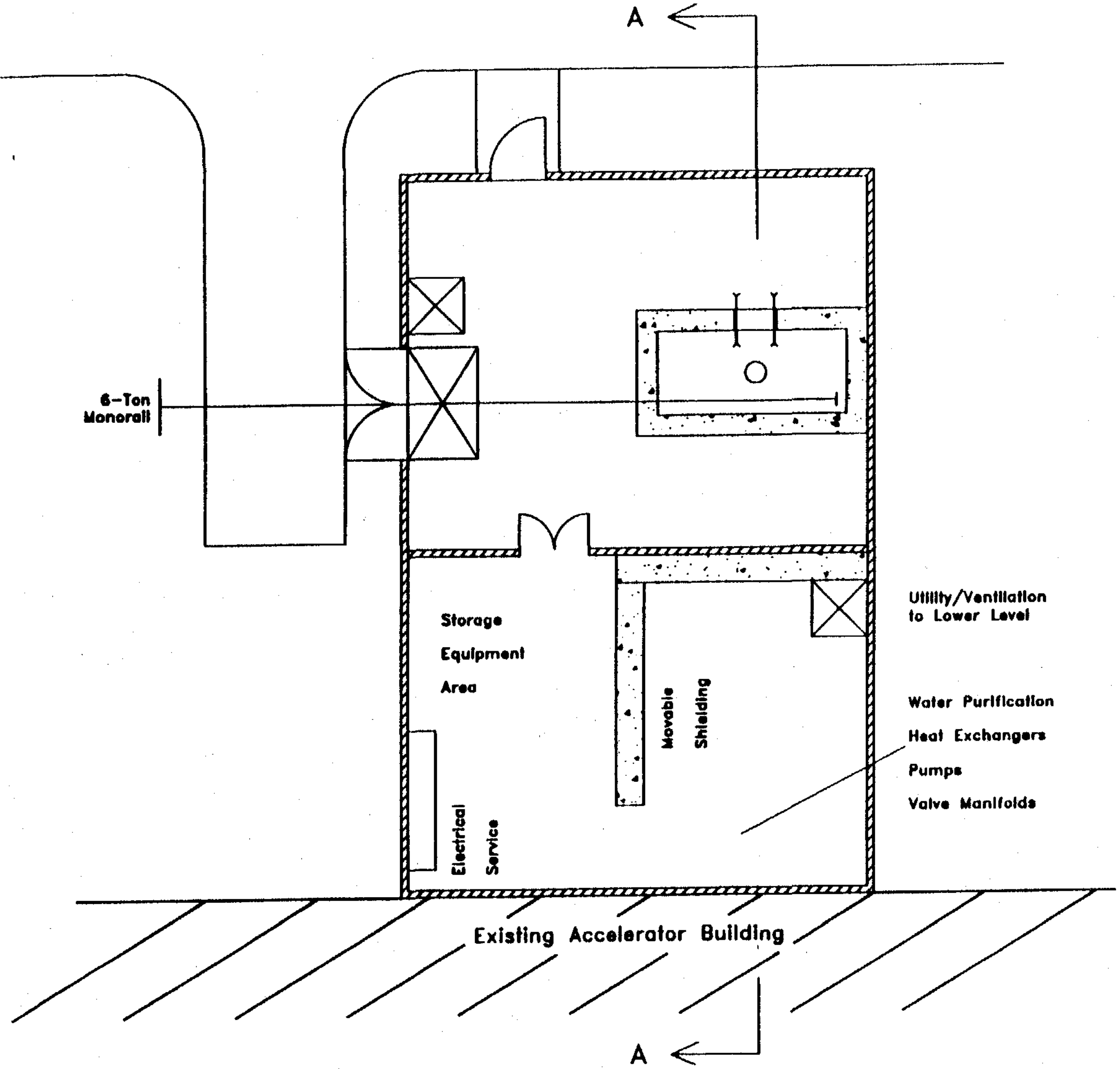



**Fig. 1.5**
**Upper Level Floor Plan for the Proposed 100 MeV Target Facility**

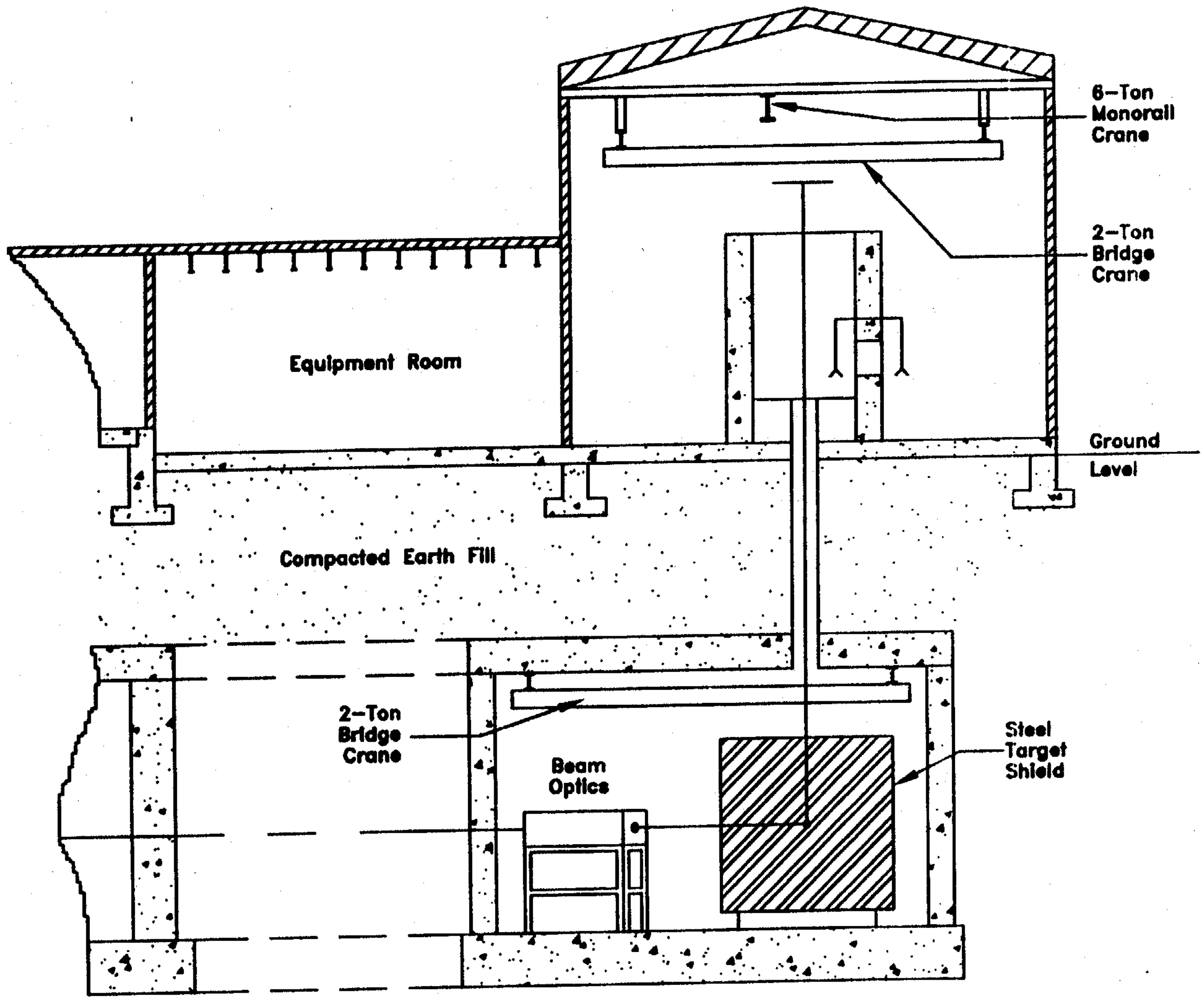



**Fig. 1.6**
**Cross-Section of the Proposed 100 MeV Target Facility**

containment. A heat exchanger will be used to transfer excess heat to an existing circulating water system at LAMPF. The heat exchanger is necessary to isolate the isotope production target cooling system from the LAMPF system, which is used to cool other equipment in the facility.

The remaining areas of the facility will house the power, control, monitoring, and HVAC systems needed to operate and maintain the beam line and target handling facility.

This design, which places the beam line and target station in an underground shielded cave and effectively separates the irradiation area from personnel access areas, maximizes operational efficiency while minimizing radiation exposures. With an accelerator capable of delivering mA currents at 100 MeV, controlling personnel radiation exposures and containing radioactive contamination will be very significant issues.

1.3.3. Advantages of the Proposed Irradiation Facility. Construction of the proposed irradiation facility has a number of advantages over possible alternatives. These include: (1) the low capital cost, (2) the sharing of operational cost with other programs, (3) the fact that maintenance of the accelerator is covered by other programs, (4) the existence of all the infrastructure needed to operate a major accelerator facility, and (5) the fact that all required permits and regulatory controls for the accelerator are in place.

Because the accelerator already exists, the considerable cost of designing and constructing a new accelerator and its associated building can be avoided. This alone can save tens of millions of dollars in capital costs. Furthermore, the existing accelerator has proven itself over a period of more than twenty years. With recent upgrades LAMPF has been able to supply beam at full power for 95 percent of its scheduled operating time.

Other programs pay the base cost of maintaining and operating the LAMPF facility. Isotope production can be carried out for only the cost of maintaining the 100 MeV beam line and the incremental cost of accelerating beam for the target station. This can be done regardless of whether the accelerator is delivering beam to other experimenters.[1] Thus the cost of delivering 100 MeV beam to the targeting station is much lower than could ever be achieved at a dedicated isotope production accelerator. Operating costs are described in detail in Section 6 of this document.

The maintenance costs for a high powered accelerator are considerable. This includes power supplies, RF power systems, vacuum systems, beam transport systems,

[1]This is possible because the injector and DTL account for only a small fraction of the operating costs of LAMPF. Use of 800 MeV beam solely for isotope production is prohibitively expensive and has never been proposed. However, generating 100 MeV beam solely for isotope production is well within the realm of possibility. This is important because it liberates isotope production activities from constraints imposed by the LAMPF/LANSCE operating schedule.

control and interlock systems, and a host of other items. These are currently paid for by other programs. Because the DTL represents a small fraction of the total LAMPF/LANSCE facility and because it is necessary for everyone, it is likely that this will continue to be the case into the indefinite future.

Operation of a major accelerator facility requires a large number of activities that are best described as infrastructure. This includes health physics, occupational safety, radiological control, environmental compliance activities, to mention a few. These are all in place and functioning at the proposed site. Furthermore the cost is spread over a large number of programs, so that isotope production will not need to support these activities alone.

Finally, construction of a new facility requires a large number of permits and may include an environmental assessment (EA) or even an environmental impact statement (EIS). These requirements can delay construction of a project for years and can even prevent it from being constructed at all. In the case of the proposed facility, operating permits for the accelerator are already in place, and the LAMPF/LANSCE complex is included in the Los Alamos site-wide environmental impact statement. Consequently most of the requirements are already satisfied. The permit status of the targeting facility is discussed in Section 4 of this document; most of the requirements are already satisfied and we anticipate no difficulties or delays in satisfying the remainder.

1.3.4. Facility Classification. We anticipate that the proposed target facility will be classified as a Radiological Facility, since the expected radioisotope inventories fall well below the category 3 values listed in DOE Standard 1027. As such it will be exempt from the requirements of DOE Order 5480.23, which applies to Nuclear Facilities. The facility will be subject to the requirements of 10 CFR 835 and DOE Order 5480.25, since it is part of an accelerator facility. For additional information on permits and regulatory requirements see Section 4 of this document.

1.3.5. The Future of the LAMPF/LANSCE Complex. Over the past several years there has been some confusion and even some misinformation about the future prospects of LAMPF and the associated facilities. In fact the accelerator has undergone a number of upgrades and is operating with much greater reliability than in the past. Program plans for the latter part of this decade call for full power operation for 8 months per year. We expect this facility to continue operations will into the next century.

Confusion over the future of LAMPF began when the DOE Office of High Energy Nuclear Physics (OHENP), which had been the prime sponsor for LAMPF, announced that it intended to cease funding of operations in FY 1994. Since that time the primary research mission at LAMPF has been shifting from nuclear physics to neutron science research. The prime support for the facility will shift from Office of Energy Research to Office of Defense Programs in FY 1996. Instead of decommissioning the facility, the Department has supported significant upgrades to the accelerator, which have greatly improved the reliability and operating effectiveness, and is continuing to modify the Los Alamos Neutron Scattering Center (LANSCE) and the proton storage ring. Several major experiments in the area of accelerator conversion technologies are being studied; it is likely that at least one of these will be funded. There remains a large user community for LAMPF/LANSCE, that includes experimenters from all over the world.

What this means for the NBTF is that the accelerator at LAMPF will be maintained and operated well into the next century, and that the 100 MeV proton beam will be available. Furthermore, the cost of generating that beam can be shared with other programs, so that the effective accelerator operating costs will be lower than could be achieved at a dedicated facility.

1.3.6. Other Irradiation Possibilities. The accelerator complex at LAMPF offers additional irradiation possibilities that complement the proposed 100 MeV target facility. The additional capabilities can be utilized at essentially no cost to the isotope production program and may significantly enhance the capabilities of the proposed NBTF.

1.3.6.1. Irradiation with 800 MeV Protons. The Los Alamos Radioisotope Program has historically used 800 MeV protons to carry out irradiations at the Isotope Production Facility (IPF), which is located at the extreme east end of the accelerator complex. The 800 MeV production method is well suited to certain long-lived isotopes that are produced by spallation reactions. One such example is Silicon-32. For many other isotopes irradiation with this high energy beam is inconvenient because of large amounts of unwanted activation products produced and because of the difficulties associated with retrieving and transporting irradiated targets.

Thus the best use of the 800 MeV irradiation capability would be for production of long-lived radioisotopes, that would require very infrequent target retrievals, perhaps once per year. Accordingly we have designed a target canister that can be inserted into beam from a vertical insert. This could be used at any point in the main proton beam where access can be gained for such an insert, and would allow production of the long-lived spallation products even after the present isotope production facility is decommissioned. This would be a highly desirable isotope production capability, provided that it was complemented by the proposed 100 MeV irradiation capability.

1.3.6.2. Isotope Production with Spallation Neutrons. Since the main focus of future research at LAMPF will be neutron science, there will be at least one and (probably more) target areas for production of spallation neutrons. This makes possible the use of such neutrons to irradiate isotope production targets, and we have always assumed that our isotope production program would carry out at least some such irradiations.

The use of neutrons for isotope production complements proton beam production. This is because the isotope produced with proton irradiation tend to be neutron-deficient, while those produced with neutron irradiation tend to be neutron-rich. Thus the addition of neutron irradiation capability would be a significant enhancement to the isotope production program.

Isotope production using spallation neutrons can be done in three ways, depending on the energies of the available neutrons. If the neutrons are thermalized, then the production mode is indistinguishable from that of a reactor. A host of isotopes could be made using (n,γ) and (n,fission) reactions. Because there are very few operating reactors available for isotope production in the United States, this would be a valuable resource. Proposals to use this neutron source are being advanced to the feasibility study stage. The efficacy of this idea depends on the magnitude of the available thermal neutron flux and on the cost of the irradiation process.

More energetic neutrons could be used to make isotopes with (n,p) reactions. The products of these reactions are chemically distinct from the target materials, which allows for easy separation of the radioactivity from the bulk of the target. In this way neutron rich isotopes could be made with very high specific activities. This would represent a unique isotope production capability.

Since the total number of neutrons from the spallation target is limited, and since the volume around the spallation target suitable for irradiating targets is limited, the isotope production program would have to compete with other experimenters for irradiation time. Fortunately the technology for inserting and retrieving targets from areas of intense neutron bombardment is well developed, and a great deal of flexibility can be incorporated into such systems. Thus it should be possible for isotope production to coexist with a number of other experimenters at such an irradiation facility.

## 2. CHEMICAL PROCESSING AND LABORATORY FACILITIES

We propose to use existing hot cell and chemical laboratory facilities located at Los Alamos Technical Area 48 to carry out target processing and radioisotope research activities. These facilities are shown schematically in Figure 2.1. Technical Area 48 is the main radiochemistry site at Los Alamos and it encompasses many programs involving nuclear and radiochemistry. These same facilities have been used for medical radioisotope research and production for more than twenty years; they are fully operational and all required permits and regulatory protocols are in place. The hot cells and the radiochemical counting capabilities are among the best in the world for the types of operations needed for the NBTF. By using these facilities in conjunction with the proposed accelerator and targeting systems, the NBTF project can benefit from both the physical plant and decades of radiochemical experience while incurring no capital costs.

### 2.1. Hot Cell Facility.

The hot cell facility contains 12 chemical processing cells plus an additional large cell for carrying out mechanical tasks. Each of the cells is individually shielded and each contains a full suite of utilities including electrical power, compressed air, vacuum, deionized water, tap water, and drain. Materials can be moved in and out of the cells and between cells using the hot cell train without passing through or interfering with work in adjacent cells. Essentially any operation that can be performed on a laboratory bench can be (and probably has been) performed in these hot cells.

In addition to chemical processing, these cells provide for in-situ radiochemical counting, in-cell sample weighing, and packaging of materials for shipment. The in-cell counting capability is particularly useful, since it allows one to obtain gamma spectra of very hot samples without having to perform dilutions or removing samples from the cell. There are two high-purity germanium detectors in the facility, plus a variety of other analytical capabilities, which are discussed in Section 2.2 below.

The cells have 20 in. of high density concrete shielding in the front and equivalent amounts between adjacent cells. The backs of the cells are accessible through 8 in. thick steel doors. This amount of shielding is sufficient for 1000 Ci of mixed fission products, and is more than adequate for the activities expected for the NBTF. It should be possible to carry out all of the chemical processing activities for the NBTF while maintaining very low radiation exposures.

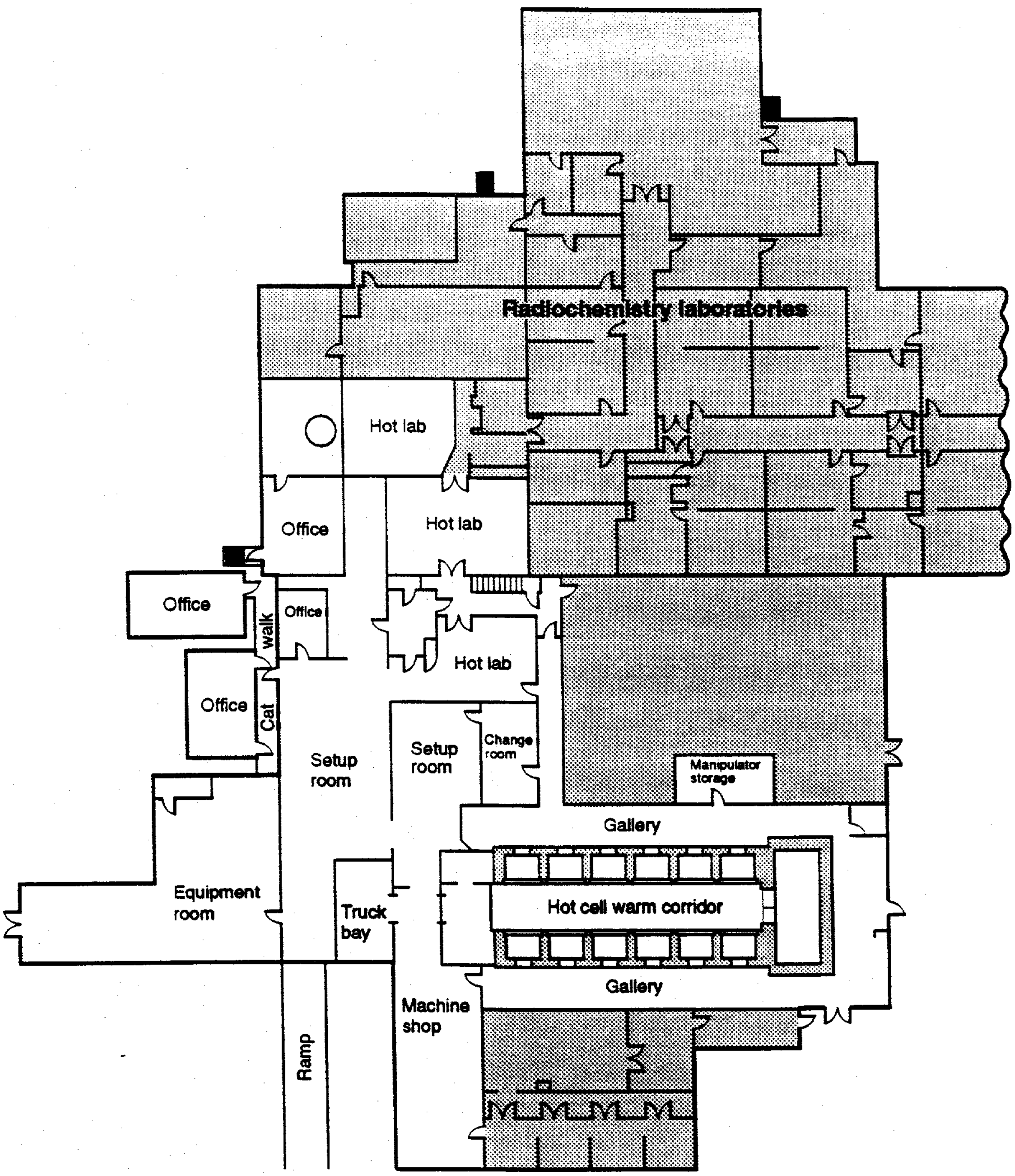



**Fig. 2.1**
**Floor Plan for the Existing Hot Cell Facility at Los Alamos Technical Area 48**

**Los Alamos**

The windows in the hot cells are constructed of multiple lead glass panes with mineral oil between the panes. These were obtained from several manufacturers, including Corning, Schott, and Penberthy, although the designs are similar. Every window has been serviced on both the hot and cold sides within the past four years; all are clear and in excellent condition.

There is a very capable machine shop located within the hot cell area. This is equipped with two lathes, two milling machines, a radial drill press, two band saws, grinders, a press, and an arc welding area. This shop is within the radiological area and can accommodate contaminated materials, if needed. This shop, along with the main machine shop, located in the basement of the same building, can adequately service both the hot cell facility and the cyclotron facility, which we propose to site nearby.

The hot cell facility was built in 1961 as a part of the Rover program. It was specifically designed for chemical processing of highly radioactive materials and is ideally suited for that purpose. Since 1974, when target irradiations at LAMPF were begun, this facility has been used exclusively for medical radioisotope research and production. It is well maintained and is in excellent condition.

The hot cell ventilation system is currently undergoing a major upgrade; this will be completed in August, 1995. This upgrade will bring the hot cell exhaust filtration and stack monitoring systems into compliance with current regulations. In addition the entire building is scheduled for a major electrical upgrade in 1997. That upgrade is not part of, and is not related to the current proposal.

When comparing the processing needs of the proposed NBTF to those for processing targets from LAMPF, we expect the NBTF to produce a larger number of targets, but those targets will be smaller and will contain substantially less unwanted activity. The result will be reduced radiation exposures and less radioactive waste. This facility can easily accommodate the increased number of targets. Since the actual processing activities are virtually the same for the current operations and the proposed NBTF, the facility is already set up and optimized for those activities.

## 2.2. Laboratory Facilities.

Chemical laboratory facilities are just as important as the hot cell facility, since most of the applications and development work will be done in these areas. Fortunately, Los Alamos Technical Area 48 has excellent chemical and radiochemical laboratory facilities. These are located both within and adjacent to the hot cell facility.

The hot cell facility itself encompasses seven chemical fume hoods, and an equivalent amount of laboratory bench space, all of which can accommodate radioactive materials. These areas are currently used for development work and for chemical analysis of radioisotope products. Also within the hot cell laboratory areas are a direct current plasma emission spectrophotometer (DCP) and an inductively coupled plasma emission spectrophotometer (ICP), which are used for stable element analysis of radioactive materials, both for the isotope production program and for environmental restoration projects.

Adjacent to the hot cell facility, and in the same building, are many individual radiochemistry laboratories. All are equipped with chemical fume hoods and large amounts of laboratory bench space. Collectively these laboratories contain nearly every type of chemical laboratory instrumentation imaginable, particularly those that relate to radiochemistry. These areas are supported by a number of research programs, including the medical radioisotope program. The programmatic mix changes along with the financial prospects of the various programs. A substantially larger biomedical research effort could be accommodated if the financial support were available.

## 2.3. Radiochemical Counting Capabilities.

The Los Alamos radiochemistry site has counting facilities that rank among the best in the world; these are located a short distance down the hallway from the hot cell facility. The count room maintains and operates more than 60 detection systems at the current time. These include high resolution gamma detectors, which represent the main effort in this area, alpha particle detectors, suitable for both gross alpha counts and alpha spectrometry, and beta counters. The counting systems, including those located in the hot cell area, are connected to a VAX cluster through a local area network, which allows data to be sent from counting systems to the VAX for processing and archiving.

## 2.4. Packaging and Transportation Capabilities.

Because there is an active radioisotope research and distribution program at Los Alamos, capabilities for packaging, transporting, and shipping radioactive materials are already in place. An inventory of certified Type A packages is kept on hand, and all the necessary procedures for documentation and invoicing have established. Shipping is carried out through Federal Express, which can deliver anywhere in the USA within one day. The program currently makes more than 150 shipments per year to customers all over the world.

2.5. Quality Assurance.

The Medical Radioisotope Program has a quality assurance program in place for its production program. Production activities are carried out in compliance with FDA Good Manufacturing Practices (GMP) as applied to bulk manufacturers. This is necessary for supplying Strontium-82 for pharmaceutical use and for supplying other isotopes for clinical trials. These procedures can be transferred to the proposed NBTF with no modifications.

Quality assurance for radiochemical detectors is maintained by the count room. Records are archived both in computer data bases and on hard copy. Balances and scales are checked periodically and records are kept by the Laboratory calibration lab. Product assays are traceable to NIST standards.

2.6. Facility Classification.

In 1993 the Laboratory relaxed the entrance requirements for Technical Area 48; security clearances are no longer required to enter this area. This makes possible the use of students and post doctoral staff on a routine basis. In fact there has been a large influx of such individuals to the area for a wide range of programs over the last two years. This is important because it makes the exceptional facilities located within the technical area available for the education and training mission of the NBTF.

The hot cell facility and the laboratory areas are currently classified as radiological (not nuclear) facilities according to DOE Standard 1027. As such they are exempt from the requirements of DOE Order 5480.23. Like all radiological facilities they are subject to the requirements of 10 CFR 835 and they do require an authorization document. The authorization document consists of a safety analysis for the site; this is currently being updated because of the changing programmatic priorities assigned to the area. For more information in permits and regulatory requirements, see Section 4 of this document.

## 3. PROJECT COSTS

The total project cost for the NBTF as described in this study is estimated to be $15.2M. The breakdown of this cost and the design basis for the estimates used to derive this cost is described in detail below.

**Total Project Cost $15.2 M**

The following discussion is divided into three parts. The first part describes the overall cost of the project, including design and construction of the cyclotron facility, design and construction of the 100 MeV target facility, and the project management costs. The second part discusses the construction costs for the cyclotron facility, and the third details the construction costs for the 100 MeV target facility.

### 3.1. Project Plan.

A capital project will be executed in order to create the proposed new irradiation facilities that when combined with the existing TA-48 facilities will form the NBTF. This section outlines the project planning elements required to execute the project. In summary it is found that :

- The Total Estimated Cost for the project is $14.2M. This includes engineering design, construction, capital equipment, and project management costs.

- The Other Project Costs are estimated to be $1.0M. This covers costs incurred by planning activities before initiation of capital funds expenditure and costs incurred making the transition between construction completion and operations.

- The schedule duration from initiation of the project to the beam on target in both the 100 MeV Target Area and the 30 MeV Cyclotron Facility is 2 1/2 years.

3.1.1. Project Activities. The project naturally breaks into two subprojects, the 30 MeV Cyclotron Facility and the 100 MeV LAMPF Target Area, that can be executed independently. These two subprojects occur at entirely separate sites and have no activities that are dependent upon activities in the other subproject.

There are a few activities that are umbrella activities for the project. These are environmental assessment and safety analysis report activities. In principal these could be broken down into two separate environmental assessments and safety analysis reports specific to each subproject. This is not recommended however since it increases the cost and difficulty for completing the project.

The general activities that will make-up the project are described as follows.

3.1.1.1. Environmental Assessment - Write, Review, FONSI. The LANL ES&H questionnaire and the DOE Environmental Checklist will be filled out. The appropriate NEPA documentation type will be determined from the results of the check list. It is anticipated that an Environmental Assessment will be prepared and submitted to DOE for review. It is also anticipated that a Finding of No Significant Impact (FONSI) will be issued. The FONSI must be issued before construction can be initiated.

3.1.1.2. Preliminary Safety Analysis Report - Write, Review, Approve. A preliminary safety analysis report will be written during the conceptual design development. It will be submitted for review by DOE. Approval of the PSAR is required prior to initiation of construction. It is assumed that the entire NBTF program, which involves a new 30 MeV Cyclotron Facility, a new 100 MeV LAMPF target area, the TA-48 hot cells, and transportation, can be covered in a single safety analysis.

3.1.1.3. Final Safety Analysis Report. A final safety analysis report will be written and approved after all the facilities and program development have been completed.

3.1.1.4. 30 MeV Cyclotron Facility Design - Conceptual, Title I, Title II. The 30 MeV cyclotron facility will be designed in three stages. A conceptual design report will be written to establish requirements and criteria, determine facility configuration, and determine system schematics and design sizes. The Title I design will verify the conceptual design with detailed calculations and carry the design to approximately 30% completion. The Title II design will complete the construction drawings.

3.1.1.5. 30 MeV Target Chamber / Experimental Equipment Design. Drawings and specifications will be produced for fabricating the target chamber, target handling equipment, and beam stop.

3.1.1.6. 30 MeV Cyclotron Facility Construction. The facility will be constructed. Construction activities commence with surveying and excavation, and end with facility turnover after final inspection.

3.1.1.7. 30 MeV Cyclotron Fabrication. The cyclotron will be purchased from a commercial vendor who builds, installs, and starts-up cyclotrons.

3.1.1.8. 30 MeV Equipment Fabrication. The experimental equipment will be fabricated and assembled by custom equipment shops with vacuum system and remote handling expertise.

3.1.1.9. 30 MeV Cyclotron and Equipment Installation. The cyclotron vendor will install the cyclotron and beam lines. The placement of the cyclotron will occur by lowering it through an opening in the roof using a crane or helicopter. Completion of the roof will occur after the cyclotron is placed. This activity includes installation of the target chambers and experimental equipment.

3.1.1.10. 30 MeV Start-up Preparation. Advance writing of operating procedures, technical safety requirements, and training program manuals is required. These will be drafted early to assure that operations plans are reflected in the design and to provide advance preparation for taking over the facility from the project team.

3.1.1.11. 30 MeV Training. Staff will be trained as required for working in the cyclotron facility safely and for producing quality products.

3.1.1.12. 30 MeV Operations Readiness Assessment. An operations readiness assessment will be performed to demonstrate that the facility and systems function properly and that appropriate regulations and requirements have been met.

3.1.1.13. 30 MeV Low Current Testing. Low current ( a few micro-amps) testing will be performed to verify that the cyclotron, beam optics, and target chamber and experimental equipment perform properly.

3.1.1.14. 30 MeV Full Current Irradiation Qualification. Full current irradiations will be performed to verify that the cyclotron, beam optics, and target chamber and experimental equipment perform properly.

3.1.1.15. 100 MeV LAMPF Target Facility Design - Preliminary, Title II. The 100 MeV LAMPF Target facility will be designed in two stages. A conceptual / preliminary design report will be written to establish requirements and criteria, determine facility configuration, determine system schematics and design sizes, and achieve approximately 30% drawing and specification completion. The Title II design will verify the preliminary design with detailed calculations and complete the construction drawings.

3.1.1.16. 100 MeV Target System and Equipment Design. Drawings and equipment lists will be produced for fabricating the target chamber, target handling equipment, and beam stop. The hot cell design is included in this activity as well.

3.1.1.17. 100 MeV Facility Construction. The facility will be constructed. Construction activities commence with surveying and excavation, and end with facility turnover after final inspection.

3.1.1.18. 100 MeV Target Chamber / Experimental Equipment Fabrication. The experimental equipment will be fabricated and assembled by custom equipment shops with vacuum system and remote handling expertise.

3.1.1.19. 100 MeV Experimental Equipment Installation. The target chamber, beam line, target handling equipment, and hot cell will be installed. The target chamber must be installed before the roof is placed on the lower level target room.

3.1.1.20. 100 MeV Start-up Preparation. Advance writing of operating procedures, technical safety requirements, and training program manuals is required. These will be drafted in parallel with the design development to assure that operations plans are reflected in the design and to provide advance preparation for taking over the facility from the project team.

3.1.1.21. 100 MeV Training. Staff will be trained as required for working in the target facility safely and for producing quality products.

3.1.1.22. 100 MeV Operations Readiness Assessment. An operations readiness assessment will be performed to demonstrate that the facility and systems function properly and that appropriate regulations and requirements have been met.

3.1.1.23. 100 MeV Low Current Testing. Low current ( a few micro-amps) testing will be performed to verify that the beam optics, target chamber, and experimental equipment perform properly.

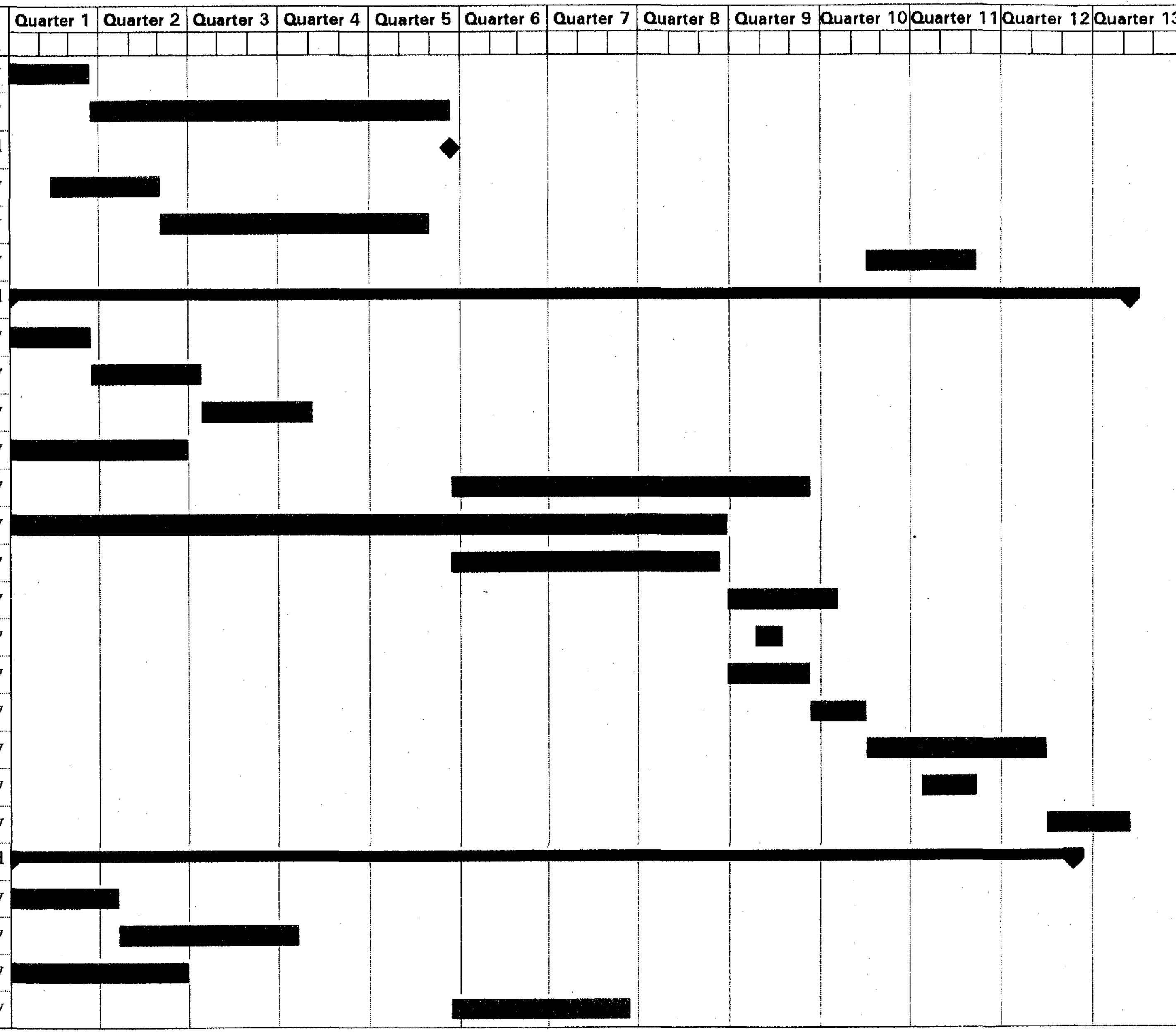
3.1.1.24. 100 MeV Full Current Irradiation Qualification. Full current irradiations will be performed to determine appropriate 100 MeV production methodology and demonstrate that the beam optics, target chamber, and experimental equipment perform properly.

3.1.2. Project Schedule Analysis. A project schedule for the activities described above is given on the following pages. The schedule indicates that it will take approximately 2 1/2 years from initiation of the project to first beam delivery from the 30 MeV cyclotron and about 3 years until full scale isotope production would be underway using this machine. The limiting schedule element is the cyclotron manufacturing and delivery time which is estimated to be two years. It should be noted that it has been assumed that the cyclotron purchase order can be placed when the project is initiated. There is a risk that this may not be allowed since such a major purchase could be considered to be a bias in the environmental assessment process.

It will take approximately 2 1/4 years from project start to first beam delivery at the 100 MeV LAMPF target station. In this case the limiting element is the review of the environmental assessment and the issuance of the FONSI. It was assumed that the EA

NBTF Project Schedule

| ID | Name | Duration |
|---|---|---|
| 1 | Write EA | 12w |
| 2 | DOE Review EA | 52w |
| 3 | Issue FONSI | 0d |
| 4 | Prelim Safety Anal Rept | 16w |
| 5 | PSAR Review | 39w |
| 6 | Final Safety Anal Rept | 16w |
| 7 | 30MeV Cyclotron Project | 810d |
| 8 | 30MeV CDR | 12w |
| 9 | 30MeVTitle I Design | 16w |
| 10 | 30MeV Title II Design | 16w |
| 11 | 30MeV Exp Equip Des | 26w |
| 12 | 30MeV Facility Constr | 52w |
| 13 | 30MeV Cyclotron Fab | 104w |
| 14 | 30MeV Exp Equip Fab | 39w |
| 15 | 30MeV Cycltrn&Equip | 16w |
| 16 | 30MeV Building Closu | 4w |
| 17 | 30MeV Start-up Prep | 12w |
| 18 | 30 MeV Training | 8w |
| 19 | 30MeV Oper Readi As | 26w |
| 20 | 30MeV Low Current T | 8w |
| 21 | 30MeV Full Current Q | 12w |
| 22 | 100MeV Target Facil Proj | 770d |
| 23 | 100Mev Prelim Design | 16w |
| 24 | 100MeV Title II Desig | 26w |
| 25 | 100MeV Exper Equip | 26w |
| 26 | 100MeV Lower Fac Co | 26w |

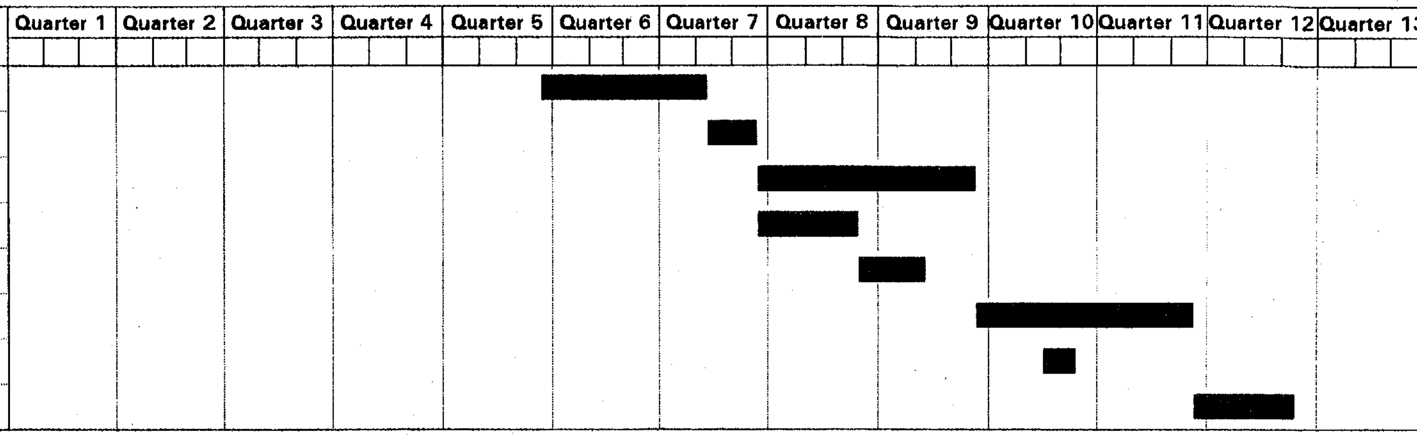



NBTF Project Schedule

Critical | Progress | Summary
Noncritical | Milestone | Rolled Up

## NBTF Project Schedule

| ID | Name | Duration |
|---|---|---|
| 27 | 100MeV Exper Equip | 20w |
| 28 | 100MeV Exper Equip I | 6w |
| 29 | 100MeV Upper Fac Co | 26w |
| 30 | 100MeV Start-up Prep | 12w |
| 31 | 100MeV Training | 8w |
| 32 | 100MeV Ops readi Ass | 26w |
| 33 | 100MeV Low Current | 4w |
| 34 | 100MeV Full Current | 12w |




NBTF Project Schedule

Critical · Progress · Summary
Noncritical · Milestone · Rolled Up

review would take about 12 months. LANL experience in recent years is that an EA for even small projects that require no new facility construction are taking this long. It may be possible to shorten the review period if active expediting is performed or if DOE HQ allows regional offices (DOE AL) to perform the review and make the FONSI determination.

In both subprojects, full scale beam is delayed by about three months in order to complete the operations readiness assessment. This is another element of uncertainty. It is assumed that the hazards associated with this project are small enough to allow local or regional office authorization for full scale operations.

3.1.3. Total Estimated Cost (TEC) and Total Project Cost (TPC). The Total Estimated Cost (TEC) is the sum of the project construction cost, the Title I, II, and III engineering and design costs, and the project management costs incurred between the date of the authorization of capital funds and the completion of the construction. The TEC is summarized in Table 3.1.

**Table 3.1**
**Total Estimated Cost (TEC) for NBTF**

| Element | Estimate ($) |
|---|---|
| 30 MeV Title I Design | 228,660.00 |
| 30 MeV Title II Design | 304,880.00 |
| 30 MeV Title III Design | 152,440.00 |
| 30 MeV Experimental Equipment Design | 120,000.00 |
| 30 MeV Construction | 3,811,000.00 |
| 30 Mev Experimental Equipment Purchase | 6,100,000.00 |
| 100 MeV Preliminary Design | 99,440.00 |
| 100 MeV Title II Design | 99,440.00 |
| 100 MeV Title III Design | 49,720.00 |
| 100 MeV Experimental Equipment Design | 150,000.00 |
| 100 MeV Construction | 1,243,000.00 |
| 100 MeV Experimental Equipment Purchase | 750,000.00 |
| Project Management | 600,000.00 |
| Procurement Support | 475,000.00 |
| Total Estimated Cost | 14,183,580.00 |

The construction cost estimate details and assumptions are in Tables 3.4 and 3.5. The Engineering & Design costs were assumed to be percentages (Title I = 6%, Title II = 8%, Title III = 4%) of construction costs as were found typical by reviewing costs of similar projects. The project management cost estimate assumes a fully burdened dedicated individual for the entire duration of the project. The procurement support charge assumes that A/E contract support will be $100,000 (existing Basic Order Agreements will be used), the cyclotron contract support will be $100,000, construction contract support will be $100,000 per contract or $200,000 total, and miscellaneous purchases will require $75,000 of purchasing support.

The Other Project Cost (OPC) breakdown is given in Table 3.2. The OPC funding is to be provided by DOE radioisotope program operating budgets.

**Table 3.2**
**Other Project Costs (OPC) for NBTF**

| Element | Estimate ($) |
|---|---|
| Project Formation | 100,000.00 |
| Environmental Assessment | 100,000.00 |
| PSAR | 100,000.00 |
| Concept Design Rpt | 50,000.00 |
| 100 MeV ORA | 100,000.00 |
| 30 MeV ORA | 400,000.00 |
| FSAR | 200,000.00 |
| Total OPC | 1,050,000.00 |

The project formation cost entry is for the purpose of allowing the project manager to create the plan and establish environmental assessment, safety analysis, and A/E contracts prior to availability of capital funds. The EA, PSAR, and Conceptual Design Report are typically initiated before capital funds are available and are therefore reported as other project costs. The ORAs and FSAR are performed after completion of the construction.

The Total Project Cost (TPC) is the sum of the Total Estimate Cost (TEC) and Other Project Costs (OPC) and is thus $15.2M.

3.1.4. Capital Funding Profile. Comparison of the TEC cost analysis table and the schedule shows that engineering design, cyclotron purchase, 50% of the project management expense, and 50% of the procurement cost will be required in the first year. These items total to $7.2M. The balance, $7.0M, will be required in the second year. The OPC will be evenly divided between the two years.

## 3.2. Cyclotron Facility Construction Plan.

To estimate construction costs of the proposed cyclotron facility, one must make some assumptions about the architectural structures and support systems associated with this project. This section describes our assumptions and details the estimated construction costs.

3.2.1. Architectural Features. The 30 MeV Cyclotron Facility will be located at Los Alamos Technical Area 48 to the west of the existing hot cell facilities. The separation of the cyclotron facility and the hot cells is only about 150 yards. Transportables that are currently at this location will be removed. This site is an ideal location for this facility because:

- Irradiated targets can be easily transported to the hot cells. Expensive road closures and associated production schedule restrictions that are currently experienced because the accelerator and the hot cells are at different technical areas will not be required.

- The main trunks for LANL utility systems run through the site. The radioactive liquid waste line which feeds the nearby liquid waste treatment facility is one of these utilities.

- The slope of the site allows for construction where the building is partly below grade and some earthen shielding can be obtained naturally.

- The proximity of the existing radioisotope program facilities means that shops are convenient and available for target making, as well as for "hot" equipment repair, instrument calibration, and so forth.

The building will contain the functions shown in Table 3.3.

Spaces assigned to Class A in Table 3.3 are the spaces where irradiation takes place. These spaces will contain radiation fields that require shielding to protect staff in other portions of the building. Class A spaces may also contain slightly irradiated air when the beam is on, as well as housing the radioactive target and beam stop water cooling systems. Access to these spaces will be prohibited when the beam is present. Class A spaces will be contained within concrete cubes having wall and roof thickness of six (6) to eight (8) feet.

Spaces assigned to Class B in Table 3.3 do not normally have radiation hazards in them. They do however have transient sources, such as irradiated targets or spent accelerator parts, that are contained and shielded when they are moving through the Class B

**Table 3.3**
**Functional Space Allocations in the 30 MeV Cyclotron Facility**

| Function | Area | Class |
|---|---|---|
| Cyclotron Vault | 720 | A |
| Target Vault #1 | 256 | A |
| Target Vault #2 | 256 | A |
| Cyclotron Services Area | 1584 | B |
| Set-up Area | 1920 | B |
| HV1 Equipment Room | 400 | B |
| Equipment Room | 484 | C |
| HV2 Equipment Space | 768 | C |
| Control / Data Collection | 300 | C |
| Restrooms | 300 | C |
| Office Area | 1500 | C |
| Janitor's Closet | 30 | C |
| Telephone Closet | 30 | C |

space. Generally the Class B space immediately surrounds the Class A space. These spaces have the potential for becoming temporarily contaminated if an error resulting in a spill occurs.

The Class C entries in the Table are spaces that never have radioactive materials in them.

The arrangement of these functions into a building plan concept for the purposes of developing a realistic estimate of the costs of construction are shown in Fig. 1.1, "Cyclotron Level Plan"; Fig. 1.2, "Second Level Plan"; and Fig. 1.3, "Building Section".

As is shown in Fig. 1.3, the core of the building is the massive concrete shielding structure that contains the cyclotron vault and the two target caves. This structure will be cast in place. An opening will be left in the roof of the cyclotron vault to allow the cyclotron to be placed by a crane when the building is nearing closure. Pre-cast concrete roof blocks will be placed in the opening by the crane once the cyclotron is placed. The cyclotron vault size is estimated to be 20 ft. X 36 ft. A ceiling height of 12 ft will allow for lights, cable trays, fire sprinklers, and other service routes, and also allow enough clear space above the cyclotron for maintenance and repair activities. Access to the cyclotron vault will be through an opening in the South wall which will be plugged by a concrete block when the machine is operating. The plug will have rails and a hydraulic drive system so that it can be pulled back. The cyclotron is supported by equipment skids that produce the RF, magnet power, and cooling water. These will be located in the service area immediately outside the south wall of the cyclotron vault. The cyclotron vault will have a pit beneath the cyclotron, where the cyclotron vacuum system will reside.

Two target caves will be provided within the shielding structure to the east and west of the cyclotron vault. The caves are anticipated to be 14 ft. X 16 ft. A 10 ft high ceiling will be sufficient to accommodate service routing and lights. Each cave will be capable of containing more than one target station. The lines to these stations will run from the steering magnets located in the cyclotron vault. These lines will contain movable iron plugs so that the target caves may be safely entered when the cyclotron is running and serving the other cave. Access to the target caves will be from the north side, where plugs mounted on rails will be driven by a hydraulic system. Withdrawal of irradiated targets in shielded transport containers will be through these openings. The target cave access has been placed opposite the cyclotron vault access to avoid interference of target handling activities and the cyclotron support equipment located in the service area. Because the beam will always be contained within the cyclotron, beam lines and target chambers and the neutron flux from the beam stop at these low energies is small, the caves will not become significantly activated. Operations in the target caves are expected to be manual with mechanical assistance. Remote systems are not anticipated but may be implemented in the future if they should prove to be cost effective or if radiation exposure analysis demonstrates that they are needed to achieve ALARA radiation exposure.

The shielding thickness on the west wall of the west target cave can be reduced since this wall is below grade. All of the concrete shielding surfaces will be epoxy painted to seal the concrete so that spills of radioactive materials will not penetrate the concrete and can be easily cleaned up.

The area to the north of the shielding structure will be used for experimental equipment set-up in advance of a run and for transportation of irradiated targets in shielded containers. This area, which is shown as 20 ft wide by the length of the building (100 ft), will contain workbenches, tools, and supplies needed for experiment preparation. There will be a roll-up door at the east end of the area. A personnel entry vestibule will be located beside the roll-up door. The vestibule will contain lab coat racks and personnel radiation survey equipment. The set-up area will be served by a small (3 ton) bridge crane to assist with moving experimental systems.

The area to the south of the shielding structure, approximately 22 ft wide by the building length (100 ft), will be divided into two rooms, one for containing mechanical systems equipment and the other for housing the cyclotron support equipment. The mechanical equipment room will be located on the west end of the building. It will have an exterior door. The purpose of isolating the mechanical equipment and providing an exterior door is to allow for facility maintenance staff access without having to enter the radiation control zone of the building. The gross area of the lower floor is estimated to be 7600 sq. ft.

The upper floor plan is shown in Fig. 1.2. The upper floor elevation is determined by the top of the shielding structure as shown in Fig. 1.3. The upper floor area is from the south building wall to the north edge of the shielding structure (approximately 54 ft) by the length of the building (100 ft). The upper floor does not extend over the set-up area to allow the bridge crane to travel above the set-up area. The total available upper level space is 5400 sq. ft.

The upper level to the south of the shielding structure (approximately 2200 sq. ft) will be finished to include a cyclotron control and experimental data collection room, bathrooms, and offices. The finish will be gypsum wall board on metal studs with a standard lay-in grid ceiling with fluorescent lights.

The area above the shielding structure (approximately 3200 sq ft) will be unfinished or rough finished, normally unoccupied space. The facility ventilation equipment will be located in this area. A zone about 15 ft wide on the north - south axis of the shielding structure, above the cyclotron must be left clear to allow the cyclotron to be installed. The areas to the east and west of this clear zone are available for the ventilation equipment. One closed room will be constructed on top of the shielding. This room will house the ventilation equipment that is dedicated to the cyclotron vault and the target caves. Isolation of this equipment is desirable in case it becomes mildly contaminated as a result of circulation of potentially contaminated air. This room may be constructed with gypsum wall board and metal stud walls and ceiling.

The total floor space of the building is estimated to be 13,000 sq. ft. The estimated eave height is 28 ft and the roof peak elevation is 35 ft.

The building will be a steel frame structure. The exterior wall will be an exterior insulated finish system with a stucco coating. The interior wall will be gypsum wall board hung on metal studs. The roof will be a pitched metal roof system. The second floor will be a metal pan and 3 in. thick concrete slab supported by bar joists.

3.2.2. Structural Features. The NBTF will be founded on disturbed volcanic tuff and where possible on undisturbed tuff that will likely be exposed when the hillside is excavated. Ultimate bearing pressure for this material, which is found throughout Los Alamos, ranges from 3500 PSF to 8000 PSF. It is generally well suited to supporting heavy loads such as the cyclotron magnet and the shielding structure. Subsurface investigations and soil analysis will be required to obtain exact design parameters. Cast in place spread footings and stem walls extending above grade will support the steel frame building structure. The lower floor will be a 6 in. reinforced concrete slab on grade. A pit will be excavated to provide a subbasement below the cyclotron.

The major structural feature of the facility will be the cast in place concrete shielding for the cyclotron vault and target caves. The walls and roof of the shield will be 6 ft to 8 ft thick high density concrete. The south side wall of the shield will support the second floor joists. The north side wall of the shield will support one of the bridge crane rails.

The function of the structural system is to provide the necessary support for the building to resist all anticipated loads in a manner that will protect employees and equipment, while adequately containing any radioactivity hazards that may be present. The structural system supports all other building systems as required, as well as offering resistance to lateral loads from natural phenomena hazards such as the maximum probable wind and seismic event defined by the Hazard Classification of the facility.

The structural performance category which defines the performance criteria for the structure when subjected to site specific design basis natural phenomenon will be PC 2.

The structural design methodology for this performance categorization is similar to the essential facility methodology in the Uniform Building Code.

The building structure will have steel frame walls. The roof design will incorporate steel roof decking welded and screwed to open-web steel trusses. Lateral resistance will be enhanced by using the upper floor to tie the exterior wall to the very rigid shield structure.

3.2.2.1. Ventilation. There will be two ventilation systems. One, designated HV1, will be dedicated to serving the Class A spaces. The other, HV2, will serve the Class B and C spaces.

The HV1 system will maintain the cyclotron vault and target caves at the most negative pressure in the facility when the rooms are sealed. The negative pressure will ensure that airborne radioactivity that may be present in these rooms when the beam is on will not leak out. The system will operate in two modes. Rooms that are sealed will be exhausted by the fan that maintains the negative pressure. The exhausted air will be blown through chilled and hot water coils at the point of entry to each room and returned to supply the sealed rooms. Some air leaving the fan outlet will be sent to the stack in order to balance the leakage into the rooms and to maintain the negative pressure. If a room is open (the plug removed) the air circulation system dampers will be closed and the room will be exhausted by a second fan in the system. This will cause air to flow through the open door and out the stack while the circulating system serves the rooms that remain closed. The circulating fan will be sized to deliver about 2000 CFM. The exhaust fan will deliver about 2000 CFM as well. The heat loads for the systems will be determined when the equipment characteristics are known.

The HV2 system will serve the volume that is not served by the HV1 system. Air will be supplied to the offices and to the area above the shielding structure. This air will flow into the set-up and service areas on the first floor where the return inlets will be located. About 85% of the return air will be recycled and 15% will be exhausted. The fan for this system will be sized to deliver about 10,000 CFM. The heat loads for the systems will be determined when the equipment characteristics are known.

The air which is exhausted by HV1 and HV2 will be discharged through a stack. The purpose of the stack is to create a well defined discharge flow that can be monitored for radioactive discharge.

3.2.2.2. Heating. Heating will be accomplished by feeding hot water to coils located in various zones throughout the building. The heating water will be supplied by a natural gas fired boiler located in the equipment room. The hot water will be delivered by pumps and flow control valves will determine the flows to each of the local coils.

3.2.2.3. General Purpose Cooling Water. Chilled water will be used to temper air and to collect heat from equipment. The primary chilled water loop will not be directly connected to the cyclotron, beam line magnets, or vacuum pumps in the cyclotron or target caves. A secondary system that may become slightly contaminated will be used to collect heat from these components. The target and beam stop cooling water will not be provided by the secondary loop. Heat will be transferred from the secondary loop to the primary loop through a heat exchanger. Equipment such as the RF amplifier that do not have the potential of creating radioactive water will be directly cooled by the primary loop. The chiller loop will contain water cooled mechanical chillers, circulation pumps, and flow control valves. The heat rejected from the chillers will be collected by a water circulation loop which will eject the heat to the atmosphere through a cooling tower. It is estimated that approximately 100 Tons of chilling capacity will be required.

3.2.2.4. Normal Power. Normal power will be derived by obtaining 13.2 KV, 3 PH, power from the underground line that runs along the east side of the site. This power will be transformed to 277/480, 3-phase, 4-wire, 60 Hz configuration for feeding into the building where the normal power will serve lighting, mechanical equipment, the cyclotron and associated equipment, and general use receptacles. The cyclotron demand will nominally be 500 KVA. The design peak demand for the facility is estimated to be 2000 KVA.

3.2.2.5. Standby Power. Standby power will be generated using a small generator set. There are no items in the facility which must run to protect the public or facility workers in the event that normal power is lost. There are, however, components that are desirable to operate for the purposes of monitoring the facility and restarting the systems upon restoration of normal power. These components include radiation monitors, communications and paging, the facility control computer, the cyclotron control computer, and the data collection computers. These items can be run from a battery driven Uninteruptible Power System. The standby generator will be used to provide charging power for the UPS when normal power is lost.

3.2.2.6. Uninterruptible Power. A battery supplied Uninteruptible Power Supply will be used to power sensitive systems such as the radiation monitors, the facility control computer, the cyclotron control computer, and experimental data collection electronics and computers, as well as providing power for fire detectors, alarms, and emergency lights. The UPS is a convenient method of providing noise free power that isolates equipment from power glitches or outages that may be caused by thunderstorms that are frequent and strong in the summer months in Los Alamos.

3.2.2.7. Lightning Protection and Grounding. A complete lightning protection system will be provided to ensure protection of electrical system components and sensitive electronic equipment. The lightning protection system will be an NFPA 78 Class I system comprised of air terminals, bonding connections to roof-top metallic items, main and secondary conductors and all associated terminations, connectors, and mounts.

The grounding system will have the following features :

- A building perimeter counterpoise
- A roof-top protection system with downleads to the perimeter counterpoise.
- Facility structural steel and rebar will be bonded to the counterpoise
- Separate insulated grounding conductors will be provided for power and instrumentation circuitry
- Resistance of the building grounding system will be less than 5 ohms
- Ground loops will be avoided to minimize noise pick-up induced by the cyclotron RF

3.2.2.8. Lighting. Generally, lighting requirements will be based upon industry standard recommendations of the Illuminating Engineering Society. General illumination will be provided by fluorescent lamps in all areas except the high bay set-up area where High Intensity Discharge (HID) metal halide lamps will be used. Lighting power will be 277 VAC.

3.2.2.9. Potable and Non-Potable Water. Water will be provided to the cyclotron facility through a connection to the existing water main at the site. Cold water will be used to supply the hydronic systems, cooling tower make-up, safety showers, eyewash sinks, first aid station, restrooms, custodial service sink, and drinking fountain. Hot water will be supplied to sinks by heating cold water. Potable water will be segregated from industrial water uses by employing separate lines and backflow preventors.

3.2.2.10. Fire Protection Water. The Fire Protection Water system will be designed as a facility wide wet pipe sprinkler system. The fire sprinkler coverage will include all areas of the facility. The system will be hydraulically designed to Ordinary Hazard (Group 2) requirements with an allowance of 500 gpm for hose stream demands. The system will be designed, fabricated, installed and tested in accordance with NFPA 13 Standards. The firewater system supply will be obtained by tying into the existing water main at the site. The firewater system will be comprised of risers, control valves, flow sensors, flow alarms, and sprinkler heads.

3.2.2.11. Sanitary Sewer. The sanitary sewer system will collect liquids from the restrooms, the janitor closet and floor drains located in the Class B and Class C spaces. The liquid sources will be sinks, toilets, mop water, leaks from the heating water and chilled water systems, and firewater. Floor drains in the target caves and cyclotron vault will not be connected to the sanitary sewer system.

3.2.2.12. Radioactive Liquid Waste Collection. Radioactive liquid waste will not normally be discharged from the cyclotron facility. Radioactive liquids will be produced in the cyclotron cooling water, the beam line magnet cooling water, and the target / beam stop cooling water. These may be accidentally discharged onto the floor in the cyclotron vault or the target floor if a line or pump seal fails. Fire protection water sprayed in these areas will also be considered to be radioactive liquid. Floor drains in these rooms will collect the accidental water leaks. These floor drains will lead to a Radioactive Liquid Waste line which will be connected to the RLW system at the site.

3.2.2.13. Target and Beam Stop Cooling Water System. The targets and beam stops in each cave will be served by dedicated water systems. It is expected that the beam will stop in a water chamber behind the target. Short lived products with half-lives less than 20 minutes are typically made as a result of reactions with the oxygen in the water and the dissolved air in the water. Very little Be-7 is made with 30 MeV protons. Impurities, such as iron, dissolved in the water may become activated. The beam stop cooling systems will consist of a mixed bed ion exchange column to constantly deionize the water, a shielded holding tank that will allow the system to drain into the tank when access to the target is desired, a heat exchanger to the facility chilled water loop capable of extracting the full beam power (about 3 tons), and a pump.

3.2.2.14. Compressed Air. Compressed air will be used to supply HVAC system components, actuators in experimental systems such as target changers, and utility stations in the set-up area. The compressed air system will include an air compressor, air filters, oil coalescing filters, compressed air dryer, and a ballast tank.

3.2.3. Instrumentation and Controls.

3.2.3.1. Radiation Monitoring. Ionization chambers and neutron detectors will be located at key locations in the facility to protect operating personnel. The following has been used for the purposes of estimating:

- One ionization chamber in the cyclotron vault and target caves.

- Three ionization chambers and three neutron detectors in the set-up area.

- Three ionization chambers and three neutron detectors in the service area.

- Three ionization chambers and three neutron detectors on the second floor.

The ionization chambers in the cyclotron vault and target caves will be part of the door interlock system. A high reading in one of these rooms will prevent the door from opening. The detectors in the balance of the building are to verify that the area is safe for occupancy. High readings on these alarms as a result of experiments that use a lot of beam current or have targets that prolifically produce neutrons will cause the cyclotron RF to be interrupted. The operator will have to take some action to assure that people are not present or to reduce the beam current in order to proceed. All of the radiation detectors will be monitored in the control room.

3.2.3.2. CCTV. A closed circuit television system shall be provided so that operators can observe the cyclotron vault and target caves. The CCTV shall be used to verify that no one is present in the vault or the target cave prior to delivery of beam. In addition a camera will be placed at each target chamber so that the experiment may be observed. It is expected that there will be four cameras in each room. There will be four monitors in the control room so that the operators can switch displays between rooms. Camera tilt, pan, and zoom control will be from the control room.

3.2.3.3. Fire Detection. The fire alarm and detection system function will be to provide early warning to personnel located within the NBTF of fire. Secondary system functions will include:

- System self monitoring for faults and other trouble

- Remote alarm and trouble transmission to the LANL central alarm station

- Pre-alarm of smoke condition within the cyclotron vault, the target caves, the service area, and the airhandling equipment.

A complete Manual and Automatic Fire Alarm and Detection system will be provided. The system will be controlled from a single point at the main entrance to the facility where the fire alarm control panel will be located.

3.2.3.4. Stack Monitoring. The stack gas will be monitored for radioactive emissions. The sample will be drawn continuously using an isokinetic sampler.

3.2.3.5. HVAC System Controls. The HVAC system controls will monitor the operating status of the system and also change the state of the HV1 system when the cyclotron or target cave doors are actuated. It is anticipated that the fan motors will run at constant speeds so there will not be a need to control fan speed based on pressure or flow signals. The HV1 state change will be initiated by a request to either open or close a door. The request to open a door for example will cause the control system check the radiation level and then to close the recirculation system dampers and open the exhaust damper if the radiation level is acceptable. The door sequence control will then open the door. The HVAC controls will consist of pressure transducers for the target caves and cyclotron vault and for the selected points in the ducts and flow transducers at selected points in the ducts. These signals will be reported to the facility control computer so that operators can observe status.

3.2.3.6. Interlocks. The facility will have a number of safety interlocks. One example might be cave door open : iron beam line plug in place : cyclotron RF. These interlocks will be actuated by limit switches, position sensors, water flow switches, and so forth. The signals will be transmitted to the facility control computer.

3.2.3.7. Facility Monitor Computer. The facility status, which consists of the signals from all the fire detectors, the ventilation pressure, flow, and damper position signals, the radiation detector signals, electrical system fault signals, vault and target cave door positions, and equipment status, will be monitored by a facility control computer. The facility control system will have the interlock logic and will generate alarms. The facility control computer will be a PC or PLC system.

Cyclotron control will not be performed by the facility control computer. The cyclotron manufacturer will provide the cyclotron control computer. There will be a data link between the two computers so that interlocks that shutdown the RF can be effected and so that a request to turn on the cyclotron will sound a warning and initiate a delay prior to RF start up.

3.2.3.8. Telephones and Voice Paging. The facility will include a telephone system and paging system that will allow staff in the cyclotron vault, target caves, or the set-up and service areas to communicate with the control room. The telephone system will be part of the LANL system.

3.2.4. Isotope Production Systems. Isotope production systems include the accelerator, beam lines, target stations, and the control systems to support these components.

3.2.4.1. Cyclotron and Beam Lines. The cyclotron will be a 30 MeV negative ion cyclotron with capabilities for accelerating both hydrogen and deuterium ions. This machine will be capable of delivering 1 mA of beam current, and shall be equipped with two beam extractors with associated beam lines for delivering beams to the two target caves. Extracted beam energies will be tunable between 10 and 30 MeV, with beam energies reproducible to 1 % and with energy spread less than 1 %.

Beam lines will include a quadrupole triplet, steering magnet, beam diagnostics, beam plugs, and associated control systems.

The cyclotron, beam lines, and the associated control systems will be designed and built by an outside manufacturer to be selected through a competitive bid process.

3.2.4.2. Cyclotron Target Stations. Target stations will be designed and constructed by Los Alamos personnel. There are many designs and prototypes to use for this task. Target stations can also be purchased commercially.

3.2.4.3. Experimental Data Collection System. Historians will be incorporated into both the facility control computer and the cyclotron control computer to collect and archive experimental data. Experimental data will also be kept in hard copy for the cyclotron operators and other experimental personnel.

3.2.5. Cyclotron Facility Construction Costs. We estimate the total cost for the building to house the cyclotron and target stations to be $3.8 M. A detailed cost analysis is shown in Table 3.4. The item quantities were derived from the facility sketches and the discussion above. Cost factors were taken from recent project data and from Means Tables. The "direct cost" entries are material and labor costs. Burden is added to these costs as detailed in the "mark-up" column in recognition of the contractor's overhead and fee. The "contingency" applied to the facility costs is 30%. We estimate that the cyclotron and beam lines will cost $ 5.7 M, and that the necessary target stations will cost $0.4 M. Consequently the net cost for the cyclotron and ancillary equipment will be $6.1 M.

| | |
|---|---|
| Cyclotron Facility (Building) | $3.8 M |
| Cyclotron and Beam Lines | $5.7 M |
| Target Stations | $0.4 M |
| **Total Cyclotron Facility Cost** | **$9.9 M** |

## 3.3. 100 MeV Target Facility Construction Plan.

To estimate construction costs of the proposed target facility, one must make some assumptions about the architectural structures and support systems associated with this

Table 3.4 : Construction Cost Estimate For The Proposed NBTF Cyclotron Facility

| COST ELEMENT | QUANTITY | UNIT | UNIT PRICE | DIRECT COST | MARK-UP | CONTINGENCY | TOTAL ITEM COST | TOTAL COST |
|---|---|---|---|---|---|---|---|---|
| *SITE* | | | | | | | | |
| Excavation | 3000 | cy | $ 5.00 | $ 15,000.00 | $ 3,300.00 | $ 5,490.00 | $ 23,790.00 | |
| Hauling | 3000 | cy | $ 5.00 | $ 15,000.00 | $ 3,300.00 | $ 5,490.00 | $ 23,790.00 | |
| Backfill | 3000 | cy | $ 1.84 | $ 3,400.00 | $ 748.00 | $ 1,244.40 | $ 5,392.40 | |
| Compaction | 3000 | cy | $ 0.76 | $ 1,900.00 | $ 418.00 | $ 509.96 | $ 2,827.96 | |
| Paving | 1000 | sy | $ 9.86 | $ 9,860.00 | $ 2,169.20 | $ 3,608.76 | $ 15,637.96 | |
| Relocate Transportables | 1 | ea | $ 35,000.00 | $ 35,000.00 | $ 7,700.00 | $ 12,810.00 | $ 55,510.00 | |
| Demolition | 1 | ea | $ 75,000.00 | $ 75,000.00 | $ 16,500.00 | $ 27,450.00 | $ 118,950.00 | |
| *Site Subtotal* | | | | $ 155,160.00 | $ 34,135.20 | $ 56,603.12 | $ 245,898.32 | $ 245,898.32 |
| *UTILITIES* | | | | | | | | |
| Electrical Service | 700 | ft | $ 95.00 | $ 66,500.00 | $ 14,630.00 | $ 24,339.00 | $ 105,469.00 | |
| Sanitary Sewer Service | 200 | ft | $ 45.00 | $ 9,000.00 | $ 1,980.00 | $ 3,294.00 | $ 14,274.00 | |
| Gas Service | 500 | ft | $ 12.40 | $ 6,200.00 | $ 1,364.00 | $ 2,269.20 | $ 9,833.20 | |
| Water | 300 | ft | $ 31.40 | $ 9,420.00 | $ 2,072.40 | $ 3,447.72 | $ 14,940.12 | |
| Radioactive Liq Waste | 100 | ft | $ 200.00 | $ 20,000.00 | $ 4,400.00 | $ 7,320.00 | $ 31,720.00 | |
| Telephone | 1 | ca | $ 15,000.00 | $ 15,000.00 | $ 3,300.00 | $ 5,490.00 | $ 23,790.00 | |
| *Utilities Subtotal* | | | | $ 126,120.00 | $ 27,746.40 | $ 46,159.92 | $ 200,026.32 | $ 200,026.32 |
| *BUILDING* | | | | | | | | |
| Foundation Concrete | 200 | cy | $ 179.00 | $ 35,800.00 | $ 7,876.00 | $ 13,102.80 | $ 56,778.80 | |
| Slab | 7600 | sf | $ 4.05 | $ 30,780.00 | $ 6,771.60 | $ 11,265.48 | $ 48,817.08 | |
| Concrete Shielding | 1272 | cy | $ 236.00 | $ 300,192.00 | $ 66,042.24 | $ 109,870.27 | $ 476,104.51 | |
| Second Floor | 2200 | sf | $ 10.25 | $ 22,550.00 | $ 4,961.00 | $ 8,253.30 | $ 35,764.30 | |
| Steel Wall Columns | 50000 | lbs | $ 0.79 | $ 39,416.21 | $ 8,671.57 | $ 14,426.33 | $ 62,514.10 | |
| Conven. Roof Trusses | 8000 | sf | $ 4.87 | $ 38,960.00 | $ 8,571.20 | $ 14,259.36 | $ 61,790.56 | |
| Stack | 1 | ea | $ 25,000.00 | $ 25,000.00 | $ 5,500.00 | $ 9,150.00 | $ 39,650.00 | |
| Exter. Insul. Finish Sys. | 8448 | sf | $ 6.84 | $ 57,784.32 | $ 12,712.55 | $ 21,149.06 | $ 91,645.93 | |
| Subgrade Wall Seal | 2760 | sf | $ 7.85 | $ 21,666.00 | $ 4,766.52 | $ 7,929.76 | $ 34,362.28 | |
| Roof System and Insulate | 7600 | sf | $ 3.14 | $ 23,871.43 | $ 5,251.72 | $ 8,736.94 | $ 37,860.09 | |
| Doors (incl Shielded) | 1 | lot | $ 100,000.00 | $ 100,000.00 | $ 22,000.00 | $ 36,600.00 | $ 158,600.00 | |
| Epoxy Coating | 15376 | sf | $ 1.84 | $ 28,291.84 | $ 6,224.20 | $ 10,354.81 | $ 44,870.86 | |
| Metal Stud / Gyp Board | 8000 | sf | $ 2.66 | $ 21,280.00 | $ 4,681.60 | $ 7,788.48 | $ 33,750.08 | |
| Carpet | 250 | sy | $ 28.00 | $ 7,000.00 | $ 1,540.00 | $ 2,562.00 | $ 11,102.00 | |
| Acoustic Tile Ceiling | 2200 | sf | $ 2.58 | $ 5,676.00 | $ 1,248.72 | $ 2,077.42 | $ 9,002.14 | |
| Wall Paint | 10000 | sf | $ 0.31 | $ 3,100.00 | $ 682.00 | $ 1,134.60 | $ 4,916.60 | |
| Crane | 1 | ea | $ 55,000.00 | $ 55,000.00 | $ 12,100.00 | $ 20,130.00 | $ 87,230.00 | |
| *Building Subtotal* | | | | $ 816,367.80 | $ 179,600.92 | $ 298,790.61 | $ 1,294,759.33 | $ 1,294,759.33 |

Table 3.4 : Construction Cost Estimate For The Proposed NBTF Cyclotron Facility

| COST ELEMENT | QUANTITY | UNIT | UNIT PRICE | DIRECT COST | MARK-UP | CONTINGENCY | TOTAL ITEM COST | TOTAL COST |
|---|---|---|---|---|---|---|---|---|
| *HVAC* | | | | | | | | |
| HV1 Circ Fan | 1 | ea | $ 5,000.00 | $ 5,000.00 | $ 1,100.00 | $ 1,830.00 | $ 7,930.00 | |
| HV1 Coils | 3 | ea | $ 2,000.00 | $ 6,000.00 | $ 1,320.00 | $ 2,196.00 | $ 9,516.00 | |
| HV1 Welded (20" Rnd) | 1500 | lb | $ 5.83 | $ 8,750.86 | $ 1,925.19 | $ 3,202.82 | $ 13,878.87 | |
| HV1 Exhaust Fan | 1 | ea | $ 5,000.00 | $ 5,000.00 | $ 1,100.00 | $ 1,830.00 | $ 7,930.00 | |
| HV1 Damp(8") (w actuat) | 6 | ea | $ 600.00 | $ 3,600.00 | $ 792.00 | $ 1,317.60 | $ 5,709.60 | |
| HV2 Airhandler | 1 | ea | $ 25,000.00 | $ 25,000.00 | $ 5,500.00 | $ 9,150.00 | $ 39,650.00 | |
| HV2 Ducts (30X30 Galv) | 4000 | lb | $ 3.22 | $ 12,868.11 | $ 2,830.99 | $ 4,709.73 | $ 20,408.83 | |
| HV2 Riser Ducts(6X12galv) | 4000 | lb | $ 3.22 | $ 12,868.11 | $ 2,830.99 | $ 4,709.73 | $ 20,408.83 | |
| VAV Boxes | 10 | ea | $ 300.00 | $ 3,000.00 | $ 660.00 | $ 4,709.73 | $ 8,369.73 | |
| Test & Balance | 1 | lot | $ 20,000.00 | $ 20,000.00 | $ 4,400.00 | $ 7,320.00 | $ 31,720.00 | |
| Misc | 1 | lot | $ 25,000.00 | $ 25,000.00 | $ 5,500.00 | $ 9,150.00 | $ 39,650.00 | |
| *HVAC Subtotal* | | | | $ 127,087.09 | $ 27,959.16 | $ 50,125.61 | $ 205,171.86 | $ 205,171.86 |
| *HEATING WATER* | | | | | | | | |
| Boiler | 2 | ea | $ 10,000.00 | $ 20,000.00 | $ 4,400.00 | $ 7,320.00 | $ 31,720.00 | |
| Circulating Pumps | 2 | ea | $ 1,500.00 | $ 3,000.00 | $ 660.00 | $ 1,098.00 | $ 4,758.00 | |
| Expansion Tank | 1 | ea | $ 500.00 | $ 500.00 | $ 110.00 | $ 183.00 | $ 793.00 | |
| Piping (assume 1" Cu) | 600 | ft | $ 6.00 | $ 3,600.00 | $ 792.00 | $ 1,317.60 | $ 5,709.60 | |
| Pipe Insulation | 600 | ft | $ 4.17 | $ 2,502.00 | $ 550.44 | $ 2,400.60 | $ 5,453.04 | |
| Valves | 20 | ea | $ 300.00 | $ 6,000.00 | $ 1,320.00 | $ 2,196.00 | $ 9,516.00 | |
| Miscellaneous | 1 | lot | $ 10,000.00 | $ 10,000.00 | $ 2,200.00 | $ 3,660.00 | $ 15,860.00 | |
| *Heating Water Subtotal* | | | | $ 45,602.00 | $ 10,032.44 | $ 18,175.20 | $ 73,809.64 | $ 73,809.64 |
| *CHILLED WATER* | | | | | | | | |
| Chiller (50 Tons) | 2 | ea | $ 32,350.00 | $ 64,700.00 | $ 14,234.00 | $ 23,680.20 | $ 102,614.20 | |
| Pumps | 4 | ea | $ 1,500.00 | $ 6,000.00 | $ 1,320.00 | $ 2,196.00 | $ 9,516.00 | |
| Piping | 600 | ft | $ 6.00 | $ 3,600.00 | $ 792.00 | $ 1,317.60 | $ 5,709.60 | |
| Pipe Insulation | 600 | ft | $ 4.17 | $ 2,502.00 | $ 550.44 | $ 915.73 | $ 3,968.17 | |
| Valves | 40 | ea | $ 300.00 | $ 12,000.00 | $ 2,640.00 | $ 4,392.00 | $ 19,032.00 | |
| Cooling Tower | 1 | ea | $ 30,000.00 | $ 30,000.00 | $ 6,600.00 | $ 10,980.00 | $ 47,580.00 | |
| Heat Exchangers | 5 | ea | $ 2,000.00 | $ 10,000.00 | $ 2,200.00 | $ 3,660.00 | $ 15,860.00 | |
| Miscellaneous | 1 | lot | $ 25,000.00 | $ 25,000.00 | $ 5,500.00 | $ 9,150.00 | $ 39,650.00 | |
| *Chilled WTR Subtotal* | | | | $ 153,802.00 | $ 33,836.44 | $ 56,291.53 | $ 243,929.97 | $ 243,929.97 |

Table 3.4 : Construction Cost Estimate For The Proposed NBTF Cyclotron Facility

| COST ELEMENT | QUANTITY | UNIT | UNIT PRICE | DIRECT COST | MARK-UP | CONTINGENCY | TOTAL ITEM COST | TOTAL COST |
|---|---|---|---|---|---|---|---|---|
| *MECHANICAL SERVICES* | | | | | | | | |
| Water Piping | 200 | ft | $ 6.00 | $ 1,200.00 | $ 264.00 | $ 439.20 | $ 1,903.20 | |
| Hot Water Heater | 1 | ea | $ 950.00 | $ 950.00 | $ 209.00 | $ 347.70 | $ 1,506.70 | |
| Sanitary Sewer | 50 | ft | $ 7.96 | $ 398.00 | $ 87.56 | $ 145.67 | $ 631.23 | |
| Air Compressor | 1 | ea | $ 9,000.00 | $ 9,000.00 | $ 1,980.00 | $ 3,294.00 | $ 14,274.00 | |
| Air Dryer | 1 | ea | $ 3,000.00 | $ 3,000.00 | $ 660.00 | $ 1,098.00 | $ 4,758.00 | |
| Compressed Air Pipe | 400 | ft | $ 11.00 | $ 4,400.00 | $ 968.00 | $ 1,610.40 | $ 6,978.40 | |
| Firewater Distribution | 13000 | sf | $ 1.70 | $ 22,100.00 | $ 4,862.00 | $ 8,088.60 | $ 35,050.60 | |
| *Mech Services Subtotal* | | | | $ 41,048.00 | $ 9,030.56 | $ 15,023.57 | $ 65,102.13 | $ 65,102.13 |
| *ELECTRICAL* | | | | | | | | |
| Substation | 1 | ea | $ 300,000.00 | $ 300,000.00 | $ 66,000.00 | $ 109,800.00 | $ 475,800.00 | |
| Motor Control Center | 1 | ea | $25,000 | $ 25,000.00 | $ 5,500.00 | $ 9,150.00 | $ 39,650.00 | |
| Fan Motor Starters | 3 | ea | $ 10,000.00 | $ 30,000.00 | $ 6,600.00 | $ 10,980.00 | $ 47,580.00 | |
| UPS | 1 | ea | $ 50,000.00 | $ 50,000.00 | $ 11,000.00 | $ 18,300.00 | $ 79,300.00 | |
| Generator (100 KW) | 1 | ea | $ 50,000.00 | $ 50,000.00 | $ 11,000.00 | $ 18,300.00 | $ 79,300.00 | |
| General Power Dist | 13000 | sf | $ 3.10 | $ 40,300.00 | $ 8,866.00 | $ 14,749.80 | $ 63,915.80 | |
| Lighting | 13000 | sf | $ 3.57 | $ 46,410.00 | $ 10,210.20 | $ 16,986.06 | $ 73,606.26 | |
| Lightning Protect | 13000 | sf | $ 0.29 | $ 3,770.00 | $ 829.40 | $ 1,379.82 | $ 5,979.22 | |
| Grounding System | 13000 | sf | $ 0.25 | $ 3,250.00 | $ 715.00 | $ 1,189.50 | $ 5,154.50 | |
| Miscellaneous Elec | 1 | lot | $ 25,000.00 | $ 25,000.00 | $ 5,500.00 | $ 9,150.00 | $ 39,650.00 | |
| *Electrical Subtotal* | | | | $ 573,730.00 | $ 126,220.60 | $ 209,985.18 | $ 909,935.78 | $ 909,935.78 |
| *INSTRUMENT & CONTROLS* | | | | | | | | |
| Ion Chambers | 12 | ea | $ 10,000.00 | $ 120,000.00 | $ 26,400.00 | $ 43,920.00 | $ 190,320.00 | |
| Neutron Detectors | 9 | ea | $ 10,000.00 | $ 90,000.00 | $ 19,800.00 | $ 32,940.00 | $ 142,740.00 | |
| HVAC Controls | 1 | lot | $ 20,000.00 | $ 20,000.00 | $ 4,400.00 | $ 7,320.00 | $ 31,720.00 | |
| Fire Detection | 13000 | sf | $ 0.38 | $ 4,940.00 | $ 1,086.80 | $ 1,808.04 | $ 7,834.84 | |
| Communications | 13000 | sf | $ 0.45 | $ 5,850.00 | $ 1,287.00 | $ 2,141.10 | $ 9,278.10 | |
| CCTV Cameras | 8 | ea | $ 2,000.00 | $ 16,000.00 | $ 3,520.00 | $ 5,856.00 | $ 25,376.00 | |
| CCTV Monitors | 4 | ea | $ 1,000.00 | $ 4,000.00 | $ 880.00 | $ 1,464.00 | $ 6,344.00 | |
| Facility Control Computer | 1 | ea | $ 50,000.00 | $ 50,000.00 | $ 11,000.00 | $ 18,300.00 | $ 79,300.00 | |
| Stack Monitor | 1 | ea | $ 50,000.00 | $ 50,000.00 | $ 11,000.00 | $ 18,300.00 | $ 79,300.00 | |
| *I&C Subtotal* | | | | $ 360,790.00 | $ 79,373.80 | $ 132,049.14 | $ 572,212.94 | $ 572,212.94 |
| **Total Construction Cost** | | | | | | | | $ 3,810,846.29 |

project. This section describes our assumptions and details the estimated construction costs.

3.3.1. Architectural Features. A branch from the main beam tunnel which was built when LAMPF was constructed will be extended and outfitted for use. Completion of the branch involves excavating, constructing an underground target hall, extending the beam line and optics, providing a remotely operated target chamber, constructing above ground support facilities, and providing services for the equipment.

The new construction will be accomplished by excavating to a depth of approximately 29 ft. An 18 in. thick concrete slab will be poured to create a floor at the same elevation as the existing branch floor. Reinforced concrete walls, 18 in. thick and 15 ft high, will be cast in place to create a tunnel and room shaped as indicated in Fig. 1.4. Approximately 800 sq ft of floor space will be constructed on the lower level.

The beam line will enter through a hole in the existing wall. This hole exists, with a 20 ft long iron pipe installed in it. The existing pipe will be removed and replaced with beam line. A thick iron target shield, approximately 10 ft by 10 ft will be installed in the northwest corner of the room. The beam line will extend from the point of entry to the center of the shield. Focusing magnets and pumping stations will be located along the beam line. The target chamber and beam stop will be located inside the shield. A shaft to the surface will be cast into the east wall. The shaft will contain a ladder for maintenance and repair personnel entry and for crane hook access. The shaft size will be large enough to allow for exchange of pumps or beam line magnets. A second shaft made from approximately 18 in. diameter steel pipe will lead to the surface along the centerline of the target chamber. A third shaft which may also be a steel pipe will lead from the upper level into the neck region to pass services and signals.

A second hole will be bored through the existing branch end wall in order to pass services from the accelerator tunnel.

The target chamber, beam line, magnets, target chamber shield, and a bridge crane will be installed before the roof is cast. Once these are in place, prestressed concrete beams will be placed. A steel deck will be placed on top of the beams and an 18 in. thick reinforced concrete slab will be cast in place.

The interior surfaces of the target hall will be finished with an epoxy paint coating. The exterior surfaces will be sealed with a membrane water proofing system to keep ground water from seeping into the room.

The section view shown in Fig. 1.6 indicates the elevations of the entire set of facilities. Approximately 10 ft. of compacted fill will be placed on top of the new target hall. A support facility will be constructed above the target hall. The upper level building will consist of two rooms. The first will be a high bay room (about 20 ft high) containing a hot cell directly above the target chamber. The shaft from the target chamber will lead into the hot cell. The hot cell will have walls but no ceiling so that a crane hook can be lowered into the cell. A bridge crane will be installed in this room. The hot cell will be used to load irradiated targets into casks so that they can be removed and loaded onto a truck for transport to the chemical processing facility. As can be seen in the upper level plan, Fig. 1.5 a truck turn-around and dock is required on the west side. Steel plates will cover the lower level access shafts so that they will not impede traffic on the upper level. The approximate area of this room will be 900 sq ft.

The second room in the above ground level will be an equipment room. This room will house ventilation equipment, heating and cooling equipment, beam line magnet power supplies, boilers and chillers, and cooling water processing equipment, as well as electrical distribution equipment. The cooling water processing equipment will collect radioactive materials. Shielding consisting of solid concrete blocks will be required to isolate this equipment and shield maintenance personnel from radiation emanating from the system. The area of the equipment room will be approximately 800 sq ft.

The above ground structure will be a steel frame building on a reinforced concrete slab. The exterior wall will be an exterior insulated finish system. Styrofoam board insulation will be placed on the interior side of the wall. The roof will be a pitched metal roof system.

Personnel entry into the upper building will be transient and for the purposes of loading or retrieving a target or for maintenance. The upper building will not house permanent residents. Experimental staff and experimental data collection will be performed in a trailer which will be moved into the area from its present location in Area A at the end of the LAMPF accelerator.

3.3.2. Structural Features. The lower facility will be founded on undisturbed tuff. Ultimate bearing pressure for this material, which is found throughout Los Alamos, ranges from 3500 PSF to 8000 PSF. It is generally well suited to supporting heavy loads such as the target shield. The upper facility will be founded on compacted fill placed above the lower facility.

The function of the structural system is to provide the necessary support for the building to resist all anticipated loads in a manner that will protect employees and equipment, while adequately containing any radioactivity hazards that may be present. The structural system supports all other building systems as required, as well as offering resistance to lateral loads from natural phenomena hazards such as the maximum probable wind and seismic event defined by the Hazard Classification of the facility.

The structural performance category which defines the performance criteria for the structure when subjected to site specific design basis natural phenomenon will be PC 2. The structural design methodology for this performance categorization is similar to the essential facility methodology in the Uniform Building Code.

The lower building structure will be formed from cast in place concrete and the upper building structure will be a steel frame with concrete block exterior on a 6 in. reinforced concrete slab. The roof design will incorporate steel roof decking welded and screwed to open-web steel trusses.

3.3.3. Support Systems.

3.3.3.1. Ventilation. The lower level will not be ventilated when the beam is on. The goal is to trap potentially slightly activated air to allow the short lived products to decay rather than exhaust them as a radioactive emissions. The shafts to the surface will be sealed with covers when the beam is on so that they will not be sources of leakage. Local coolers consisting of fans and a chilled water heat exchanger will be used to circulate and cool the air in the lower level when the beam is on. The lower level will be ventilated if personnel entry is required. A once-through ventilation system consisting of an exhaust fan and intake heating and cooling coils will activate when a request for entry is made. The intake will be in the wall of the upper level equipment room. The exhaust fan and heating and cooling coils will be in the upper level as well. The exhaust flow will be determined by the equipment heat loads. 1500 CFM has been assumed for the purposes of estimating at this time.

The upper level ventilation system will be a recirculating system with approximately 15% make-up and exhaust. The system will consist of a fan, heating and cooling coils, and intake lover and damper, and exhaust damper, and balancing dampers. All exhaust from the facility will be collected in a stack so that effluent can be monitored for radioactivity.

3.3.3.2. General Purpose Heating and Cooling Water. Air temperature control in the facility will be achieved by circulating hot and cold water through heat exchanger coils placed in the air streams. The hot water circulating system will consist of a gas fired boiler, circulation pumps, and control valves. The chilled water circuit will consist of a chiller with an air cooled condenser, circulation pumps, and control valves. The chilled water loop will also include a heat exchanger that will withdraw heat from the target / beam stop water cooling system.

3.3.3.4. Magnet Cooling. The beam line magnets will be cooled by extending the accelerator cooling water through the branch end wall to the magnets.

3.3.3.5. Power. 480 / 277 VAC three phase power and 208 / 120 VAC three phase power will be distributed from existing LAMPF systems. No new service will be required. The power system will consist of distribution panels, wiring, and motor starters.

Standby power will not be required.

Uninteruptible power derived from batteries will be provided for emergency lights and for the target / beam stop cooling pump.

3.3.3.6. Lightning Protection and Grounding. A complete lightning protection system will be provided to ensure protection of electrical system components and sensitive electronic equipment. The lightning protection system will be an NFPA 78 Class I system comprised of air terminals, bonding connections to roof-top metallic items, main and secondary conductors and all associated terminations, connectors, and mounts.

The grounding system will have the following features :

- A building perimeter counterpoise
- A roof-top protection system with downleads to the perimeter counterpoise.
- Facility structural steel and rebar will be bonded to the counterpoise
- Separate insulated grounding conductors will be provided for power and instrumentation circuitry
- Resistance of the building grounding system will be less than 5 ohms
- Ground loops will be avoided to minimize noise pick-up induced by the accelerator RF

3.3.3.7. Lighting. Generally, lighting requirements will be based upon industry standard recommendations of the Illuminating Engineering Society. General illumination will be provided by fluorescent lamps in all areas except the high bay hot cell area where High Intensity Discharge (HID) metal halide lamps will be used. Lighting power will be 277 VAC.

3.3.3.8. Potable and Non-Potable Water. Water will be provided to the target facility through a connection to the existing LAMPF water system. Cold water will be used to supply the hydronic systems.

3.3.3.9. Fire Protection Water. The fire protection water system will be designed as a facility wide wet pipe sprinkler system. The fire sprinkler coverage will include all areas of the facility. The system will be hydraulically designed to Ordinary Hazard (Group 2) requirements with an allowance of 500 gpm for hose stream demands. The system will be designed, fabricated, installed and tested in accordance with NFPA 13 Standards. The firewater system supply will be obtained by tying into the existing LAMPF firewater system. The firewater system will be comprised of risers, control valves, flow sensors, flow alarms, and sprinkler heads.

3.3.3.10. Sanitary Sewer. There will be no sanitary sewer connection.

3.3.3.11. Radioactive Liquid Waste Collection. Radioactive Liquid Waste will not normally be discharged from the target facility. Radioactive liquids will be produced in the beam line magnet cooling water and the target / beam stop cooling water. These may be accidentally discharged onto the floor in the target room or in the equipment room if a line or pump seal fails. Firewater sprayed in these areas will also be considered to be radioactive liquid. Floor drains in the these rooms will collect the accidental water leaks. These floor drains will lead to the existing LAMPF Radioactive Liquid Waste system.

3.3.3.12. Target and Beam Stop Cooling Water System. The target and beam stop will be served by a dedicated water system. It is expected that the beam will stop in a water chamber behind the target. Short lived products with half lives less than 20 minutes, Be-7, and tritium are typically made as a result of reactions with the oxygen in the water and the dissolved air in the water. Impurities, such as iron, dissolved in the water may become activated and recoils from the target may become entrained. The beam stop cooling systems will consist of a shielded mixed bed ion exchange column to constantly deionize the water, a shielded holding tank that will allow the system to drain into the tank when access to the target is desired, a heat exchanger connected to the chilled water system capable of extracting the full beam power (about 3 tons), and a pump. A recent study regarding radioactive water waste minimization at LAMPF found that it should be possible to operate a system of this type without discharging liquid waste. It is likely that radiation levels from the water system when steady state concentration is reached can be safely managed. It may be occasionally necessary to dispose of the ion exchange resin as low level solid waste.

3.3.3.13. Compressed Air. Compressed air will be used to supply actuators in experimental systems such as target changers and vacuum system valves. The compressed air system will include a small air compressor, air filters, oil coalescing filters, compressed air dryer, and a ballast tank.

3.3.4. Instrumentation and Controls.

3.3.4.1. Radiation Monitoring. Ionization chambers will be located at key locations in the facility to protect operating personnel. The anticipated scheme includes three (3) in the equipment room, three in the hot cell room, and three in the lower level. High radiation level alarms and warning lights will be triggered by the detectors.

3.3.4.2. CCTV. A closed circuit television system shall be provided so that operators can observe the target caves. The CCTV shall be used to verify that no one is present in the target room prior to delivery of beam. In addition, a camera will be placed at each target chamber so that the experiment may be observed. It is expected that there will be four cameras in the target room.

3.3.4.3. Fire Detection. The fire alarm and detection system function will be to provide early warning to personnel located within the 100 MeV target facility of fire. Secondary system functions will include: (1) system self monitoring for faults and other trouble, (2) remote alarm and trouble transmission to the LANL central alarm station, and (3) pre-alarm of smoke condition within the facility

A complete Manual and Automatic Fire Alarm and Detection system will be provided. The system will be integrated with the existing LAMPF system.

3.3.4.4. Stack Monitoring. The stack gas will be monitored for radioactive emissions. The sample will be drawn continuously using an isokinetic sampler.

3.3.4.5. HVAC System Controls. The HVAC system is simple requiring no active control when operating other than thermostat control of the hot and chilled water flow to the system coils. Change of state of the lower level ventilation from circulation to once-through flow for personnel entry can be accomplished by manually repositioning dampers or by simple pneumatic actuation.

3.3.4.6. Telephones and Voice Paging. The facility will include a telephone system and paging system that will allow staff in the upper level to communicate with the lower level and will allow for communication with the LAMPF control room.

3.3.5. Isotope Production Systems. The target system includes the steel target shield, the beam line exit window, the target insertion and retrieval system, the target cooling system, and the associated monitoring and diagnostic equipment. The design of the target system must be integrated with the beam line design to facilitate maintenance and repair operations.

This system will be designed and fabricated by Los Alamos personnel, using existing design concepts and in collaboration with targeting experts from other institutions.

3.3.6. 100 MeV Target Facility Construction Costs. We estimate the total cost for the building structures to house the target station and its support systems at $1.24 M. A detailed cost analysis is shown in Table 3.5. The item quantities were derived from the facility sketches and the discussion above. Cost factors were taken from recent project data and from Means Tables. The "direct cost" entries are material and labor costs. Burden is added to these costs as detailed in the "mark-up" column in recognition of the contractor's overhead and fee. The "contingency" applied to the facility costs is 30%. We estimate that the target station and beam line will cost \$0.75 M. Consequently the net cost for the 100 MeV target facility will be \$1.99 M.

| | |
|---|---|
| Building Structures | \$1.24 M |
| 100 MeV Quadrupole Triplet | \$0.10 M |
| Target Shield | \$0.05 M |
| Target System | \$0.30 M |
| Hot Cell and Manipulators | \$0.30 M |
| **Total Facility Cost** | **\$1.99 M** |

Table 3.5 : Construction Cost Estimate For the Porposed 100 MeV Target Building

| COST ELEMENT | QUANTITY | UNIT | UNIT PRICE | DIRECT COST | MARK-UP | CONTINGENCY | TOTAL ITEM COST | TOTAL COST |
|---|---|---|---|---|---|---|---|---|
| *SITE* | | | | | | | | |
| Excavation | 2000 | cy | $ 5.00 | $ 10,000.00 | $ 2,200.00 | $ 3,660.00 | $ 15,860.00 | |
| Hauling | 2000 | cy | $ 5.00 | $ 10,000.00 | $ 2,200.00 | $ 3,660.00 | $ 15,860.00 | |
| Backfill | 1000 | cy | $ 1.84 | $ 3,400.00 | $ 748.00 | $ 1,244.40 | $ 5,392.40 | |
| Compaction | 1000 | cy | $ 0.76 | $ 1,900.00 | $ 418.00 | $ 509.96 | $ 2,827.96 | |
| *Site Subtotal* | | | | $ 25,300.00 | $ 5,566.00 | $ 9,074.36 | $ 39,940.36 | $ 39,940.36 |
| *UTILITIES* | | | | | | | | |
| Electrical Service | 0 | ft | $ 95.00 | $ - | $ - | $ - | $ - | |
| Sanitary Sewer Service | 0 | ft | $ 45.00 | $ - | $ - | $ - | $ - | |
| Gas Service | 0 | ft | $ 12.40 | $ - | $ - | $ - | $ - | |
| Water | 0 | ft | $ 31.40 | $ - | $ - | $ - | $ - | |
| Radioactive Liq Waste | 0 | ft | $ 200.00 | $ - | $ - | $ - | $ - | |
| Telephone | 0 | ea | $ 24,800.00 | $ - | $ - | $ - | $ - | |
| *Utilities Subtotal* | | | | $ - | $ - | $ - | $ - | $ - |
| *BUILDING* | | | | | | | | |
| Lower Level Concrete | 250 | cy | $ 268.00 | $ 67,000.00 | $ 14,740.00 | $ 24,522.00 | $ 106,262.00 | |
| Upper Level Slab | 1800 | sf | $ 4.05 | $ 7,290.00 | $ 1,603.80 | $ 2,668.14 | $ 11,561.94 | |
| Steel Wall Columns | 50000 | lbs | $ 0.79 | $ 39,416.21 | $ 8,671.57 | $ 14,426.33 | $ 62,514.10 | |
| Conven. Roof Trusses | 2000 | sf | $ 4.87 | $ 9,740.00 | $ 2,142.80 | $ 3,564.84 | $ 15,447.64 | |
| Lower Level Roof Beams | 1 | lot | $ 20,000.00 | $ 20,000.00 | $ 4,400.00 | $ 7,320.00 | $ 31,720.00 | |
| Stack | 1 | ea | $ 25,000.00 | $ 25,000.00 | $ 5,500.00 | $ 9,150.00 | $ 39,650.00 | |
| Exter. Insul. Finish Sys. | 3440 | sf | $ 6.84 | $ 23,529.60 | $ 5,176.51 | $ 8,611.83 | $ 37,317.95 | |
| Subgrade Wall Seal | 2900 | sf | $ 7.85 | $ 22,765.00 | $ 5,008.30 | $ 8,331.99 | $ 36,105.29 | |
| Roof System and Insulate | 1768 | sf | $ 3.14 | $ 5,553.25 | $ 1,221.71 | $ 2,032.49 | $ 8,807.45 | |
| Doors | 1 | lot | $ 5,000.00 | $ 5,000.00 | $ 1,100.00 | $ 1,830.00 | $ 7,930.00 | |
| Epoxy Coating | 7500 | sf | $ 1.84 | $ 13,800.00 | $ 3,036.00 | $ 5,050.80 | $ 21,886.80 | |
| Cranes | 2 | ea | $ 55,000.00 | $ 110,000.00 | $ 24,200.00 | $ 40,260.00 | $ 174,460.00 | |
| *Building Subtotal* | | | | $ 349,094.06 | $ 76,800.69 | $ 127,768.42 | $ 553,663.17 | $ 553,663.17 |

Table 3.5 : Construction Cost Estimate For the Porposed 100 MeV Target Building

| COST ELEMENT | QUANTITY | UNIT | UNIT PRICE | DIRECT COST | MARK-UP | CONTINGENCY | TOTAL ITEM COST | TOTAL COST |
|---|---|---|---|---|---|---|---|---|
| *HVAC* | | | | | | | | |
| HV1 Coils | 2 | ea | $ 2,000.00 | $ 4,000.00 | $ 880.00 | $ 1,464.00 | $ 6,344.00 | |
| HV1 Welded (20" Rnd) | 500 | lb | $ 5.83 | $ 2,916.95 | $ 641.73 | $ 1,067.61 | $ 4,626.29 | |
| HV1 Exhaust Fan | 1 | ea | $ 5,000.00 | $ 5,000.00 | $ 1,100.00 | $ 1,830.00 | $ 7,930.00 | |
| HV1 Damp(8") (w actual) | 6 | ea | $ 600.00 | $ 3,600.00 | $ 792.00 | $ 1,317.60 | $ 5,709.60 | |
| HV2 Airhandler | 1 | ea | $ 25,000.00 | $ 25,000.00 | $ 5,500.00 | $ 9,150.00 | $ 39,650.00 | |
| HV2 Ducts (30X30 Galv) | 2000 | lb | $ 3.22 | $ 6,434.06 | $ 1,415.49 | $ 2,354.86 | $ 10,204.41 | |
| HV2 Riser Ducts(6X12galv) | 2000 | lb | $ 3.22 | $ 6,434.06 | $ 1,415.49 | $ 2,354.86 | $ 10,204.41 | |
| Test & Balance | 1 | lot | $ 10,000.00 | $ 10,000.00 | $ 2,200.00 | $ 3,660.00 | $ 15,860.00 | |
| Misc | 1 | lot | $ 15,000.00 | $ 15,000.00 | $ 3,300.00 | $ 5,490.00 | $ 23,790.00 | |
| *HVAC Subtotal* | | | | $ 78,385.07 | $ 17,244.72 | $ 28,688.94 | $ 124,318.72 | $ 124,318.72 |
| *HEATING WATER* | | | | | | | | |
| Boiler | 1 | ea | $ 10,000.00 | $ 10,000.00 | $ 2,200.00 | $ 3,660.00 | $ 15,860.00 | |
| Circulating Pumps | 1 | ea | $ 1,500.00 | $ 1,500.00 | $ 330.00 | $ 549.00 | $ 2,379.00 | |
| Expansion Tank | 1 | ea | $ 500.00 | $ 500.00 | $ 110.00 | $ 183.00 | $ 793.00 | |
| Piping (assume 1" Cu) | 200 | ft | $ 6.00 | $ 1,200.00 | $ 264.00 | $ 439.20 | $ 1,903.20 | |
| Pipe Insulation | 200 | ft | $ 3.60 | $ 720.00 | $ 158.40 | $ 876.00 | $ 1,754.40 | |
| Valves | 6 | ea | $ 300.00 | $ 1,800.00 | $ 396.00 | $ 658.80 | $ 2,854.80 | |
| Miscellaneous | 1 | lot | $ 5,000.00 | $ 5,000.00 | $ 1,100.00 | $ 1,830.00 | $ 7,930.00 | |
| *Heating Water Subtotal* | | | | $ 20,720.00 | $ 4,558.40 | $ 8,196.00 | $ 33,474.40 | $ 33,474.40 |
| *CHILLED WATER* | | | | | | | | |
| Chiller (20 Tons) | 1 | ea | $ 20,000.00 | $ 20,000.00 | $ 4,400.00 | $ 7,320.00 | $ 31,720.00 | |
| Pumps | 2 | ea | $ 1,500.00 | $ 3,000.00 | $ 660.00 | $ 1,098.00 | $ 4,758.00 | |
| Piping | 300 | ft | $ 6.00 | $ 1,800.00 | $ 396.00 | $ 658.80 | $ 2,854.80 | |
| Pipe Insulation | 300 | ft | $ 3.60 | $ 1,080.00 | $ 237.60 | $ 395.28 | $ 1,712.88 | |
| Valves | 15 | ea | $ 300.00 | $ 4,500.00 | $ 990.00 | $ 1,647.00 | $ 7,137.00 | |
| Heat Exchangers | 5 | ea | $ 2,000.00 | $ 10,000.00 | $ 2,200.00 | $ 3,660.00 | $ 15,860.00 | |
| Miscellaneous | 1 | lot | $ 10,000.00 | $ 10,000.00 | $ 2,200.00 | $ 3,660.00 | $ 15,860.00 | |
| *Chilled WTR Subtotal* | | | | $ 50,380.00 | $ 11,083.60 | $ 18,439.08 | $ 79,902.68 | $ 79,902.68 |

Table 3.5 : Construction Cost Estimate For the Porposed 100 MeV Target Building

| COST ELEMENT | QUANTITY | UNIT | UNIT PRICE | DIRECT COST | MARK-UP | CONTINGENCY | TOTAL ITEM COST | TOTAL COST |
|---|---|---|---|---|---|---|---|---|
| *MECHANICAL SERVICES* | | | | | | | | |
| Water Piping | 200 | ft | $ 6.00 | $ 1,200.00 | $ 264.00 | $ 439.20 | $ 1,903.20 | |
| Air Compressor | 1 | ea | $ 9,000.00 | $ 9,000.00 | $ 1,980.00 | $ 3,294.00 | $ 14,274.00 | |
| Air Dryer | 1 | ea | $ 3,000.00 | $ 3,000.00 | $ 660.00 | $ 1,098.00 | $ 4,758.00 | |
| Compressed Air Pipe | 300 | ft | $ 11.00 | $ 3,300.00 | $ 726.00 | $ 1,207.80 | $ 5,233.80 | |
| Firewater Distribution | 2500 | sf | $ 2.11 | $ 5,275.00 | $ 1,160.50 | $ 1,930.65 | $ 8,366.15 | |
| *Mech Services Subtotal* | | | | $ 21,775.00 | $ 4,790.50 | $ 7,969.65 | $ 34,535.15 | $ 34,535.15 |
| *ELECTRICAL* | | | | | | | | |
| Motor Control Center | 1 | ea | $ 25,000.00 | $ 25,000.00 | $ 5,500.00 | $ 9,150.00 | $ 39,650.00 | |
| Fan Motor Starters | 2 | ea | $ 10,000.00 | $ 20,000.00 | $ 4,400.00 | $ 7,320.00 | $ 31,720.00 | |
| UPS | 1 | ea | $ 10,000.00 | $ 10,000.00 | $ 2,200.00 | $ 3,660.00 | $ 15,860.00 | |
| General Power Dist | 2500 | sf | $ 3.10 | $ 7,750.00 | $ 1,705.00 | $ 2,836.50 | $ 12,291.50 | |
| Lighting | 2500 | sf | $ 3.57 | $ 8,925.00 | $ 1,963.50 | $ 3,266.55 | $ 14,155.05 | |
| Lightning Protect | 2500 | sf | $ 0.29 | $ 725.00 | $ 159.50 | $ 265.35 | $ 1,149.85 | |
| Grounding System | 2500 | sf | $ 0.25 | $ 625.00 | $ 137.50 | $ 228.75 | $ 991.25 | |
| Miscellaneous Elec | 1 | lot | $ 15,000.00 | $ 15,000.00 | $ 3,300.00 | $ 5,490.00 | $ 23,790.00 | |
| *Electrical Subtotal* | | | | $ 88,025.00 | $ 19,365.50 | $ 32,217.15 | $ 139,607.65 | $ 139,607.65 |
| *INSTRUMENT & CONTROLS* | | | | | | | | |
| Ion Chambers | 9 | ea | $ 10,000.00 | $ 90,000.00 | $ 19,800.00 | $ 32,940.00 | $ 142,740.00 | |
| Fire Detection | 2500 | sf | $ 0.38 | $ 950.00 | $ 209.00 | $ 347.70 | $ 1,506.70 | |
| Communications | 2500 | sf | $ 0.45 | $ 1,125.00 | $ 247.50 | $ 411.75 | $ 1,784.25 | |
| CCTV Cameras | 4 | ea | $ 2,000.00 | $ 8,000.00 | $ 1,760.00 | $ 2,928.00 | $ 12,688.00 | |
| Stack Monitor | 1 | ea | $ 50,000.00 | $ 50,000.00 | $ 11,000.00 | $ 18,300.00 | $ 79,300.00 | |
| *I&C Subtotal* | | | | $ 150,075.00 | $ 33,016.50 | $ 54,927.45 | $ 238,018.95 | $ 238,018.95 |
| Total | | | | | | | | $ 1,243,461.08 |

# 4. ENVIRONMENT, SAFETY, AND HEALTH

## 4.1. Environmental Reports and Permit Applications.

The NBTF project will require a variety of environmental reports and permit applications. The process of preparing the analyses, reports, and permit applications will be treated as an integral part of the design process for three reasons: (1) analysis of the NBTF emissions requires analysis of the experimental designs and operating procedures and analysis of the mitigating features of the NBTF systems, (2) feedback of requirements from the environmental considerations to the systems designers can drive design decisions, and (3) the milestones in the environmental considerations schedule are integrally related to the design and construction schedule. Certain design issues must be settled before environmental analysis can be performed and authorization to proceed with Definitive Design and Construction requires completion of specific environmental program milestones.

Our NBTF proposal involves two new facilities, which will be addressed separately. Since the chemical processing and laboratory facility already exists and is operating, all of the required permits and safety analyses are in place; these do not need to be discussed here. The cyclotron facility will be a new facility, whereas the 100 MeV targeting facility will be an addition to an existing facility. In each of these cases we will prepare an Environmental Considerations Action Plan prior to initiation of Title I Design. These plans will address the considerations listed below. It should be noted that even decisions needing no action require supporting analysis.

- National Environmental Policy Act (NEPA): An ES&H Questionnaire will be submitted for each of the two new facilities. (In fact this has already been done.) From these, DOE Environmental Checklists (DEC) will be prepared and submitted to DOE to determine the level of National Environmental Policy Act (NEPA) documentation to be required. If required, an Environmental Assessment (EA) or Environmental Impact Statement (EIS) will be prepared, revised, and approved by DOE before the project proceeds beyond the Title I design stage.

- Flood Plains/Wetlands: There are no impacts expected for the proposed sites. However, these will be reviewed to determine whether action will be taken within a flood plain as defined in Executive Order 11988 or within a wetland as defined in

Executive Order 11990. If so the required assessments will be developed and implemented before construction begins.

- Threatened and Endangered Species: No known cases exist. However, a survey will be performed to determine the presence of state and federally listed threatened and endangered species and for the presence of characteristic habitat for those species. If any are identified within the project areas, mitigation measures will be developed and implemented before construction begins.

- Archaeological and Cultural Resources: The areas are not known to contain any archaeological sites. Nevertheless, the sites will be surveyed to determine the extent of remediation required, if any. If any are identified, a mitigation plan and, if appropriate, a data recovery plan will be developed and implemented in consultation with the New Mexico Historic Preservation Office and Council on Historic Preservation.

- National Emissions Standards for Hazardous Air Pollutants (NESHAP): The permit will be prepared to indicate the facilities' compliance with the air emission standards set forth in 40 CFR 61. This permit will apply to hazardous as well as radioactive emissions and the air pollution control equipment specified to control these emissions.

- New Mexico Air Permit to Construct (PTC): This state required permit applies to the emission of pollutants listed in the New Mexico Ambient Air Quality Standards (NMAAQS). This process is required to ensure that ambient air quality standards for the given locality will not be exceeded and the processes involved comply with any new source performance standard.

- National Pollution Discharge Elimination System (NPDES): A revision of the site NPDES permit may be required if the waste water effluent from the facility significantly increases the hazardous waste burden required for treatment. Any contaminated effluent is expected to be below regulatory concern; however, this assumption will have to be documented with appropriate mass flow rate calculations.

- Prevention of Significant Deterioration (PSD) Permit: This permit requires approval from the New Mexico Environmental Improvement Division (EID) to ensure that the air emissions from the facility will not cause the ambient air standards for the class of national forest area adjacent to the facility to be exceeded.

- SWMU Investigation: The proposed sites are not known to contain any Solid Waste Management Units. A formal investigation and SWMU report will be required. Remedial action will be taken prior to construction if a SWMU is to be disturbed.

Some important information already exists concerning the required environmental permits. An ES&H Questionnaire was submitted and reviewed for an earlier proposed version of the NBTF in 1992, which was to be located on the same site as the proposed cyclotron facility. At that time there were no potential problems identified. Accordingly we expect that all of the permit applications will be approved without unexpected delays when the proper time comes. Similarly, an ES&H Questionnaire was submitted in 1993 for a 100 MeV target facility at LAMPF similar to that proposed here. Preliminary review of that questionnaire revealed no unexpected obstacles. Again, we expect that all of the permit applications will approved without unexpected delays when the proper time comes.

## 4.2. Safety and Health.

4.2.1. Requirements. We anticipate that each of the proposed new facilities will be classified as a radiological facility, according to the guidelines set forth in DOE Standard 1027. As such these facilities will be exempt from many of the requirements of DOE Order 5480.23. In effect a formal Nuclear Facility Safety Analysis Report (SAR) will not be required. However, each will require an authorization document that includes a safety analysis. Accordingly a safety analysis will be prepared for each new facility prior to Definitive Design and Construction.

All radiological facilities fall under the purview of 10 CFR 835, which deals with radiation protection. In addition, both facilities will comply with the requirements of DOE Order 5480.25, which covers accelerators.

There is a myriad of requirements promulgated by various government agencies covering hazardous chemical substances. Since neither of the proposed new facilities contains chemical laboratory space, we do not expect that these requirements will strongly affect the project. Both facilities will be designed to avoid the unnecessary use of hazardous materials in either construction or operation.

The Technical Area 48 hot cell and laboratory facilities are currently classified as radiological facilities and are subject to all of the requirements noted above. This classification will not change with the implementation of the NBTF project. All of the necessary documentation for operation of these facilities is approved and in place.

4.2.2. Design Considerations.

Since the chemical processing and laboratory components of the proposed project are already in operation, the following discussion relates only to the two proposed new structures.

The proposed new facilities do not contain any hazards that might run away upon loss of control, nor do they contain mobile radioactive materials that would require operation of primary confinement HVAC systems to maintain containment. It is expected that a passive shutdown will prove to be acceptable upon completion of a safety analysis. Uninterruptable power should be provided to radiation monitors, stack monitors, fire detectors, alarms, emergency lighting, and any other equipment required to perform personnel safety functions during a facility shutdown.

The major hazards associated with these facilities will be (1) radiation associated with the cyclotron and target caves, and (2) electrical hazards. Radiation associated with the cyclotron and target caves will be addressed by taking the following actions.

The cyclotron and target caves will be located below ground whenever possible to take advantage of earthen shielding, and concrete shielding will be provided as necessary to minimize radiation fields in the occupied parts of the facility. The cyclotron RF systems will be interlocked to the accelerator and target cave entry doors and gates so that accidental attempts at entry will stop the beam. Similarly, the beam diverter magnet and injector systems will be interlocked with the target cave at the 100 MeV beam spur at LAMPF. Target caves will be equipped with warning horns, panic shutdown buttons, and television cameras connected to monitors at the control console. These will allow a trapped person to interrupt the start of the machine as well as allowing the operator to check that the caves are vacant. Radioactive gas production should be at a minimum since the beam will be contained within evacuated beam tubes and target chambers. Nonetheless, some radioactive gas will be made by neutron bombardment. The cyclotron vault and target rooms will be ventilated by a circulating system that will retain the atmosphere for a long period to allow for decay of the short half-life activated air. For the 100 MeV target station the beam stop is located within a large steel shield to reduce exposure to maintenance staff from the radioactivity emanating from the beam stop. The cooling water will be a recirculating system with the reservoir being a shielded tank. Remote handling and transport systems will be provided for retrieving irradiated targets.

Electrical hazards will be addressed by using normal industrial safety techniques for high power equipment.

# 5. WASTE MANAGEMENT

Los Alamos is unique among the various institutions interested in NBTF because it is the only one with permitted, licensed, and operating radioactive waste disposal facility located on site. This assures the ability to properly dispose of such wastes, both now and in the future, without concerns about whether the waste acceptance policies of remote disposal facilities may change. In addition the close proximity of the waste facility to the chemical processing area minimizes the transportation difficulties between sites. Waste management capabilities may be among the most important factors in selecting a site for NBTF, for without the ability to properly dispose of processing wastes, the facility cannot operate.

The Medical Radioisotope Program at Los Alamos has been conducting research and development of radioisotopes for more than 20 years. During this time the necessary protocols for packaging, transporting, and disposing of radioactive wastes have been perfected and are fully in place. These procedures can be directly transferred to the proposed NBTF operations. Thus we anticipate no problems or delays in implementing waste management practices for the proposed facility.

The waste streams from NBTF operations will be virtually the same as those for the existing isotope production and research program. In fact, we expect the amounts of radioactive wastes to **decrease** when NBTF comes on line. There are two reasons for this. The first is that the smaller targets and lower beam energies used for isotope production at NBTF will result in less unwanted radioactivity being produced. Accordingly both the volume and the amounts of activity to be disposed of will be reduced. The second reason is that there is an active waste minimization program under way at Los Alamos, and we expect to implement new procedures that will significantly reduce the volume of radioactive wastes from the chemical processing facility. In any event, the historical data from the existing radioisotope program provide useful information for projecting the waste disposal needs and costs for the proposed new facilities.

Management of hazardous and/or radioactive wastes is heavily regulated. Rather than present long lists of regulatory requirements, we describe instead the results of those requirements as they relate to the current radioisotope production program and to the proposed NBTF. These discussions illustrate an important point. Implementation of a new waste management and disposal plan where one does not already exist would be a time consuming and expensive process; one can not even guarantee that such an implementation would be successful. We feel that the existence of functioning waste management and disposal procedures combined with operating on site waste disposal facilities is a strong point in favor of siting NBTF at Los Alamos.

## 5.1. Waste Types.

There are a number of different waste types that would emanate from the proposed facilities. These will be managed and disposed of in different ways.

5.1.1. Sanitary Landfill Waste. Waste that does not contain radioactive materials, hazardous chemicals, explosives, or any combination thereof constitutes sanitary landfill waste. This waste originates from areas and facilities in which no radioactive or hazardous materials are handled or from radiation or hazardous materials work areas that operate under controlled conditions. In practice this consists mostly of trash from office areas and meeting rooms, and also includes packaging materials from supplies brought into the facility and any other waste items originating outside of the radiological areas. This waste will be placed in dumpsters for disposal in the Los Alamos County landfill.

5.1.2. Suspect Radioactive Waste. Waste that is generated in an area where radioactive materials are present but that cannot be verified as being either radioactive or non-radioactive is classified as suspect radioactive waste. This waste is handled and disposed of as if it were low-level radioactive solid waste (See Section 5.1.3 of this document.). Since this also accounts for the largest volume of waste originating from the chemical processing facility, considerable expense could be saved if this could be certified as non-radioactive. Accordingly the Los Alamos Radioisotope Program is implementing assay capabilities to accomplish this. Therefore, we are projecting that when NBTF comes on line that the majority of the suspect waste will be disposed of as sanitary landfill waste.

5.1.3. Low-Level Radioactive Solid Waste. Solid radioactive waste not classified as high-level waste, transuranic waste, or spent nuclear fuel as defined in Department of Energy Order 5820.2A is classified as low-level radioactive solid waste. Test specimens of fissionable material irradiated for research and development only, and not for the production of power or plutonium, may also be classified as low-level waste, provided that the concentration of transuranic nuclides is $<100$ nCi/g of waste. Virtually all of the solid radioactive waste originating from the current Medical Radioisotope Program falls in this category; the same will be true for the NBTF. This includes items ranging from contaminated gloves and anti-C clothing, to chemical laboratory wastes, to hot cell trash and hot cell processing wastes.

In the current radioisotope production program low-level wastes are handled in three different ways, depending on the amount of radioactivity involved. Low-level wastes not requiring shielding are packaged in strong tight containers, assayed, and transported to the radioactive waste disposal site for disposal. Waste that is too hot to handle without shielding is packaged in 30 gallon steel drums, which are then loaded into a special shield for transporting to the disposal site. Every item is assayed before placement in the barrel; the barrel is loaded, capped, and placed in the shield remotely using the hot cell manipulators. Waste that is extremely hot is packaged in special canisters designed to fit inside the target transfer cask, which provides much more shielding than the barrel cask. The cask is then taken to the waste disposal site and unloaded. Special procedures have been implemented for unloading the barrel and target casks at the waste disposal site while minimizing personnel radiation exposures. All of the low-level radioactive solid wastes are disposed of at Los Alamos Technical Area 54.

For NBTF we expect that all the waste will be handled in one of the first two ways noted above. This is because the lower beam energies to be used at NBTF will simply not produce the amounts of unwanted radioactivity that would require use of the target cask for transport. For the same reasons the number of barrels needed will be significantly reduced when compared to current operations. Consequently the waste disposal costs should be significantly lower for NBTF than for the current isotope production program. Waste management costs are discussed more fully in Section 5.6 of this document.

5.1.4. Hazardous Wastes. Hazardous waste is defined by the Resource Conservation and Recovery Act (RCRA) as any solid waste intended for disposal that is corrosive, toxic, ignitable, or reactive, or that contains a listed (40 CFR 261, Subpart D) hazardous constituent. Hazardous wastes commonly generated include all types of laboratory research chemicals, solvents, acids, bases, carcinogens, compressed gases, metals, and other solid wastes contaminated with hazardous waste. Wastes containing hazardous substances must be segregated from other wastes and handled separately. The Los Alamos Technical Area 48 hot cell facility has two satellite waste storage areas that can be used to store hazardous wastes until they can be properly disposed. Hazardous wastes are disposed of through the Laboratory waste management group, which maintains facilities for handling and disposing of these materials. These procedures will also apply to the proposed NBTF facilities.

In fact the amounts of hazardous wastes generated by the current isotope production program are very small, thanks to revisions in chemical processing methods and an aggressive waste minimization program. We expect that the amount of hazardous waste generated by NBTF will be of similar magnitude, and that hazardous waste disposal costs will not be an important factor for operating the facility.

5.1.5. Mixed Wastes. Wastes that contain both hazardous and radioactive components are termed mixed wastes. These are very difficult and expensive to dispose of; the best way to dispose of mixed wastes is to not generate them to begin with. Through careful planning and by revising and modifying chemical procedures, the Los Alamos Medical Radioisotope Program has successfully reduced the amounts of mixed wastes produced to virtually nil. Similar approaches will be used for NBTF. When mixed wastes are produced, they can be disposed of through the Laboratory waste management group, which maintains facilities for handling and disposing of these materials.

5.1.6. Transuranic (TRU) Wastes. Solid waste that is contaminated with alpha-emitting radionuclides with half-lives >20 years to levels > 100 nCi/g of waste, with the exception of natural and depleted uranium, is classified as transuranic (TRU) waste. The Los Alamos Medical Radioisotope Program does not produce any TRU waste; we anticipate that NBTF will not produce any either. However, if any is produced, it will be packaged and deposited in retrievable storage at the waste disposal site (Los Alamos Technical Area 54) to await future shipment to the Waste Isolation Pilot Plant (WIPP). Because other programs at Los Alamos do generate TRU wastes, procedures for accomplishing this exist and can be used, if needed.

5.1.7. Liquid Wastes. Certain laboratory sites at Los Alamos are served by a liquid radioactive waste collection system. Laboratory group CST-13 operates waste treatment plants and maintains the radioactive liquid waste collection system from the point where a building connects to the radioactive liquid waste pipeline. The drains in the hot cells and radiochemistry laboratories at Technical Area 48 are connected to a portion of this system that leads directly to the main treatment plant at Los Alamos Technical Area 50. The Los Alamos Medical Radioisotope Program uses this system for disposal of once-through condenser water from the hot cells and for other liquid wastes known to contain less than 0.5 μCi/L total activity. These same capabilities and restrictions will apply to NBTF.

The main buildings at the LAMPF accelerator site are connected to radioactive liquid waste pipelines that transport waste to storage tanks. From the storage tanks, the waste is pumped either directly into the lined lagoon at the east end of the LAMPF site, or into tank trucks, which then transfer the waste to the main treatment plant. This same system will be used for liquid wastes originating from the proposed 100 MeV target facility. The primary liquid waste component from that facility will be spent cooling water. A recently completed study suggests that the radioactive cooling water discharge from TA-53 facilities can be eliminated by utilizing a large holding tank and taking advantage of decay. The Laboratory is looking toward verifying this analysis and implementing it.

Liquid materials containing more than 0.5 µCi/L of gross activity will be converted to solid form and then disposed as low-level radioactive solid wastes. Such procedures are currently in use by the Los Alamos Medical Radioisotope Program.

5.2. Waste Minimization.

Because disposal of radioactive and hazardous wastes is expensive, waste minimization is an important concept. Both the Los Alamos Laboratory and the Medical Radioisotope Program have active waste minimization programs. The waste stream from the isotope production program has been cut in half over the last two years. In fact the isotope production team received a waste minimization award from the Laboratory Pollution Prevention Program Office in 1994. We expect similar reductions in waste disposal costs to continue, as we develop ways to dispose of more of our waste in forms that are subject to less regulation.

These concepts will be transferred directly to NBTF. A waste minimization plan will be developed for each of the proposed facilities during preparation of the operating protocols. Existing waste minimization plans for the hot cell facilities and for the LAMPF accelerator complex will provide the basis for those documents.

5.3. Solid Waste Disposal Facilities (Los Alamos Technical Area 54).

Area G is the low-level waste disposal and transuranic (TRU) waste storage facility for Los Alamos National Laboratory (LANL). Low-level waste in a variety of forms is disposed of in pits and shafts. Located on Mesita del Buey at Technical Area 54, Area G has been managing solid radioactive waste since 1957 and will remain the Laboratory's solid radioactive waste management area into the foreseeable future. In the early 1990s, the US Department of Energy (DOE) designated Area G a nonreactor nuclear facility requiring rigorous quality assurance and control and formality of operations.

A Low-level Waste (LLW) Disposal Team develops LLW disposal capacity and programs and executes disposal operations at Area G. This team ensures that all LLW waste disposal operations at Area G comply with DOE, EPA, state, and LANL requirements. This responsibility includes final waste acceptance at the control gate, and writing and following up on nonconformance reports. The LLW Disposal Team interfaces with the Waste Acceptance Team and waste generators to certify compliance with waste handling, packaging, labeling, documentation, and disposal requirements.

Routine waste loads are transported to the disposal pit, where they are unloaded, compacted in place, and, if they are uncontained and could be dispersed, covered with a protective layer of crushed tuff. Waste loads are placed in specific locations inside the pit to maximize disposal volume, and the locations are recorded with surveying equipment. The pits are typically 600 feet long, 80 feet wide, and 60 feet deep.

Waste streams that exhibit such special characteristics as high external dose rates, biological decay, or inhalation hazards are placed in engineered augered shafts in the mesa top. This disposal method enhances control of the waste form. Soil is used periodically as a barrier to shield workers from penetrating radiation. When shafts reach capacity, they are capped, and a permanent identification marker is attached. Shafts are typically 60 feet deep, and 2-6 feet in diameter.

A Transuranic (TRU) Waste Storage Team develops TRU waste storage capacity and programs and coordinates TRU waste storage operations at Area G. This mission includes operating and maintaining four active storage facilities at Area G.

## 5.4. Liquid Waste Disposal Facilities (Los Alamos Technical Area 50).

The laboratories, accelerators, reactors, and shops at the Los Alamos National Laboratory annually generate about 8,000,000 gallons of dilute liquid radioactive waste and about 46,000 gallons of a more highly radioactive process liquid waste. Special doubly contained, continuously monitored collection systems convey these wastes to a central processing plant at Technical Area 50. Two collection systems operate full time. The main system collects dilute wastes and a separate system collects the more highly radioactive process wastes from the plutonium processing facility.

Radionuclides of principal concern are plutonium, americium, and uranium. Dilution solutions of mixed fission products and mixed activation products are also treated. The plant uses ferric hydroxide precipitation followed by filtration and dewatering of concentrates in a 250 gallon per minute facility. Activity levels in the liquid effluents are generally considerably below discharge standards. The dewatered concentrates from the treatment process are packaged into 55 gallon drums (about 400 per year), which are then stored at the solid radioactive waste management area.

5.5. Transportation Issues.

Transportation of radioactive wastes from their point of origin to the disposal site deserves careful consideration, since such transport can be very expensive or even impossible in some cases. At Los Alamos the solid waste disposal site is located only 3 miles from the Technical Area 48 hot cell facility, and all the intervening territory is Laboratory property; there are no populated areas on the transport route. Nevertheless, all waste shipments are carried out in full compliance with all applicable DOT and DOE requirements. The primary cost for waste transfers is the documentation required to assure compliance with regulatory requirements.

5.6. Waste Management Costs.

We have used data from the current isotope production program at Los Alamos, including operations at the hot cell facility and at the isotope production facility, to estimate the amounts of various waste types that will be generated by the proposed NBTF. Allowances have been made for differences in the amounts of activation and the different target sizes expected for NBTF. In addition we have assumed that suspect waste (non-radioactive waste that comes from radiological areas) will be disposed of as unregulated sanitary waste.

**Table 5.1**
**Estimated Annual Waste Volumes for NBTF**

| | Sanitary Landfill Waste (cu. ft.) | Low-Level Rad-Waste (cu. ft.) | Hazardous Waste (cu. ft.) | Mixed Waste (cu. ft.) | Liquid Waste[1] (gallons) |
|---|---|---|---|---|---|
| Cyclotron Facility | 630 | 150 | 0 | 0 | 1000 |
| 100 MeV Target Facility | 0 | 40 | 0 | 0 | 1000 |
| Hot Cell Areas | 550 | 200 | 1 | 1 | 50000 |
| Research Laboratories | 270 | 80 | 2 | 1 | 5000 |
| Totals | 1450 | 470 | 3 | 2 | 57000 |

[1]Includes spent cooling water and once-through condenser water discharged to the radioactive waste water treatment plant.

Radioactive waste disposal at the Los Alamos National Laboratory is covered under a direct allocation from the Department of Energy, Office of Environmental Management (DOE-EM). Under the current funding arrangement there will be no radioactive waste disposal costs for the NBTF if it is sited at Los Alamos.

# 6. BUSINESS PLAN

## 6.1 Anticipated Isotope Sales.

The scope of the NBTF was determined through a series of workshops and studies carried out during the 1988 to 1992 time frame. Table 6.1 lists the isotopes that were identified during those discussions. The large number of isotopes is indicative of the wide range of interests represented at these workshops. It is impossible to state *a priori* which isotopes are most important without some system of measurement that everyone agrees upon. NBTF has the dual mission of satisfying the nation's need for rare and exotic research isotopes while still striving toward self sufficiency. Therefore it is necessary to design a facility that can develop a reasonable cash flow while maintaining the flexibility to produce a wide range of isotopes for research.

The Department of Energy has supplied radioisotopes for many years through a number of production sites. Analysis of sales and revenue trends from these sites can be useful in constructing a business plan for NBTF. Data from the national laboratories at Los Alamos and Brookhaven are the most relevant, since these are the only sites that have supplied accelerator isotopes in recent years. These data are shown in Tables 6.2 and 6.3. It is clear from these tables that most of the revenues derived from isotope sales come from only a few isotopes. In fact, only four isotopes account for nearly 90% of the revenues. These are Sodium-22, Germanium-68, Strontium-82, and Cadmium-109. A similar suite of isotopes will likely account for most of the revenues obtained for NBTF.

### 6.1.1. NBTF Production Isotopes.

6.1.1.1. Na-22. Sodium-22 ($t_{1/2}$ = 2.605 a) has applications in positron sources and as a tracer in oil well logging. The material used in positron sources must have very high specific activity, while that used for other purposes can be of much lower isotopic purity. The high specific activity material has a market potential not exceeding 1.5 Ci/year at $120/mCi; the current customer for this material is DuPont/Merck Pharmaceutical Company. The low specific activity material has a current market of 300 mCi/y at a price of $50/mCi. This might expand somewhat if the price were reduced to $30/mCi. Companies interested in this material include North Sea Instruments Ltd., Institutt for Energiteknikk, and Tracer Technologies International, Inc. Assuming that NBTF replaced Los Alamos as the sole source for this material, then $189,000 in annual revenues could be expected.

**Table 6.1**
**Radioisotopes Listed in NBTF Workshops and Studies**

| Isotope | Half-Life | 1988 Workshop[1] | HERAC Report[2] | Purdue Workshop[3] | SNM Report[4] | Production Method |
|---|---|---|---|---|---|---|
| Be-7 | 53.3 d | X | | X | X | $^{6}$Li(d,n) |
| C-11 | 20.4 m | | X | | | $^{11}$B(p,n) |
| N-13 | 9.96 m | | X | | | $^{12}$C(d,n) |
| O-15 | 2.04 m | | X | | | $^{14}$N(d,n) |
| F-18 | 1.83 h | | X | | X | $^{18}$O(p,n) |
| Na-22 | 2.60 y | X | | | | $^{24}$Mg(d,$\alpha$) |
| Mg-28 | 20.9 h | X | | X | | $^{30}$Si(p,3p) |
| Al-26 | 7.2e5 y | X | | | | $^{26}$Mg(p,n) |
| Si-32 | 104 y | X | | | | $^{nat}$Cl(p,spall) |
| P-32 | 14.3 d | X | X | | | $^{32}$S(n,p) |
| Sc-46 | 83.8 d | X | | | | $^{45}$Sc(n,$\gamma$) |
| Sc-47 | 3.34 d | X | | X | X | $^{48}$Ca(p,2n) |
| Ti-44 | 47 y | X | | | | $^{45}$Sc(p,2n) |
| V-48 | 16.0 d | X | | X | X | $^{48}$Ti(p,n) |
| V-49 | 330 d | | | X | | $^{48}$Ti(d,n) |
| Cr-51 | 27.7 d | X | X | | | $^{50}$Cr(n,$\gamma$) |
| Mn-52 | 5.59 d | X | | | | $^{52}$Cr(p,n) |
| Fe-52 | 8.28 h | X | | X | X | $^{55}$Mn(p,4n) |
| Fe-55 | 2.73 y | | | X | X | $^{54}$Fe(n,$\gamma$); $^{55}$Mn(p,n) |
| Fe-59 | 44.5 d | X | X | | | $^{58}$Fe(n,$\gamma$) |
| Co-55 | 17.5 h | | X | | X | $^{56}$Fe(p,2n) |
| Co-56 | 77.7 d | X | | X | | $^{56}$Fe(p,n) |
| Co-57 | 272 d | | X | X | X | $^{58}$Ni(p,2n)$^{57}$Cu$\rightarrow$ |
| Co-60 | 5.27 y | X | | | | $^{59}$Co(n,$\gamma$) |
| Cu-61 | 3.41 h | | X | X | X | $^{60}$Ni(d,n) |
| Cu-62 | 9.74 m | | X | | X | daughter $^{62}$Zn |
| Cu-64 | 12.7 h | X | X | X | X | $^{63}$Cu(n,$\gamma$) |
| Cu-67 | 2.58 d | X | X | X | X | $^{70}$Zn(p,$\alpha$) |
| Zn-62 | 9.26 h | X | | X | X | $^{63}$Cu(p,2n) |
| Ga-67 | 3.26 d | X | X | X | X | $^{66}$Zn(d,n) |
| Ge-68 | 271 d | X | X | X | X | $^{nat}$Ga(p,xn) |
| As-72 | 1.08 d | X | X | X | X | daughter $^{72}$Se |
| As-73 | 80.3 d | X | | X | X | $^{nat}$Ge(p,x) |
| As-74 | 17.8 d | | X | | X | $^{nat}$Ge(p,x) |
| As-76 | 1.10 d | | | | | $^{75}$As(n,$\gamma$) |

**Table 6.1 (Continued)**
**Radioisotopes Listed in NBTF Workshops and Studies**

| Isotope | Half-Life | 1988 Workshop[1] | HERAC Report[2] | Purdue Workshop[3] | SNM Report[4] | Production Method |
|---|---|---|---|---|---|---|
| As-77 | 1.62 d | X | X | | | $^{76}Ge(n,\gamma)^{77}Ge\rightarrow$ |
| Se-72 | 8.4 d | X | | X | X | $^{75}As(p,4n)$ |
| Se-75 | 120 d | | X | | | $^{75}As(p,n)$; $^{74}Se(n,\gamma)$ |
| Br-75 | 1.62 h | | X | | X | $^{74}Se(d,n)$ |
| Br-76 | 16.2 h | | | X | | $^{77}Se(p,2n)$ |
| Br-77 | 2.38 d | X | | X | X | $^{78}Se(p,2n)$ |
| Br-80m | 4.42 h | X | | X | | $^{79}Br(n,\gamma)$ |
| Br-82 | 1.47 d | X | | | | $^{81}Br(n,\gamma)$ |
| Kr-81m | 13 s | X | X | | | daughter $^{81}Rb$ |
| Rb-81 | 4.58 h | X | | | | $^{82}Kr(p,2n)$ |
| Rb-82 | 1.27 m | | X | | | daughter $^{82}Sr$ |
| Rb-83 | 86.2 d | X | | | | $^{84}Kr(p,2n)$ |
| Rb-86 | 18.7 d | X | | | | $^{85}Rb(n,\gamma)$ |
| Sr-82 | 25.6 d | X | | X | X | $^{85}Rb(p,4n)$ |
| Sr-89 | 50.6 d | X | | | | $^{88}Sr(n,\gamma)$ |
| Sr-90 | 28.5 y | | | | X | fission |
| Y-88 | 107 d | X | | X | X | $^{88}Sr(p,n)$ |
| Y-90 | 2.67 d | X | | | | $^{89}Y(n,\gamma)$ |
| Zr-88 | 83.4 | X | | | | $^{89}Y(p,2n)$ |
| Zr-89 | 3.27 d | | X | X | X | $^{89}Y(p,n)$ |
| Tc-95 | 20.0 h | | | | X | $^{95}Mo(p,n)$ |
| Tc-95m | 61 d | | | X | | $^{95}Mo(p,n)$ |
| Tc-96 | 4.3 d | | | X | X | $^{96}Mo(p,n)$ |
| Tc-99m | 6.01 h | | X | | X | daughter $^{99}Mo$ |
| Ru-97 | 2.88 d | X | X | X | X | $^{99}Tc(p,3n)$ |
| Ru-103 | 39.2 d | X | | | | $^{102}Ru(n,\gamma)$; fission |
| Rh-103m | 56.1 m | X | | | | daughter $^{103}Ru$, $^{103}Pd$ |
| Rh-105 | 1.47 d | X | X | | | $^{104}Ru(n,\gamma)^{105}Ru\rightarrow$ |
| Pd-103 | 17.0 d | | | | | $^{103}Rh(d,2n)$ |
| Pd-109 | 13.7 h | X | X | | | $^{108}Pd(n,\gamma)$ |
| Ag-105 | 41.3 d | X | | | | $^{nat}Pd(p,x)$ |
| In-114m | 49.5 d | | | X | | $^{113}In(n,\gamma)$ |
| In-115m | 4.49 h | X | | | | $^{114}Cd(n,\gamma)^{115}Cd\rightarrow$ |
| Sn-117m | 13.6 d | X | | | | $^{116}Sn(n,\gamma)$ |

**Table 6.1 (Continued)**
**Radioisotopes Listed in NBTF Workshops and Studies**

| Isotope | Half-Life | 1988 Workshop[1] | HERAC Report[2] | Purdue Workshop[3] | SNM Report[4] | Production Method |
|---|---|---|---|---|---|---|
| Sb-119 | 1.59 d | X | | | | $^{119}$Sn(p,n) |
| Te-118 | 6.00 d | X | | | | $^{121}$Sb(p,4n) |
| I-123 | 13.2 h | X | X | X | X | $^{124}$Xe(p,2n)$^{123}$Cs→ |
| I-124 | 4.18 d | | | X | | $^{124}$Te(p,n) |
| I-125 | 60.1 d | X | X | | | $^{124}$Xe(n,γ)$^{125}$Xe→ |
| I-131 | 8.04 d | X | X | | X | fission |
| Xe-122 | 20.1 h | X | | X | | $^{127}$I(p,6n) |
| Xe-127 | 36.4 d | X | X | X | X | $^{127}$I(p,n) |
| Xe-133 | 5.24 d | | X | | | fission |
| Ba-128 | 2.43 d | X | | X | | $^{133}$Cs(p,6n) |
| Ce-139 | 138 d | | | X | X | $^{139}$La(p,n) |
| Pr-142 | 19.1 h | X | X | | | $^{141}$Pr(n,γ); $^{142}$Ce(d,2n) |
| Pm-145 | 17.7 y | X | | | | daughter $^{145}$Sm |
| Pm-149 | 2.21 d | X | X | | | $^{148}$Nd(n,γ)$^{149}$Nd→ |
| Sm-145 | 340 d | X | | | | $^{144}$Sm(n,γ) |
| Sm-153 | 1.95 d | X | X | | | $^{152}$Sm(n,γ) |
| Gd-146 | 48.3 d | X | | | | $^{nat}$Ta(p,spall) |
| Gd-148 | 75 y | X | | | | $^{151}$Eu(p,4n) |
| Gd-153 | 242 d | X | | | | $^{153}$Eu(d,2n) |
| Gd-159 | 18.6 h | X | X | | | $^{158}$Gd(n,γ) |
| Dy-165 | 2.33 h | X | X | | | $^{164}$Dy(n,γ) |
| Ho-163 | 33 y | X | | | | $^{165}$Ho(p,3n)$^{163}$Er→ |
| Ho-166 | 1.12 d | X | X | | | $^{165}$Ho(n,γ) |
| Lu-172 | 6.70 d | X | | | | $^{172}$Yb(p,n) |
| Lu-173 | 1.37 y | X | | | | $^{173}$Yb(p,n);daughter $^{173}$Hf |
| Hf-172 | 1.87 y | X | | | | $^{175}$Lu(p,4n) |
| Ta-178 | 9.31 m | | X | | | daughter $^{178}$W |
| Ta-179 | 1.79 y | | | X | X | $^{181}$Ta(p,3n)$^{179}$W→ |
| W-178 | 21.5 d | | | X | X | $^{181}$Ta(p,4n) |
| Re-186 | 3.78 d | X | X | | | $^{185}$Re(n,γ); $^{186}$W(p,n) |
| Re-188 | 17.0 h | X | X | | | $^{187}$Re(n,γ) |
| Os-191 | 15.4 d | | | | X | $^{190}$Os(n,γ) |
| Ir-191m | 4.94 s | X | X | | | daughter $^{191}$Os |
| Ir-192 | 73.8 d | | X | | | $^{191}$Ir(n,γ); $^{192}$Os(d,2n) |

## Table 6.1 (Continued)
## Radioisotopes Listed in NBTF Workshops and Studies

| Isotope | Half-Life | 1988 Workshop[1] | HERAC Report[2] | Purdue Workshop[3] | SNM Report[4] | Production Method |
|---|---|---|---|---|---|---|
| Ir-194 | 19.2 h | X | X | | | $^{193}Ir(n,\gamma)$ |
| Au-195m | 30.5 s | | X | X | | daughter $^{195}Hg$ |
| Au-198 | 2.69 d | | X | | | $^{197}Au(n,\gamma)$ |
| Au-199 | 3.14 d | X | X | | | $^{198}Pt(d,n)$ |
| Hg-195 | 9.5 h | | | | X | $^{197}Au(p,3n)$ |
| Hg-197 | 2.67 d | X | | | | $^{197}Au(p,n)$ |
| Tl-201 | 3.05 d | | X | X | | $^{203}Tl(p,3n)^{201}Pb\rightarrow$ |
| Pb-203 | 2.17 d | X | X | X | X | $^{203}Tl(p,n)$ |
| Pb-212 | 10.6 h | X | | | X | descendant $^{228}Th$ |
| Bi-205 | 15.3 d | X | | X | | $^{206}Pb(d,3n)$ |
| Bi-206 | 6.24 d | X | | X | | $^{206}Pb(d,2n)$ |
| Bi-207 | 32 y | X | | X | | $^{207}Pb(d,2n)$ |
| Bi-212 | 1.01 h | | X | | | descendant $^{228}Th$ |
| At-211 | 7.21 h | X | X | | | $^{209}Bi(\alpha,2n)$ |
| Np-235 | 1.08 y | | | X | | $^{235}U(d,2n)$ |
| Np-236 | 1.55e5 y | | | X | | $^{235}U(d,n)$ |
| Pu-237 | 45.2 d | | | X | | $^{237}Np(d,2n)$ |

[1]D. C. Moody and E. J. Peterson, "Proceedings of the DOE Workshop on the Role of a High-Current Accelerator in the Future of Nuclear Medicine", Los Alamos National Laboratory report LA-11579-C (May 1989).

[2]Sheldon Wolff, ed., "Review of the Office of Health and Environmental Research Program: Nuclear Medicine", report by the Subcommittee on Nuclear Medicine Research to the Health and Environmental Research Advisory Committee (HERAC) (August 1989).

[3]K. L. Kliewer and M. A. Green, "Proceedings of the Purdue National Biomedical Tracer Facility Workshop", Department of Medicinal Chemistry, Purdue University (1992).

[4]R. D. Holmes, et al., "National Biomedical Tracer Facility Planning and Feasibility Study", report of the Society of Nuclear Medicine to the U. S. Department of Energy, (March 1991).

6.1.1.2. Co-57. Cobalt-57 ($t_{1/2}$ = 271.8 d) is used in nuclear medicine for calibration purposes and for transmission imaging. We estimate the annual market demand to be between 8 and 10 Ci/year at a price between $40 and $50 per mCi. Because there are other suppliers NBTF would not be able to capture all of this market. We estimate that NBTF could capture 25 percent of the total market. Thus NBTF might realize $125,000 in annual revenues from this isotope. Possible purchasers for this isotope include Isotope Products Laboratories, Amersham, DuPont Merck Pharmaceutical Company, DuPont/NEN, and others.

**Table 6.2**

**Radioisotopes Produced and Sold by the Los Alamos National Laboratory**

| | Sales, in $K and (Production Level, in mCi) | | | | |
|---|---|---|---|---|---|
| **Radioisotope** | **FY1990** | **FY1991** | **FY1992** | **FY1993** | **FY1994** |
| Aluminum-26 | 10.8 (0.006) | 22.4 (0.0006) | 18.5 (0.0005) | 36.8 (0.0009) | 11.3 (0.0003) |
| Americium-241 | n/a | n/a | 29.6 (101400) | 49.9 (229676) | n/a |
| Arsenic-72/73 | 5 (30) | 3.8 (117) | 4.8 (23) | 10.4 (66) | 10.5 (67) |
| Beryllium-7 | n/a | 2.8 (5.5) | 3.9 (9) | 3.4 (7) | 0.8 (3.3) |
| Bismuth-207 | n/a | n/a | 5.9 (0.4) | 3.7 (0.2) | n/a |
| Cadmium-109 | 111 (2844) | 121 (3036) | 165.1 (3401) | 198 (3564) | 21.1 (345) |
| Copper-67 | 37 (1540) | 33.1 (1296) | 106 (2081) | 30 (408) | 17.6 (246) |
| Gadolinium-148 | n/a | n/a | 4.6 (0.01) | 9.2 (0.02) | 6.9 (0.015) |
| Germanium-68 | 184 (1063) | 165 (1091) | 236.9 (1129) | 405.9 (1554) | 278.3 (936) |
| Rubidium-83 | 5.8 (35) | 1.8 (6) | 4.3 (20) | n/a | 2.4 (6.45) |
| Selenium-75 | n/a | n/a | n/a | 2.3 (204) | 1.3 (2.04) |
| Silicon-32 | n/a | 1.5 (0.001) | 39.0 (0.04) | 21.8 (0.02) | 19.2 (0.02) |
| Sodium-22 | 46.8 (1304) | 49.0 (1477) | 78.8 (1368) | 147.4 (1702) | 129.8 (1505) |
| Strontium-82 | 300(4434) | 633 (8600) | 482 (5650) | 391 (4255) | 295.2 (2925) |
| Strontium-85 | n/a | n/a | 0.4 (1) | n/a | 0.1 (0.125) |
| Technetium-95m | n/a | n/a | 3.3 (3) | 7.4 (7) | 7.1 (7) |
| Titanium-44 | n/a | n/a | n/a | n/a | 4.4 (0.02) |
| Vanadium-48/49 | n/a | 0.8 (4) | 0.9 (3) | 2.6 (10) | 1.1 (2) |
| Yttrium-88 | 20.4 (83) | 19.2 (78) | 17.8 (63) | 15.1 (61) | 21.7 (79) |
| Zinc-65 | n/a | n/a | n/a | 2.3 (100) | 1.3 (50) |
| Zirconium-88 | 1.2 (5) | 0.6 (2) | n/.a | 0.5 (0.1) | 0.8 (2.15) |
| **Total** | **723** | **1,053** | **1,201** | **1,337** | **831** |

## Table 6.3

**Radioisotopes Produced and Sold by the Brookhaven National Laboratory**

| Radioisotope | Sales, in $K and (Production Level, in mCi) | | | | |
|---|---|---|---|---|---|
| | FY1990 | FY1991 | FY1992 | FY1993 | FY1994 |
| Beryllium-7 | 10.7 (57) | 0.2 (1) | n/a | 3.0 (12) | 1.0 (5) |
| Copper-67 | 10.4 (224) | 13.9 (258) | 14.7 (258) | 27.9 (382) | 38.2 (559) |
| Germanium-68 | 110.6 (601) | 143.9 (805) | 198.6 (838) | 100.4 (398) | 159.6 (651) |
| Magnesium-28 | 4.4 (10) | 12.3 (21) | 4.4 (0.4) | n/a | n/a |
| Rubidium-83 | n/a | 0.8 (10) | n/a | n/a | n/a |
| Ruthenium-97 | n/a | n/a | n/a | 5.8 (100) | n/a |
| Strontium-82 | 183.4 (2321) | 318.0 (4350) | 309.4 (3436 | 612.0 (4539) | 393.6 (3925) |
| Nickel-56 | n/a | n/a | n/a | n/a | 0.3 (3) |
| Technetium-96 | 1.4 (n/a) | 0.2 (64) | 4.2 (44) | 3.5 (30) | n/a |
| Xenon-127 | 32.4 (3220) | 1.3 (90) | 4.4 (195) | 1.6 (65) | n/a |
| Zinc-65 | n/a | n/a | n/a | n/a | 0.3 (1) |
| **Total** | **353.3** | **490.7** | **535.6** | **754.2** | **593.1** |

6.1.1.3. Cu-67. Copper-67 ($t_{1/2}$ =2.58 d) is an isotope with an interesting history and a great deal of potential. Its radiations are such that it has possibilities for both diagnosis and therapeutic applications in medicine. Possible customers include the University of California at Davis, Purdue University, Washington University, and many others.

Our interactions with researchers using Copper-67 suggest that its price should be comparable to that for Y-90 (about $15/mCi) for the market to expand to its full potential. If Copper-67 were routinely available at the correct price, we estimate the immediate market to be 12 Ci/year. At $20/mCi this represents potential revenues of $240,000, of which NBTF might capture 80 percent or $192,000. This could expand significantly if certain cancer treatment protocols show promise.

6.1.1.4. Ge-68. Germanium-68 ($t_{1/2}$ = 270.8 d) is used in calibration sources for PET scanners and as the parent in Ge-68/Ga-68 generators. It is critically important to the PET industry. We estimate the market potential to be 5 Ci/year at a price of $200/mCi. This isotope is currently produced at Los Alamos and Brookhaven. Recently Russian manufacturers have made significant inroads into this market. Thus we estimate that NBTF might capture 50 percent of the world market, assuming that current domestic production at

Los Alamos and BNL is curtailed. This represents possible annual revenues of $500,000. Potential customers are CTI Services Incorporated, Sanders Medical Products, General Electric Corporation, DuPont/NEN, DuPont Merck Pharmaceutical Company, Amersham, Isotope Products Laboratories, North American Scientific, Inc., and others.

6.1.1.5. Sr-82. Strontium-82 ($t_{1/2}$ = 25.36 d) is the parent isotope for the Sr-82/Rb-82 generator. The rubidium daughter is used for cardiac imaging through a product marketed by Bristol-Meyers Squibb. Bristol-Meyers Squibb is the only customer for Strontium-82. We estimate the current market to be 18 Ci per year at a price of $75/mCi. This could increase if Squibb decides to market their product more aggressively. There are a number of suppliers, including Los Alamos, Brookhaven, M.A.P. (Finland), Paul Scherrer Institut, and Nordion, as well as the Russians at Troitsk, and possibly the South Africans. Over the past couple of years Squibb has preferred to purchase this isotope from suppliers other than DOE because of the high price and the difficulty in negotiating long-term contracts. We estimate that NBTF might initially capture 10 percent of this market, yielding annual revenues of $135,000.

6.1.1.6. Cd-109. Cadmium-109 ($t_{1/2}$ = 462.6 d) is used commercially in x-ray sources; the x-rays of interest actually come from the $^{109m}$Ag daughter. We estimate the annual demand for Cd-109 to be 12 Ci at a price of $50/mCi. This isotope has been produced at various locations in the past, however, most of the current production is in Russia. Los Alamos has large quantities of unsold material that were produced before the Russians entered the market, and attempts to sell this material at bargain prices have been only partially successful. We estimate that NBTF could capture 50 percent of this market with good quality material and aggressive sales tactics. This represents an potential annual revenue of $300,000. Potential customers include DuPont/NEN, DuPont Merck Pharmaceutical Company, Amersham, Isotope Products Laboratories, North American Scientific, Inc., and others.

6.1.1.7. Re-186. Rhenium-186 ($t_{1/2}$ = 3.777 d) has interesting medical applications, as its chemistry is similar to that of technetium. If high specific activity Rhenium-186 were available with suitable purity we estimate a market of 48 Ci/year at $10/mCi. Since NBTF would initially capture all of this market, this represents potential revenues of $480,000 per year. Possible customers for this isotope include DuPont Merck Pharmaceutical Co., NeoRx Corporation, Mallincrodt Medical, Inc., and others.

6.1.2. Other NBTF Isotopes. We have categorized the other isotopes listed in Table 6.1 as research isotopes. This effectively means that one would not expect significant revenues to be derived from their production in the near term. This does not mean that these isotopes are unimportant, only that they do not have developed markets at this time. Since one of the prime motives for building NBTF is to foster research and development of new radioisotopes, a significant portion of the operating time should be devoted to these isotopes.

It is not appropriate to prioritize or even categorize research isotopes as part of this discussion. This activity falls under the purview of the NBTF advisory committee, which may evaluate proposals for production and research in various isotopes based on their technical merits and allocate resources accordingly. Virtually all of the listed research isotopes can be produced with a cyclotron at 30 MeV or less (Table 1.1). This is one of the primary reasons why we feel that construction of the NBTF should focus on such a machine.

We have not included very short-lived isotopes, such as F-18 or I-123, in our discussions of production isotopes because these would be used only regionally. Under proper circumstances these could lead to significant additional revenues for the facility.

## 6.2. Anticipated Sales Revenues.

Table 6.4 lists the projected sales revenues from the production isotopes for the proposed NBTF. The category labeled "Others" includes all other isotopes not listed explicitly in the table. These have been assigned 10 percent of the total revenues, which is consistent with historic trends from the DOE isotope production program.

Radioisotope sales is a dynamic market, which means that the mix of isotopes actually produced at NBTF in the future may differ from what is described here. However, the revenues projected in Table 6.4 are not out of line with those currently being derived from Los Alamos and Brookhaven, so that we are confident that our projections are realistic.

## 6.3. Revenue from Other Sources.

6.3.1. Additional Research and Development Opportunities. The research mission of the NBTF is multifaceted. The output of the facility will encourage nuclear medicine and biomedical research throughout the user community. It will also lead to new products and services through the NBTF's intramural research programs. We anticipate that the NBTF research program will enjoy some level of Federal support. However, there is the opportunity for support for research activities from the private sector. If the NBTF is sited at Los Alamos this private sector support could come in many forms. We have over

**Table 6.4**
**Projected Isotope Sales Revenues**

| Isotope | Market (Ci/year) | Price ($/mCi) | NBTF Share (%) | Net Revenue (K$/year) |
|---|---|---|---|---|
| Na-22 (HSA) | 1.5 | 120 | 100 | 180 |
| Co-57 | 10.0 | 50 | 25 | 125 |
| Cu-67 | 12.0 | 20 | 80 | 192 |
| Ge-68 | 5.0 | 200 | 50 | 500 |
| Sr-82 | 18.0 | 75 | 10 | 135 |
| Cd-109 | 12.0 | 50 | 50 | 300 |
| Re-186 | 48.0 | 10 | 100 | 480 |
| Others | --- | --- | --- | 213 |
| Total | --- | --- | --- | 2125 |

ten mechanisms for working with industry. These range from funds in agreements where the costs of the research is covered by the industrial partner to Cooperative Research and Development Agreements (CRADAs) where each partner provides the costs for the collaboration. It is clear that the NBTF as we have defined it will have extensive capabilities for studying low energy production routes to therapeutic radioisotopes. There are potentially large markets for therapeutic radioisotopes if their utility is proven in clinical trials. Thus, there could be significant industrial interest in pursuing low energy production routes that could then be implemented at the NBTF by the industrial organization or could be incorporated into the industrial organization's own production facilities. In either case, the industrial organization would benefit greatly by facilitating the research program at the NBTF by either the funds in or CRADA route.

Although much of the above discussion is directed at the radiopharmaceutical industry, other industries that rely on radioisotopes could be interested in supporting further development of products, either to improve the cost efficiency of production or to develop alternative radioisotopes for applications. Our work on production methodologies for Tantalum-179, discussed elsewhere in this document, is a good example of this potential interest.

6.3.2. Intellectual Property, Licensing Fees, and Royalties. In the longer-term the NBTF can reasonably expect to generate some revenue for the intellectual property developed in the early years of operation. The Los Alamos Medical Radioisotope Research and Production programs have generated much intellectual property over the past five years. They were responsible for 15% of the patents issued to the Laboratory in 1993 and 10% in 1994. The program currently has a number of patent disclosures being processed. A similar flow of intellectual property can be anticipated from the NBTF, and in the long-term could result in licensing fees and royalties to support NBTF operations. As mentioned previously, opportunties for development of therapeutic radioisotopes at the NBTF are numerous, and significant monies could be realized if one of the NBTF products finds therapeutic application.

On the shorter-term, if the NBTF were sited at Los Alamos, the opportunity exists for contributions to operating expenses from existing Los Alamos intellectual property. The rights for all patents generated by the program over the last five years have been assigned to the University of California and the Department of Energy. Any licensing fees or royalties from these patents could be available to offset cost of the NBTF. This possibility is small but real.

6.3.3. Additional Opportunitites for Funding Educational Programs. These additional opportunities are described in more detail in section 9, where educational programs are described.

## 6.4. Operating Costs.

The NBTF operating costs discussed below were developed using certain assumptions concerning the operation of the facility. The staffing plan and concomitant cost described below, are adequate to support the production schedule discussed in section 8. The proposed operating budget also contains costs for a moderate sized research program, as described in section 8. The management and administrative costs have been steamlined reflective of the management plan described in section 7. Other operating plans could lead to other operating costs, but the current scenario is designed to meet the NBTF objectives as defined by the various NBTF workshops.

6.4.1. Los Alamos Budgeting Explanation. Los Alamos develops budgeted cost information using a total modified cost approach. Laboratory burden (46.5%) and organizational support (8% Division tax) are applied to personnel costs, materials and services, and facility charges. Burdened personnel costs at Los Alamos are $156.5 K for a staff FTE and $83.8 K for a technical support (other) FTE. Materials and services are costs for supplies that are necessary to complete the technical work. Lastly, the facility charge, costed at $22 sq. ft. for that space required for the technical work, covers utility costs, facility engineering, and other charges required to keep the physical plant operating.

6.4.2. NBTF Staffing Plan. The proposed staffing plan is given in Table 6.5. This staffing plan is designed to accomplish the isotope production schedule described in section 8. It assumes that the NBTF is operating at capacities described, and that a moderate research program is being pursued. It is probable that the NBTF will take several years to completely commission and operate at full capacity, and a phased staffing plan with real operating costs for the fiscal years directly after construction of the facility would be developed during the construction phase of the project. Since it is probable that it will be several years before the NBTF operates at capacity, it would be several years before the staffing level described in Table 6.5 would be required. Early year operating budgets are expected to be lower than the steady state operating costs that are summarized in Table 6.6.

The staffing plan was developed by Los Alamos personnel with many years experience in radioisotope production. We are quite confident that the staffing levels are sufficient to accomplish the objectives and missions of the NBTF. We further believe that the operating costs, $6.2 M, represent a cost effective approach to satisfying the objectives of the NBTF.

6.4.3. Operating Cost Elements. The management and administrative costs are estimated to be $757 K. This includes costs for the NBTF Director, a facility manager, a program management support person, and two customer service representatives to operate the isotope production sales office. This is considered to be a modest cost for management of the NBTF and is consistent with the Los Alamos National Laboratory philosophy of flat organizational structures.

Isotope production costs are estimated to be $3,276 K. This represents 5 staff members and 13 technical support personnel. The range of skills required is described in the proposed staffing plan in Table 6.5. The $632 K M&S costs are based on historical trends from the existing Los Alamos isotope production activities extrapolated to the increased production levels expected for the NBTF. The facility charges are estimated from the proposed footprints for the buildings that will constitute the NBTF facility. The facility charge estimate is $772 K.

**Table 6.5**

**Proposed NBTF Staffing Plan**

| Activity | Staff | Tech Support |
|---|---|---|
| Target Fabrication (Cyclotron and 100 MeV Station) | | |
| Production Targets, Loading and Retrieving | | 1.0 |
| Cyclotron Operation and Maintenance | | |
| Operations Supervisor | 1.0 | |
| Operators | | 5.0 |
| Operator Assistant | | 0.5 |
| 100 MeV Target Station Operation | | 1.0 |
| Target Transportation | | 0.1 |
| Chemical Processing | 2.0 | 2.0 |
| Equipment Maintenance | | 0.5 |
| Manipulators | | |
| Detectors | | |
| Train | | |
| Hot Cells | | |
| Instrument Repair | | |
| Waste Management | 0.2 | 0.4 |
| Health Physics | | |
| Cyclotron Facility | | 0.25 |
| 100 MeV Facility | | 0.25 |
| Processing Facility | | 1.0 |
| Facility Manager | 1.0 | |
| NBTF/Program Management | 1.0 | 1.0 |
| Research Personnel | 3.0 | 3.0 |
| Packaging and Transportation | | 1.0 |
| Quality Assurance | 0.5 | |
| Marketing | 0.5 | |
| Sales Office | | 2.0 |
| Facility Documentation | 0.8 | |
| SOPs | | |
| RWPs | | |
| Safety Analyses | | |
| Occurence Reports | | |
| Audits | | |
| Authorization Documents | | |
| Inventory Management | | |
| Training Programs | | |
| Total | 10.0 | 19.0 |

**Table 6.6**

**NBTF Operating Costs**

| Cost Element | Cost ($K) | Description |
|---|---|---|
| 1.) Management and Administration | | |
| Burdened Personnel Cost | 313 | Staff (2) |
| | 251 | Tech Support (3) |
| | 564 | Subtotal |
| Materials and Services | 100 | M&S |
| | 8 | 8% Division Tax |
| | 50 | 46.5% Burden |
| | 158 | Subtotal |
| Facility Charges | 22 | $22/sq. ft. |
| 5 Offices - 700 sq. ft. | 2 | 8% Division Tax |
| 1 Conf. Rm. - 300 sq. ft. | 11 | 46.5% Burden |
| | 35 | Subtotal |
| **Management and Administration Total** | **757** | |
| 2.) Isotope Production | | |
| Burdened Personnel Costs | 782 | Staff (5) |
| | 1,090 | Tech Support (13) |
| | 1,872 | Subtotal |
| Materials and Services | 400 | M&S |
| | 32 | 8% Division Tax |
| | 200 | 46.5% Burden |
| | 632 | Subtotal |
| Facility Charges | 488 | $22/sq. ft. |
| cyclotron - 8500 sq. ft. | 39 | 8% Division Tax |
| 100 MeV station - 2840 sq. ft. | 245 | 46.5% Burden |
| hot cells - 9600 sq. ft. | | |
| offices - 1300 sq. ft. | 772 | Subtotal |
| **Isotope Production Total** | **3,276** | |

3.) Research and Development

| | | |
|---|---|---|
| Burdened Personnel Costs | 470 | Staff (3) |
| | 251 | Tech Support (3) |
| | 721 | Subtotal |
| Materials and Services | 200 | M&S |
| | 16 | 8% Division Tax |
| | 100 | 46.5% Burden |
| | 316 | Subtotal |
| Facility Charges | 57 | $22/sq. ft. |
| Radiochem. Labs (5) - 2000 sq. ft. | 5 | 8% Division Tax |
| Offices (5) - 600 sq. ft. | 29 | 46.5% Burden |
| | 91 | Subtotal |
| **Research and Development Total** | **1,128** | |

4.) Laboratory Indirect Program includes: 0 — Services provided for 46.5% burden charge already loaded

Education and Training Coordination
Special Programs (postdoc, GRA, etc.)
Industry Liason
Finance
Accounting
Procurement
Human Resources
Emergency Management
E,S&H Compliance Support
General and Administrative Costs

5.) Summary of Costs

| | | |
|---|---|---|
| Management and Administration | 757 | |
| Isotope Production | 3,276 | |
| Research and Development | 1,128 | |
| Laboratory Indirect Services | 0 | Above costs burdened |
| Other Costs | | |
| LAMPF beam delivery | 1,000 | |
| **GRAND TOTAL** | **6,161** | |

The research and development effort was costed at $1,128 K. This would support a level of effort from 3 staff FTEs and 3 technical support FTEs. Based again on the Los Alamos isotope production and research experience, modest size research program at this level provides tremendous synergism with the production program. Of course any level of research support could be negotiated depending on resources available.

In addition to these costs there will also be a cost for providing beam to the proposed 100 MeV target station. This costs has been estimated by our Accelerator Operations and Technology Division personnel to be $1,000 K.

## 6.5. Costs of Waste Removal.

Waste management is discussed fully in Section 5 of this document. Radioactive waste disposal at the Los Alamos National Laboratory is covered under a direct allocation from the Department of Energy, Office of Environmental Management (DOE-EM). Under the current funding arrangement there will be no radioactive waste disposal costs for the NBTF if it is sited at Los Alamos.

# 7. OPERATING PLAN

Los Alamos will operate the NBTF as a national user facility. Access to the facility by universities, research hospitals, private industry, and others will be facilitated by Los Alamos experience with operating user facilities, Los Alamos special educational programs (discussed in Chapter 9), and Los Alamos mechanisms for collaborating with industry.

## 7.1. Los Alamos Experience with User Facilities.

The Laboratory has been committed to a broad range of scientific collaboration with universities, industry, and government agencies by providing access to many Laboratory facilities. Below are descriptions of our most visible user facilities. This discussion is intended to elucidate Los Alamos' ability to manage and operate national resources such as the NBTF.

7.1.1. Los Alamos Meson Physics Facility. Among these user facilities, the Los Alamos Meson Physics Facility (LAMPF) is by far the largest. LAMPF is one of the world's largest and most sophisticated nuclear science facilities. It provides unique accelerator-generated beams of protons, pions, muons, neutrons, and neutrinos. Scientists use these beams to study fundamental conservation laws, weak interactions, nuclear structure, nucleon/nucleon and pion/nucleon interactions, condensed-matter physics, atomic physics, and nuclear chemistry. Applications-oriented activities that use LAMPF beams include radioisotope production, investigations of radiation effects in materials, and national-defense-related studies.

The present LAMPF users' group consists of 951 U.S. and foreign scientists representing some 99 external organizations: 96 universities and laboratories and 3 industrial organizations. During a typical year, the LAMPF research program provides beams for about four months to about forty experiments involving nearly 300 scientists and students from more than 60 institutions. Since the beginning of research operations at LAMPF, 1202 research proposals have been submitted for approval, and 651 experiments have been completed. About 2,150 people from outside the Laboratory have used the facility since it came on line, including 530 graduate and 175 undergraduate students. About 155 Ph.D. theses have been completed, and approximately 230 postdoctoral scientists have received training and experience. About 1,125 papers reporting scientific results have been published in refereed journals. At present, there are 90 experiments in active status, with 459 participants from 77 U.S. institutions and 30 from foreign institutions.

7.1.2. Los Alamos Neutron Scattering Center. The Manuel Lujan, Jr. Neutron Scattering Center (LANSCE), a designated user facility at Los Alamos, takes proton pulses from the LAMPF/Proton Storage Ring facility to produce intense bursts of spallation neutrons from a tungsten target for scientific research. About 80% of the available beam is intended for unclassified condensed-matter work and structural biology. Of the time available for condensed-matter work, three-fourths is distributed to a formal user program. LANSCE is rapidly becoming an international facility for neutron scattering experiments in solid-state physics, chemistry, crystallography, biophysics, materials science, and nuclear physics. Scientific endeavors at the facility will add to the Laboratory's collaborative and cooperative research programs significantly.

7.1.3. Other National User Facilities. Other officially designated user facilities include the National Flow Cytometry and Sorting Research Resource (NFCSRR), the National Stable Isotopes Resource (NSIR), the National Laboratory Gene Library Project (NLGL)), the National Genetic Sequence Data Bank (GenBank), and the Los Alamos National Environmental Research Park (NERP).

The cytometry and sorting resource is designed to make state-of-the-art flow cytometric instrumentation available to the biomedical research community. Flow cytometry uses electro-optical techniques to provide quantitative analyses of various cell properties that are sequentially studied in a continuous flow system. On the basis of these measure properties, the cells may then be physically isolated for their use in biological studies. Cells and subcellular constituents, such as chromosomes, can be analyzed and sorted at rates of thousands per second.

The overall objective of the Los Alamos stable isotopes resource (NSIR) is to extend the uses of stable isotopes in biomedical research with a view toward promoting the development of a viable commerce in these materials. The research component of this resource is the continued development of procedures for the efficient incorporation of $^{2}H$, $^{13}C$, $^{15}N$, $^{17,18}O$, and S into amino acids, nucleic acids, enzyme cofactors, carbohydrates, and precursor molecules. The service component explores new uses of stable isotopes in fundamental and clinical sciences through collaborative interactions with scientists in universities, hospitals, and other research institutions. In this context, stable isotopically labeled compounds are distributed to both internal and external users. We also promote technology transfers by consulting freely with private suppliers of isotopically labeled compounds.

GenBank was established by the National Institutes of Health (NIH) with cosponsorship by DOE, NSF, and DoD. Los Alamos and an industrial partner (Intelligenetics, Inc.) share the development and operation of this facility. Los Alamos collects, organizes, and annotates DNA sequence data in a way that makes it useful to a wide spectrum of research activities. An an essential tool of data management, the Laboratory develops and applies methods of computational analysis for discerning significant features and relationships within the data. To encourage direct contribution, correction, and criticism of data, we support electronic mail and other computer-processable media for communication with our group. Our industrial partner distributes the data, offering both magnetic tapes of the data base and on-line access to them.

The gene library project is a collaborative research effort between scientists at the Los Alamos and Lawrence Livermore National Laboratories. The objectives of this effort are to produce human-chromosome-specific DNA libraries and to disseminate them to geneticists throughout the world. Libraries are constructed at Los Alamos or Livermore and placed in a repository at the American type-culture collection in Rockville, Maryland, where they are distributed to individual scientists.

The environmental research park is an area containing the Laboratory and adjacent lands that has been set aside for a study of the impact of man's activities on his environment, that is, the interaction between man-altered systems and adjacent natural systems. The park resources can be made available to individuals and organizations outside the Laboratory to facilitate self-supported environmental research on appropriate subjects that are compatible with the Laboratory's programming mission.

7.1.4. Other Laboratory Facilities. In addition to the officially designated user facilities described above, the Laboratory has many other user resources which DOE and Laboratory management believe also may be of interest and benefit to qualified users. Examples of such facilities are the Time-of-Flight Isochronous (TOFI) Spectrometer, the Los Alamos Ion Beam Facility (IBF), the Los Alamos Ion Beam Materials Laboratory (IBML), the Weapons Neutron Research (WNR) Facility, the Mechanical Fabrication Facility (MFF), and the Advanced Weapons Diagnostic Facility (AWDF).

The TOFI spectrometer and its associated transport line are the major components of a facility designed to measure the masses of energetic recoiling nuclear reaction products. The TOFI facility is sited at LAMPF to take advantage of the high yields of exotic light nuclei produced in interactions between the intense 800-MeV proton beam and heavy- and medium-mass targets. Using measurements of the recoil's transit time through the spectrometer, we can make direct mass measurements with precisions of 100 to 1000 keV, depending on production rates. To date, we have measured the masses of more than 60 neutron-rich nuclei that range of $^{11}$Li to Fe. With the development of a new atomic number identification technique and the employment of high-geometry, beta neutron, or beta-gamma detection systems, we can use the TOFI as a fast-recoil tagging device to determine the gross decay-property characterizations for many of these exotic species.

The IBF houses tandem Van de Graaff accelerators and a low-energy (10- to 150-keV) light-ion accelerator. These accelerators produce ion beams of most elements and many molecules at energies from a few keV to tens of MeV. A new experimental capability, the acceleration of dust particles to hypervelocities, began in FY 1988. Initial results were very encouraging: measured velocities of 70 kilometers power second for subpicogram particles.

The IBML provides ion-beam materials characterization and modification to a wide variety of programs both within and outside the Laboratory. Two major instruments housed in the IBML provide the beams necessary for these programs. One is a 3-MV tandem electrostatic accelerator; the other is a 200-keV ion implanter. Rutherford backscattering analysis and nuclear reaction analysis are the most useful of the various analytical techniques available. The IBML is operated by Group MST-10 with the sponsorship of the Center for Materials Science and is classified as a DOE User Resource. Users are organized into participating research teams, which include many divisions and groups from within the Laboratory and researchers from outside the Laboratory. This organization provides great flexibility along with a variety of technical expertise, rapid access, and ease of use.

The WNR facility is a pulsed spallation neutron source used for basic and applied research.

The MFF is available on the basis of noninterference with DOE work to support research and development without regard to the sponsor's identity. The staff of this facility has extensive experience with manufacturing prototypes, close-tolerance components and apparatus, and the fabrication of radioactive and toxic materials. This facility also has the capability to machine metal laser mirrors by diamond turning.

The Isotope Measurement and Production Laboratory (IMPL) was conceived as an ultra-clean chemical separations and mass spectrometry facility to provide analytical support. The special instrumentation and chemical processing techniques developed for this program find very broad application in the fields of geochemistry, hydrology, atmospheric tracing, and environmental assessment of element migration.

Approximate numbers of experimenters or users of Laboratory multiuser facilities in FY 1989 are given in the Table 7.1. Additional descriptions of these and other facilities, as well as information about arrangements and contacts are available to potential users through either the Industrial Partnership Office or the University Relations Office at Los Alamos.

**Table 7.1**
**Experimenters/Users at Multiuser Laboratory Facilities**

| Designated | Laboratory | | Universities | | Industry | | Total |
|---|---|---|---|---|---|---|---|
| User Facilities | Number | %Use | Number | %Use | Number | & Use | Number |
| LAMPF | 90 | 32 | 188 | 67 | 2 | 1 | 280 |
| LANSCE | | | | | | | |
| NFCSRR | | | | | | | |
| NSIR | 10 | 14 | 60 | 83 | 2 | 3 | 72 |
| Gen Bank | | | | | | | |
| NERP | | | | | | | |
| Other User Facilities: | | | | | | | |
| TOFI | 4 | 57 | 3 | 43 | 0 | 0 | 7 |
| IBF | | | | | | | |
| IBML | 29 | 74 | 8 | 21 | 2 | 5 | 39 |
| WNR | | | | | | | |
| MFF | | | | | | | |
| IMPL | 10 | 100 | 0 | 0 | 0 | 0 | 10 |

7.2. NBTF Management Plan.

The NBTF will be managed with a minimum of management resources consistent with the Laboratory's policy of flat organizational structure. There will be a Director of the NBTF. The Director will be responsible for the leadership of the NBTF. He is responsible for the technical directions of the NBTF, the radioisotope product portfolio and scheduling, and external representation of the NBTF. There will also be a facility manager responsible for the daily operations of the NBTF facilities. In support of these two management positions will be a program management support person for effective project management and control and two customer service personnel who will be reponsible for radioisotope sale, distribution and services.

Advice, consultation, and review will be important components of the management of the NBTF. There will be an NBTF Advisory Council to provide technical input to the research directions of the facility and prioritization of isotope availability. This advisory committee will consist of researchers, industrial participants, and SNM representatives who have knowledge and interests that can be utilized by the NBTF management. In addition to the Advisory Council, there will be an external review committee whose purpose will be to examine, evaluate, and recommend regarding the NBTF technical output, products, and services. These reviews will occur on a biannual basis; enough time for substantial progress without overly impacting the operations of the NBTF. Lastly, there will be an industrial advisory board to counsel the NBTF management about commercial opportunities and advise both the NBTF management and DOE concerning the business practices of the NBTF enterprise. The efforts of this board will complement the NBTF Advisory Council by dividing the responsibilities for the technical and the business operations of the NBTF.

Industrial participation in the isotope distribution activities of the NBTF could be a very effective way to "corporatize" this component of the NBTF mission. Los Alamos would welcome industrial interest in developing mechanisms for Los Alamos and industrial interactions. This would be done in concert with the major federal sponsors for the NBTF, presumably the DOE Office of Health and Environmental Research and the Office of Isotope Production and Distribution.

## 8. PRODUCTS AND SERVICES

NBTF will have a three-fold mission that includes: (1) production and distribution of radionuclides for the biomedical and scientific communities, (2) conduct of research in radionuclide production, separation, and purification, and in development of biomedical applications of radionuclides, and (3) provision of education and training in radioisotope production, separation, and purification, and in applications of radiotracer methodologies. These mission components effectively define the products and services that will be offered by NBTF. Accordingly the following discussion is divided into production, research, and education components.

The various mission components discussed below are synergistic. The production efforts provide the materials needed to carry on the research and education missions. The research efforts provide direction and impetus to the production mission, while supplying intellectual challenges and training opportunities for the educational program. The educational efforts effectively promote the development and application of radionuclides and ensure the growth of this technology. Thus it is important that each of these three areas be promoted effectively and that none of them overshadows the others.

### 8.1. Radioisotope Production.

The radioisotope production component of NBTF has received more than its fair share of discussion during the previous workshops and project studies. This has been largely due to the fact that production capability is the component that is most lacking. Furthermore, implementation of a production capability is capital intensive. However, once a production capacity is implemented, it is important that the isotope production resources be allocated in an equitable and productive way. The following discussion describes our perceptions of the possibilities and priorities for radioisotope production.

8.1.1. Revenue Isotopes. We define revenue isotopes as those that can generate appreciable amounts of revenue through their sales in the near term. This limits classification of isotopes in this group to those with existing markets. There are a number of additional isotopes with potential for generating substantial revenues in the future. However, these will not affect the financial position of NBTF until their markets are established, and they are not included here.

8.1.1.1. Na-22. Sodium-22 ($t_{1/2}$ = 2.605 a) has applications in positron sources and as a tracer in oil well logging. The material used in positron sources must have very high specific activity, while that used for other purposes can be of much lower isotopic purity. The high specific activity material has a market potential not exceeding 1.5 Ci/year. The low specific activity material has a current market of 300 mCi/y; this might expand somewhat if the price were reduced. NBTF could become the sole source for this material.

Sodium-22 of high specific activity (>1000 Ci/g) is currently produced at Los Alamos by irradiating high purity aluminum metal with 750 MeV protons. Acceptable material has been supplied in the past by South African researchers, who irradiated magnesium targets. At NBTF Sodium-22 would best be produced by irradiating magnesium targets with protons or deuterons in the 20 - 22 MeV energy range. Significantly better yields would be achieved with deuterons. With a 500 μA deuteron beam one could produce Sodium-22 at the rate of 45 mCi/day. After allowing for decay and processing losses, we estimate that 1.9 Ci at end of bombardment (EOB) would be required to satisfy the market demand for this isotope. Thus 42 beam days would be required to fulfill the Sodium-22 demand with a cyclotron.

The threshold energy for production of Sodium-22 by proton irradiation of aluminum is approximately 33 MeV, with the production cross-section reaching a maximum value at 43 MeV. With 250 μA of 80 MeV protons it should be possible to produce Sodium-22 at the rate of 110 mCi/day. Thus 17.3 beam days would be required to fulfill the Sodium-22 demand with a high energy (>80 MeV) proton accelerator.

8.1.1.2. Co-57. Cobalt-57 ($t_{1/2}$ = 271.8 d) is used in nuclear medicine for calibration purposes and for transmission imaging. We estimate the annual market demand to be between 8 and 10 Ci/year. Because there are other suppliers NBTF would not be able to capture all of this market; we estimate that NBTF could capture 25 percent of the total market.

This isotope can be produced in good yield by irradiating nickel targets with low energy (<22 MeV) protons. With a 500 μA proton beam one can make cobalt-57 at the rate of approximately 350 mCi/day. After allowing for decay and processing losses, an annual production of 3.5 Ci at EOB would be required to satisfy the market demand. Thus 10 beam days would be required for this isotope.

8.1.1.3. Cu-67. Copper-67 ($t_{1/2}$ =2.58 d) is an isotope with an interesting history and a great deal of potential. Its radiations are such that it has possibilities for both diagnosis and therapeutic applications in medicine. Currently there are only three research groups in the United States who are seriously studying this isotope. However, one of those groups is using Copper-67 in human patients to treat certain types of cancer. If those studies yield promising results then interest in this isotope could expand dramatically.

Use of Copper-67 in medical research is limited by two factors, its high price and its limited availability. If Copper-67 were routinely available at the correct price, we estimate the immediate market to be 12 Ci/year, of which NBTF might capture 80 percent. This could expand significantly if the current treatment protocols show promise. Both Los Alamos and BLIP produce Copper-67 by high-energy proton irradiation of natural zinc. This process is inefficient and produces other isotopes of copper that compromise the quality of the product. At Los Alamos we have recently developed an alternate production method based on low-energy (20 MeV) proton irradiation of zinc metal isotopically enriched in Zn-70. This method allows production with less expensive accelerators and avoids the co-production of other isotopes of copper. With a 500 µA proton beam at 20 MeV one could produce 30 mCi/h. After allowing for processing and decay losses, NBTF would need to produce approximately 19.2 Ci/year at EOB to satisfy its market share. This would require 26.6 beam days of irradiation time.

8.1.1.4. Ge-68. Germanium-68 ($t_{1/2}$ = 270.8 d) is used in calibration sources for PET scanners and as the parent in Ge-68/Ga-68 generators. It is critically important to the PET industry. We estimate the market potential to be 5 Ci/year. This isotope is currently produced at Los Alamos and Brookhaven. Recently Russian manufacturers have made significant inroads into this market. Thus we estimate that NBTF might capture 50 percent of the world market, assuming that current domestic production at Los Alamos and BNL is curtailed.

Cyclotron production of Germanium-68 can be accomplished by irradiating gallium targets with protons. With a 200 µA proton beam at 22 MeV one can produce 3.6 mCi per hour (ORNL produced 3 mCi/h with their 86 in. cyclotron). Higher currents would improve this yield provided that gallium targets can be made to withstand this treatment. Allowing for decay and process yields indicates that 3.5 Ci (EOB) would be required to satisfy the expected 2.5 Ci annual demand for this isotope. This could be satisfied with 40.5 beam days of irradiation time.

8.1.1.5. Sr-82. Strontium-82 ($t_{1/2}$ = 25.36 d) is the parent isotope for the Sr-82/Rb-82 generator. The rubidium daughter is used for cardiac imaging through a product marketed by Bristol-Meyers Squibb. We estimate the current market to be 18 Ci/year. This could increase if Squibb decides to market their product more aggressively. There are a number of suppliers, including Los Alamos, Brookhaven, M.A.P. (Finland), Paul Scherrer Institut, and Nordion, as well as the Russians at Troitsk, and possibly the South Africans. Over the past couple of years Squibb has preferred to purchase this isotope from suppliers other than DOE because of the high price and the difficulty in negotiating long-term contracts. We estimate that NBTF might capture 10 percent of this market.

This isotope can be produced by proton irradiation of rubidium. The optimum proton energy is 40 to 50 MeV within the target itself. The energy must be kept above approximately 40 MeV to minimize production of Strontium-85. Thus the incident proton beam should be in the 60 - 70 MeV range, since the rubidium target will need to be encapsulated. With 250 μA of 70 MeV protons one could produce 130 mCi of Strontium-82 per day. After accounting for decay and processing losses, NBTF would need to make 3.5 Ci at EOB to satisfy its 1.8 Ci market share. This could be done with 27 beam days of irradiation.

8.1.1.6. Cd-109. Cadmium-109 ($t_{1/2}$ = 462.6 d) is used commercially in x-ray sources; the x-rays of interest actually come from the $^{109m}Ag$ daughter. We estimate the annual demand for Cd-109 to be 12 Ci. This isotope has been produced at various locations in the past, however, most of the current production is in Russia. Los Alamos has large quantities of unsold material that were produced before the Russians entered the market, and attempts to sell this material at bargain prices have been only partially successful. We estimate that NBTF could capture 50 percent of this market with good quality material and aggressive sales tactics.

Both Los Alamos and the Russians produce Cadmium-109 by irradiating indium metal targets with high energy protons. The Russian irradiations are done a lower energy (160 MeV versus 750 MeV). As a result their material contains less $^{113m}Cd$ and is thus more desirable. However, the best way to produce this material is with low-energy proton or deuteron irradiation of silver targets. This avoids the production of heavy isotopes of cadmium altogether. In addition, silver makes an excellent cyclotron target, capable of withstanding large beam currents. Cadmium-109 is also produced at Obninsk in Russia using this method. Production rates of 3 mCi/h can be obtained with 500 μA of 22 MeV protons or 3.5 mCi/h with 500 μA of 22 MeV deuterons. After allowing for decay and processing losses, we project that 7.3 Ci would need to be produced at EOB to satisfy a 6 Ci demand. This would require 101 beam days with protons or 87 beam days with deuterons.

8.1.1.7. Re-186. Rhenium-186 ($t_{1/2}$ = 3.777 d) has interesting medical applications, as its chemistry is similar to that of technetium. If high specific activity Rhenium-186 were available with suitable purity we estimate a market of 48 Ci/year. NBTF would initially capture all of this market. Cashing in on this potential market depends on developing a production method with an adequate yield and acceptable isotopic purity. To be viable this method must approach production rates of 1 Ci/day or approximately 40 mCi/h. After allowing for decay and processing losses we expect that production of 100 Ci/year at EOB would be required to satisfy the demand. This would require 100 beam days of irradiation.

8.1.2. Non-Revenue Isotopes. There are many isotopes needed for research purposes that will not generate significant revenues, either because the amounts required are too small, or because the markets are not developed. These isotopes are still important for the mission of NBTF. In some cases they will support internal research activities, while in others they will support outside research and development programs that may not be possible without the isotopes. There are also a few examples in which such isotopes could become revenue isotopes in the future, depending on market developments or on implementation of other research capabilities.

8.1.2.1. Currently Produced Non-Revenue Isotopes. Table 8.1 lists non-revenue isotopes that are currently supplied by Los Alamos (LANL) and the Brookhaven Linac Isotope Producer (BLIP). This illustrates the range of isotope types and amounts that are currently being produced; this trend will continue with NBTF. Many of these isotopes are by-products of the large scale production of revenue isotopes, made possible by the non-selective irradiations carried out at these two facilities, particularly Los Alamos. At NBTF it will be necessary to produce these materials directly and to cover their production costs by means other than sales revenues.

8.1.2.2. Requested Non-Revenue Isotopes. Isotopes listed in Table 8.1 are restricted to those that can be produced at Los Alamos or Brookhaven in currently existing facilities. Additional isotopes would certainly be included if the capacity to produce them existed. Accordingly, Table 8.2 lists inquiries for accelerator-produced isotopes received by the Department of Energy since the Department began keeping track of such requests in February, 1995. While this list is short, it does suggest interest in some isotopes not normally produced at Los Alamos or Brookhaven. The shortness of the list probably reflects the facts that the Department of Energy has not been collecting these data for very long and that relatively few researchers know where to inquire for radioisotopes and radiotracers.

8.1.2.3. The Purdue List. The proceedings of the Purdue workshop on the National Biomedical Tracer Facility contains a list of isotopes said to be illustrative of those to be produced by the facility if it were operating today[2]. This represents the collective input of all the interested participants of the workshop, and can be viewed as another

[2]K. L. Kliewer and M. A. Green, "Proceedings of the Purdue National Biomedical Tracer Facility Workshop", Department of Medicinal Chemistry, Purdue University (1992).

**Table 8.1**
**Non-Revenue Radioisotopes Produced by LANL and BLIP**

| Isotope | Application(s) | Amount (mCi/year) |
|---|---|---|
| Beryllium-7 | Medical, Physical, and Industrial Research | 10 |
| Aluminum-26 | Medical Research | 0.0005 |
| Magnesium-28 | Medical Research | 10 |
| Silicon-32 | Environmental Research | 0.02 |
| Titanium-44 | | 0.02 |
| Vanadium-48,49 | Industrial Research | 5 |
| Nickel-56 | | 3 |
| Zinc-65 | | 50 |
| Arsenic-72,73 | Medical, Physical, and Environmental Research | 75 |
| Selenium-75 | Medical Research; Industrial Applications | 100 |
| Rubidium-83 | | 10 |
| Strontium-85 | | 1 |
| Yttrium-88 | Medical and Industrial Research | 80 |
| Zirconium-88 | Various Research Applications; $^{88}$Y Parent | 2 |
| Technetium-95m | Medical and Environmental Research | 7 |
| Technetium-96 | Medical Research | 50 |
| Ruthenium-97 | Medical Research | 100 |
| Xenon-127 | Medical Research | 200 |
| Gadolinium-148 | | 0.02 |
| Bismuth-207 | Medical, Physical, and Environmental Research | 0.4 |

indication of the types of radioisotopes that should be produced at the NBTF. Table 8.3 is a concise summary of the non-revenue isotopes on the Purdue list, along with their supposed applications and our estimate of the amounts required. Revenue isotopes on the Purdue list are discussed above in Section 8.1.1 of this document.

Not all of the isotopes listed in Table 8.3 can be produced at NBTF. For example, $^{64}$Cu, $^{80m}$Br, and $^{114m}$In are normally produced by (n,$\gamma$) reactions; this requires an

**Table 8.2**
**Radioisotope Inquiries Received by DOE**

| Date | Isotope | Amount | Requester |
|---|---|---|---|
| 2-4-95 | Cobalt-55 | 1 - 5 mCi | Campro Scientific |
| 2-4-95 | Cobalt-57 | 1 - 5 mCi | Campro Scientific |
| 3-10-95 | Cobalt-57 | 15 Ci/y | Bionucleonics |
| 3-10-95 | Yttrium-89 | 300 Ci | Bionucleonics |
| 3-30-95 | Lead-203 | --- | Texas A&M University |
| 4-10-95 | Beryllium-7 | --- | CEA-DAMRI |
| 4-10-95 | Zirconium-95 | 10 mCi | U. C. Berkeley |
| 4-14-95 | Selenium-75 | --- | University of Florida |
| 4-24-95 | Rhenium-186 | --- | University of Pittsburgh |
| 4-27-95 | Iodine-123 | --- | ? |

intense neutron source, usually a reactor. Efficient production of $^{28}Mg$ requires proton energies in excess of 100 MeV, which will not be available at NBTF. In addition, one of the isotopes listed ($^{195m}Au$) has a very short half-life (30.5 s). Even its parent, $^{195}Hg$, has a half-life of only 9.5 h. This could only be used on site.

Many of the isotopes in Table 8.3 would be produced only when an experiment required the isotope. This is indicated in the table by the comment, "on demand", and it applies to all cases in which the half-life is shorter than the anticipated time period between requests for the isotope. In many of these cases it is important to coordinate the production of the isotope with the conduct of the experiment. This is especially so when animal experiments are involved. Such experiments provide prime opportunities for collaborations between researchers at NBTF and other institutions, or even among researchers within the same institution.

The predominance of medical research isotopes in the Purdue list is most likely an artifact of the clientele of the workshop, which consisted mainly of biomedical research people along with accelerator manufacturers and individuals from the isotope production laboratories. We suspect that there is considerably more interest in isotopes for environmental research and industrial applications than is evident in this table.

8.1.2.4. Other Non-Revenue Isotopes. There are a number of isotopes not mentioned in the various workshops and studies that are worthy of consideration. The next few paragraphs discuss some examples of these isotopes; these examples do not exhaust the possibilities and serve only as illustrations.

## Table 8.3
## Non-Revenue Radioisotopes Included in the Purdue List

| Isotope | Application(s) | Amount (mCi/year) | Production Frequency |
|---|---|---|---|
| Beryllium-7 | Medical, Physical, and Industrial Research | 100-200 | 2/year |
| Magnesium-28 | Medical Research | | on demand |
| Scandium-47 | Medical Research | | on demand |
| Vanadium-49 | Industrial Research | 1-100 | 1/year |
| Cobalt-56 | Industrial Research | 1-100 | 2/year |
| Zinc-62 | Medical Research | | on demand |
| Copper-64 | Medical Research | | on demand |
| Arsenic-73 | Medical, Phys. and Environmental Res. | 100-1000 | 2/year |
| Bromine-76 | Medical Research | | on demand |
| Bromine-77 | Medical Research | | on demand |
| Bromine-80m | Medical Research | | on demand |
| Zirconium-88 | Various Research Applns.; $^{88}$Y Parent | 1000 | 4/year |
| Zirconium-89 | Medical Research | | on demand |
| Yttrium-88 | Medical and Industrial Research | 1000 | 4/year |
| Technetium-95m | Medical and Environmental Research | 100-200 | 2/year |
| Technetium-96 | Medical Research | | on demand |
| Ruthenium-97 | Medical Research | | on demand |
| Indium-114m | Medical Research | | on demand |
| Iodine-124 | Medical Research | | on demand |
| Xenon-122 | Medical Research | | on demand |
| Xenon-127 | Medical Research | 1000 | 1/month |
| Barium-128 | Medical and Physical Research | | on demand |
| Gold-195m | Medical Research | | on demand |
| Lead-203 | Medical and Environmental Research | | on demand |
| Bismuth-205 | Medical Research | | on demand |
| Bismuth-206 | Medical Research | | on demand |
| Bismuth-207 | Medical, Phys., and Environmental Res. | .010-.050 | 1/year |
| Neptunium-235 | Environmental Research | <10 | 1/year |
| Neptunium-236 | Environmental Research | <10 | 1/year |
| Plutonium-237 | Environmental Research | <10 | 1/year |

Tantalum-179 has possibilities for use as industrial sources and in medical instrumentation. This results from the fact that it has radiations similar to Americium-241, but does not share the licensing, handling, and disposal difficulties associated with that isotope. If Tantalum-179 proves acceptable for the proposed application there could be a 20 Ci/year market. At $20/mCi, this represents $400,000 in annual revenues. Thus Tantalum-179 could become a revenue isotope if it is qualified for the proposed application and priced correctly. This isotope can, in principal, be made in two different ways: irradiation of tantalum via the reaction $^{181}Ta(p,3n)^{179}W \rightarrow ^{179}Ta$, or irradiation of hafnium via the reactions $^{179}Hf(p,n)^{179}Ta$ and $^{180}Hf(p,2n)^{179}Ta$. The method chosen and the viability of the production method will depend on the production cross-sections and the purity of the resulting products.

Periodically we have received inquiries about Selenium-75. These result from two different applications. The first comes from interest in selenium tracers for biomedical studies. This requires $^{75}Se$ with high specific activity for labeling compounds. The second application is for use in x-ray fluorescence sources. This market is normally supplied by reactor produced materials. However, reactor irradiation services are becoming increasingly difficult to obtain, resulting in more inquiries about the availability of this isotope from accelerator facilities. The x-ray source market is a high volume, low cost market that is probably not economically feasible for an accelerator facility like NBTF. However, the high specific activity material may command a price in the $200/mCi range, while satisfying a critical research need. Selenium-75 can be made from natural arsenic by the reaction $^{75}As(p,n)^{75}Se$ in good yield.

Iodine-123 is an interesting medical research isotope that has been produced by the Department of Energy in the past. Production at Los Alamos ceased a number of years ago because of difficulties in dealing with this short lived material with the existing irradiation facilities. Either of the proposed production facilities would be more amenable to production of this isotope. If this isotope were available routinely, it is likely that a significant market would develop. Because of the short half-life (13.2 h) the best use for this isotope would be with in-house research programs, although this isotope has been shipped to remote users in the past. There are several production methods for this isotope. The choice depends on the available energy. At high energies (65 MeV), it can be produced from natural iodine by the reaction, $^{127}I(p,5n)^{123}Xe \rightarrow ^{123}I$, at a rate of 15 mCi/μA·h. At low energies (25 MeV) it can be produced from xenon by the reaction, $^{124}Xe(p,2n)^{123}Cs \rightarrow ^{123}I$, at a rate of 9 mCi/μA·h. Thus $^{123}I$ could be produced at either of the proposed irradiation facilities, although both entail some interesting and challenging target design.

Fluorine-18 also deserves some comment. This is one of the premier PET isotopes, particularly for brain imaging. Because of its short half-life (1.83 h) this isotope would have to be used on site or at an imaging facility located close by. Note that the imaging capability cannot survive without the isotope supply, and the isotope production capacity cannot survive without the imaging capacity. It is quite possible that NBTF will attract an imaging (PET) capability wherever it is sited. This would then provide the nucleus of a research program with potential to grow and to encompass other applications of radionuclides. Thus, while we have not included $^{18}F$ among the revenue isotopes for the proposed NBTF, this isotope may play an important role in the future growth of the NBTF and its research programs.

8.1.3. Production Schedules.

Production schedules for NBTF will be determined by the needs of the customers and not by the dictates of the accelerator operating schedules. This makes it very difficult to predict what the production schedules might be for an operating NBTF without making many assumptions. Nevertheless, we have projected a schedule that would include the revenue isotopes and some of the non-revenue isotopes, based upon our assessment of the market demands that are discussed in Section 6 of this document. It is likely that projections for any specific isotope will change, but the overall trends are probably realistic. Our projections are summarized in Tables 8.4, 8.5, and 8.6.

We discuss the production schedules in terms of accelerator time. This is possible because the chemical processing facilities at Los Alamos that will be used with NBTF have sufficient capacity and flexibility so that virtually any irradiation schedule can be accommodated. As a result we do not expect chemical processing capabilities to be a limiting factor in determining production schedules for our proposed NBTF.

All of the revenue isotopes except for Strontium-82 can be produced with the cyclotron. However, to make better use of the irradiation facilities we have assigned half of the Sodium-22 production and half of the Cadmium-109 production to the 100 MeV target facility. This distributes the production load more equitably and provides for ample time for research activities at both facilities.

In some cases the number of total beam days in the projected production schedules do not exactly agree with those noted above in Section 8.1.1. This occurs because some isotopes are produced in a number of batches during the year, which prevents one from using the minimum beam time to produce a given amount of the isotope. When the irradiation times of all the individual batches are added up the sum is more than if all the production were done in a single batch.

**Table 8.4**
**Cyclotron Beam Allocations for Revenue Isotopes**

| Isotope | Batch Frequency | Amount Delivered (per batch) | Beam Days (per year) |
|---|---|---|---|
| Sodium-22 | 1/year | 750 mCi | 20 |
| Cobalt-57 | 2/year | 1250 mCi | 10 |
| Copper-67 | 2/month | 500 mCi | 30 |
| Germanium-68 | 4/year | 625 mCi | 40 |
| Cadmium-109 | 2/year | 1500 mCi | 50 |
| Rhenium-186 | 2/month | 2100 mCi | 105 |

Our proposed operating schedule calls for operating the cyclotron 6 days per week for 46 weeks during the year. Operation for 7 days per week will be possible, but will not be necessary except possibly for special cases. With 2 beam lines this allows for a total of 552 beam days in a year. Since the total of all the beam days in Table 8.4 is 255, the cyclotron will be only 46 percent subscribed for production of revenue isotopes. This allows for ample accelerator time for production of non-revenue isotopes and for other research applications. This also indicates that significant changes (increases) in the revenue isotope production schedule can be accommodated without compromising the research mission of NBTF.

Table 8.5 shows possible production schedules for non-revenue isotopes that we would normally expect to keep in stock. This list is based on our current experience; it will probably change when NBTF becomes operational. Other non-revenue isotopes will be produced when required by their users. There appears to be ample accelerator time available to accommodate those needs.

**Table 8.5**
**Cyclotron Beam Allocations for Non-Revenue Isotopes**

| Isotope | Batch Frequency | Amount Delivered (per batch) | Beam Days (per year) |
|---|---|---|---|
| Beryllium-7 | 2/year | 100 mCi | 0.5 |
| Vanadium-49 | 2/year | 12 mCi | 1.0 |
| Cobalt-56 | 2/year | 50 mCi | 0.5 |
| Arsenic-73 | 2/year | 250 mCi | 2.2 |
| Selenium-75 | 2/year | 150 mCi | 1.0 |
| Zirconium-88 | 1/year | 500 mCi | 2.2 |
| Technetium-95m | 2/year | 50 mCi | 1.2 |
| Xenon-127 | 1/month | 85 mCi | 6.0 |
| Bismuth-207 | 1/year | 20 Ci | 0.5 |

All of the irradiations in Table 8.5 account for only a little over 15 days of beam time. This is a consequence of the small amounts of these isotopes required and the relative infrequency of production. However, demand for some of these could increase significantly if interest picks up or if commercial markets materialize.

A possible production schedule for the 100 MeV beam is shown in Table 8.6. This schedule is driven by production of Strontium-82 and Cadmium-109. Note however that Cadmium-109 can be co-produced with any of the other isotopes; thus the schedule accounts for 90 days of operation. This facility could be conveniently operated for 6 days per week for 30 weeks during the year. Thus a net 180 beam days are available. Accordingly the targeting facility is 50 percent subscribed for production of revenue isotopes.

**Table 8.6**
**100 MeV Beam Allocations for Revenue Isotopes**

| Isotope | Batch Frequency | Amount Delivered (per batch) | Beam Days (per year) |
|---|---|---|---|
| Sodium-22 | 1/year | 750 mCi | 9 |
| Copper-67 | --- | --- | --- |
| Germanium-68 | --- | --- | --- |
| Strontium-82 | 1/month | 300 mCi | 31.5 |
| Cadmium-109 | 1/year | 1500 | 90 |

Our market analysis assumes a small market penetration for Strontium-82 production. This is based on historical precedent, which may or may not apply to NBTF. If a better market penetration can be achieved, through negotiation of long-term contracts, then this facility could generate substantially larger revenues for NBTF without straining its irradiation capacity.

Finally it should be noted that some of the isotopes above can be produced simultaneously by using special targets or combinations of targets. These possibilities have not been incorporated into the schedules above, except for cadmium production at the 100 MeV beam line. However, there are a number of such possibilities for optimizing accelerator usage. The proposed accelerator facilities are more than adequate to supply the demands of NBTF, and should be able to accommodate significant increases in market demands that may occur in the future.

8.1.4. Priorities. Our projections indicate that there should be ample accelerator time to satisfy the anticipated markets for the revenue isotopes and still provide an equivalent amount of time for non-revenue isotope production and research activities. Priorities will be determined first by whatever agreements are negotiated between DOE and/or the NBTF with its customers for products and services. We expect that those agreements will consist of long-term contracts for supply of revenue isotopes, collaborations with users and research programs, and purchase orders accepted for isotopes and services. Once the negotiated agreements are satisfied, then additional requests for isotope production and services will be handled in the order that the requests are received.

Negotiation of long-term contracts and research collaboration agreements is a critically important activity. If properly done, this can allow the productivity of the facility to be optimized with knowledge that the products and services produced will be timely and appropriate. If done improperly, this can result in ineffective operation and conflicting or incompatible programmatic requirements. Accordingly the ability to negotiate agreements and long-term contracts must be an integral part of the NBTF operating team. The operation of NBTF is discussed on more detail in Section 7 of this document.

## 8.2. Research.

The second component of the NBTF missions is conduct of research in radionuclide production, separation, and purification, and in development of biomedical applications of radionuclides. The specifics of the research conducted will depend on funding received and will evolve as the facility matures. In this discussion we share some of our ideas about the directions that such research might take.

8.2.1. Targetry Research. Isotope production targetry is one area that NBTF could contribute significantly. In fact, the optimization of isotope production methodologies and the most effective allocation of NBTF resources will require such research.

Maximum production rates will be limited not by the amount of beam current the accelerators can provide, but rather by the amount of beam current that the targets can stand. Building cyclotron targets that can tolerate 500 μA of beam current will be a challenge in itself. Initially targets will be run at lower beam currents; with time and experience those currents will be increased and target refinements implemented until the desired power levels are achieved. We anticipate that the general problems of target geometry and cooling will be optimized fairly quickly. After this attention will be focused on specific cases in which innovative target designs and target materials may be needed to achieve the desired results. An example might be investigations of various compounds and amalgams of gallium that could be used in targets for production of Germanium-68. Gallium by itself has poor properties as a target material.

Use of gas targets and liquid targets may form the basis for some interesting design challenges. One method for production of Iodine-123 involves irradiation of enriched Xenon-124. This is an expensive material, and great pains must be taken to avoid losing any of the starting material during or after the irradiation. Designing gas targets with the necessary levels of containment will be an interesting exercise. Liquid targets may provide some similar challenges. These offer some advantages for heat transfer and may make possible the continuous and real-time production and recovery of radioisotopes. However, implementation of circulating liquid targets will be a research project in its own right.

Development of co-production methods will also be a fruitful area for targetry research. This involves production of more than one isotope from a single irradiation, either by stacking targets appropriately, by using layered targets, or by using compounds, amalgams, or alloys to make materials containing more than one target nuclide. Co-production methods would be particularly useful for the revenue isotopes, since producing more than one of these isotopes during a single irradiation would effectively more additionally accelerator time available for other (research) applications.

Finally, recovering irradiated targets while minimizing personnel radiation exposure is a worthy area of investigation. This work may range from development of simple remote handling procedures to sophisticated gas removal or in-situ chemical processing operations, depending on the type of target involved. In either case it is important to remember that the radioactive materials handling problems begin in the target cave and not at the chemical processing facility.

8.2.2. Production Research. Production research encompasses all aspects of isotope production not mentioned above in the targetry discussions. This includes selection of nuclear reactions and energies, cross-section measurements, and chemical isolation and purification techniques. These can be applied to production of new isotopes or to improving the production of currently produced isotopes. The Los Alamos Medical Radioisotope Program has effectively pursued research in this area over the past several years, as evidenced by 7 patent applications and numerous papers and presentations. Following are some examples of possible research problems in this area; these are only examples and there are many other possibilities.

Tantalum-179 is being considered as a replacement for Americium-241 in x-ray sources and in proprietary medical equipment. There is an estimated 20 Ci/year market if commercially viable production methods can be developed. This isotope may be produced by irradiation of tantalum via the reaction $^{181}Ta(p,3n)^{179}W \rightarrow ^{179}Ta$, or irradiation of hafnium via the reactions $^{179}Hf(p,n)^{179}Ta$ and $^{180}Hf(p,2n)^{179}Ta$. The method chosen and the viability of the production method will depend on the production cross-sections and the purity of the resulting products. We have unpublished information that the reaction with Hf requires more than 22 MeV. Recent searches of the National Nuclear Data Center (NNDC) have not revealed any useful data for either of the two production methods. Measurement of the excitation functions for the proposed reactions and subsequent development of the separation chemistry, if appropriate, would be a worthy research problem at the present time.

Rhenium-186 has a significant potential as a medical radioisotope if a method can be found to produce it in sufficient purity. Preliminary experiments with enriched Tungsten-186 irradiations were disappointing in that the products contained other isotopes of rhenium in unacceptable concentrations. Nevertheless, this production route may still be possible if the incident and exit beam energies are properly chosen. An alternate production route involves irradiation of osmium and production via the reaction $^{188}Os(d,\alpha)^{186}Re$. There are conflicting claims regarding the cross-section for this reaction, but no concrete data. We are in the process of trying to measure the relevant cross-sections. This would be an obvious research problem for NBTF if it were operating today.

Another isotope deserving attention is Copper-67. This is currently available only from Los Alamos and Brookhaven, which both use high-energy proton irradiation of natural zinc to produce this material. Production at lower energies would make it easier to supply this material on a year round basis. We recently filed a patent disclosure on such a low-energy production method. This is based on irradiation of enriched zinc, and produces Copper-67 by the reaction $^{70}Zn(p,\alpha)^{67}Cu$. Cross-section data suggest that material can be produced in adequate quantities using this reaction, and the material should have excellent specific activity, since other isotopes of copper are not produced during the irradiation. However, we have not been able to do the definitive experiment, that is, carry out a production run and measure the properties of the produced material, because we do not have the requisite high-current accelerator to do the irradiations. If NBTF were operational this would be an obvious candidate for an early experiment.

Much of the development work done at Los Alamos over the past several years has dealt with improvements in process chemistry. This has focused on several areas, including waste minimization, improving process efficiency, and improving product purity.

Waste minimization efforts are directed at eliminating unnecessary wastes (especially hazardous wastes), reducing the amounts of wastes produced, and modifying processes to produce wastes in forms that are more easily dealt with. In some cases we have been able to find salable products in our wastes. An example is the recovery of Germanium-68 from molybdenum target residues. This effectively increased our Germanium-68 production capacity by 50 percent. Another example is the fact that the Los Alamos radioisotope production program has produced no mixed wastes for the past 3 years, and effectively cut its overall waste stream by half.

Processing efficiency is of obvious concern. This is especially so when isotopically enriched target materials are used. These must be recovered in good yield in order to avoid the cost of replenishing the target material. This puts great demands on the chemistry used to process the target and recover the starting material. For NBTF a number of the production methods require enriched targets, so it is likely that process research will be an important factor the facility's ability to satisfy its mission.

Radiochemical purity of the product isotopes is important to the acceptability of the radioisotopes produced. This is especially so for isotopes with medical applications. Thus it will be important to develop chemical recovery methods with high efficiencies and excellent selectivity whenever new isotopes are developed.

8.2.3. Applications Research. The ultimate payoff for NBTF will be in the applications that are developed for the isotopes produced. The applications research will be done internally, by external users of the produced isotopes, and by collaborations of external users with NBTF researchers. Thus we expect the NBTF to maintain a strong applications research effort. This will include biomedical as well as environmental and industrial components.

Good examples of applications research that was done in the past includes development of the Sr-82/Rb-82 generator and its use in cardiac imaging, and in the use of Copper-67 for cancer diagnosis and treatment. In both cases the initial development work was done in the isotope research programs at the national laboratories. Work was then pursued through collaborations and by university research groups, ultimately leading to medical applications of the isotope. While the Sr/Rb generator is now a commercial product, the use of Copper-67 has not yet progressed to that stage.

Radiochemical labeling techniques will be a fertile area for NBTF. The combination of an isotope production capacity, the necessary laboratory facilities for handling radioactive materials, and radioactive waste disposal capabilities will make NBTF unique in its ability to encompass the entire range of radiochemical labeling activities. One can envision many types of labeling experiments. Our own recent experience lies in the area of arsenic labeling and radiopharmaceutical development. Following are a some examples of this type of research. We envision that similar efforts with a wide range of radiotracers will be possible using the resources of NBTF in collaboration with university and private research groups.

Arsenic, possessing both metallic and non-metallic properties, can be used in a wide array of labeling strategies, permitting the development of an impressive number of potential radiopharmaceutical agents. An exciting example is described by Mahesh K. Bhalgat, under the direction of Dr. Jeanette Roberts, in a Masters Degree research proposal submitted to the University of Utah. Neuropeptide Y (NPY) has been suggested to play a role in hypertension as a neuroregulator in the cardiovascular system. Many NPY receptors innervate the heart acting as a vasoconstrictor and inducer of presynaptic inhibition of norepinephrine release. Labeling of this polypeptide with $^{72}$As could allow PET mapping of these receptors. This could provide insight into any mechanistic role played by NPY in hypertension. There could also be possible clinical applications in staging and therapy evaluation for hypertensive individuals.

Similar labeling strategies can be applied to molecules other than peptides. An important example is spiperone, an antipsychotic agent with high affinity for the dopamine D2 receptor. One could imagine preparing, for example, arsonoxypropyl spiperone labeled with $^{72}$As using the N-acylation reaction. This would be a good model compound for comparative PET studies since $^{18}$F-labeled spiperone has been used for quantitative PET studies of these receptors. There is reason to believe that this arsenic-labeled agent might have specificity advantages for D2 receptors over the $^{18}$F agent (R. H. Mach, J. R.

Jackson, R. R. Luedtke, K. J. Ivins, P. B. Molinoff, and R. L. Ehrenkaufer, "Effect of N-Alkylation on the Affinities of Analogues of Spiperone for Dopamine D2 and Serotonin 5-HT2 Receptors," J. Med. Chem. 35, 423-430 (1992)).

Another area that we feel there is a high probability of success for $^{72}$As PET agents is in the labeling of analogs of alkylphosphonates that have shown high uptake in bone. Arsonomethylphosphonate has been shown by double tracer studies using $^{76}$As and $^{99m}$Tc to have very high bone affinity. Such compounds labeled with $^{72}$As could have great value in whole body PET imaging in bone oncology, inflammation, and trauma. Synthetic methods for these agents are well established (F. Hosain, R. K. Sripada, P. Hosain, A. Emran, and R. P. Spencer, "Substitution of Arsenic for Phosphorus," in Radiopharmaceuticals: Structure-Activity Relationship, R. P. Spencer, ed., Grune and Stratton, New York, 267-279 (1981)).

8.2.4. Collaborations. Over the years Los Alamos personnel have established many productive collaborative relationships with people in medical, industrial, and academic institutions for developing applications of radioisotopes in medical, biomedical, and environmental areas. The following listing is meant to be exemplary rather than all-inclusive and shows the breadth and depth of the collaborative relationships that can be established between Los Alamos National Laboratory investigators and investigators from other institutions.

8.2.4.1 Sr-82/Rb-82. The approval by the Food and Drug Administration of the Sr-82/Rb-82 generator for clinical PET procedures was substantially facilitated by provision of Sr-82 by Los Alamos during the generator development by Bristol-Meyer, Squibb (formerly E. R. Squibb and Sons). Los Alamos continues to be an approved supplier of the bulk Sr-82 for the commercial generator.

8.2.4.2 Cu-67. Los Alamos pioneered the spallation production of Cu-67 on ZnO targets with subsequent recovery and purification at high specific activity using electrochemical methods. This effort led to numerous fruitful research collaborations in biomedical applications of this isotope. In collaboration with Dr. David Lavallee of Hunter College we developed labeling chemistries for synthesis of novel Copper-67 meso-tetra(4-carboxyphenyl) porphines that were used in experiments aimed at radioimmunotherapy applications.

Los Alamos has worked with personnel from St. Mary's Hospital in Grand Junction, Colorado, Johns Hopkins School of Medicine, and the National Cancer Institute to develop applications of Cu-67 for detection and treatment of lung cancer in its earliest stages.

We worked with a research group at the Mayo Clinic, headed by Dr. Vanda Lennon, to label with Cu-67 a small fragment of the acetylcholine receptor for potential application in the clinical management of myasthenia gravis.

We have cooperative research agreements with Rhomed, Inc. of Albuquerque, New Mexico to develop methods of direct labeling of proteins with Cu-67 for radioimmunotherapy.

8.2.4.3 As-72, As-73, and As-76. We have worked in close collaboration with the University of Texas Health Science Center in Houston to demonstrate the viability of generator-produced As-72 as a PET imaging isotope. Related to this work are collaborations with personnel at the Emory University Hospital Radiology Department PET Center and the University of New Mexico College of Pharmacy to develop labeling strategies for arsenic-containing radiopharmaceuticals. These agents would find applicability not only in As-72 PET but also in therapy when labeled with As-76.

We have also collaborated with researchers using As-73 in tracer research for biomedical applications. Possibly the most signiciant of these collaborations has been with the University of San Diego Cancer Center where development of antimony-containing chemotherapeutic agents has been facilitated by the availability of the As-73 as a stand-in tracer for antimony.

8.2.4.4 Al-26. We have worked with Dr. Judith Walton of the Ageing and Alzheimer's Disease Research Institute in Concord, Australia to provide Al-26 as a tracer in animal studies to investigate wheter aluminum is causally linked to Alzheimer brain changes.

8.2.4.5 Si-32. We are actively involved in a study of the application of Si-32 as a tracer in biological oceanographic studies. The ability of the oceans to mitigate future greenhouse effects largely depends on the ability of the phytoplankton, the microscopic plant life which are the dominate primary producers in the sea, to take up $CO_2$ from the atmosphere and through their death and sinking, carry this carbon to the deep sea. One class of phytoplankton, the diatoms are important in this regard since they are relatively large and sink to depth more readily compared to other forms. These algae have the unusual feature that they require silicon to grow using it to construct an opaline shell. The need for diatoms to form this shell means that the availability of the element in sea water can control the abundance and distribution of these organisms and thus their ability to grow and fix atmospheric $CO_2$. The availability of $^{32}Si$ and the collaborative development of radioanalytical methods for its application in oceanography has provided tremendous potential for expanding the knowledge of the role of diatoms in $CO_2$ uptake processes.

This will be of considerable significance to theories pertaining to carbon fixation and its impact on global climate.

8.3. Education and Training.

Education and training is the third component of the NBTF mission. This is not the least important of the activities of NBTF. In fact all of the activities envisioned for this facility have great educational potential. The education and training component of NBTF is discussed in Section 9 of this document.

# 9. RESEARCH AND EDUCATIONAL PROGRAMS

## 9.1. Need for Nuclear and Radiochemists.

Although nuclear and radiochemistry is a relatively small field, its scope is extraordinarily broad. It involves the use of radioactivity and nuclear techniques combined with the knowledge and methodology of chemistry. A number of areas of major national need depend critically on scientists trained in nuclear and radiochemistry. Among these areas are:

- health care, including nuclear medicine and the radiopharmaceutical industry,
- national security (the nuclear weapons program),
- nuclear energy, which currently provides 17 percent of U.S. electric power,
- nuclear waste isolation, particularly from defense and power plants,
- monitoring the management of the environment, and
- basic nuclear science, including chemical effects of nuclear transformations

(*Training Requirements for Chemists in Nuclear Medicine, Nuclear Industry, and Related Areas,* 1988).

Thus, the continued welfare and competitive strength of the nation demand that the future of the field of nuclear and radiochemistry be assured.

Because of the current and projected future demand for personnel trained in nuclear and radiochemistry, the United States is faced with a critical situation. The need for scientists in these fields amounts to several hundred professionals with training in nuclear and radiochemistry. This need is not being met! The opportunity for academic training in nuclear and radiochemistry is declining in the United States, (ibid.) the National Research Council's *Summary Report 1986: Doctorate Recipients from United States Universities* shows that only 10 to 12 Ph.D. students are graduating each year in this field, and that number is decreasing. Twenty percent are not U.S. citizens. Scientists from other disciplines also need training in nuclear and radiochemistry. The NBTF provides a unique opportunity for training in a variety of areas of nuclear and radiochemistry, which could help meet important national needs.

## 9.2. Role of the NBTF in Educational Opportunities.

Training and education are important components in the use of the accelerator. The educational potential of a dedicated radioisotope production facility is in the following areas, selection of targeting material to produce a particular isotope (or suite of isotopes), radioanalytical and radiochemistry, separations chemistry, and radiolabeling chemistry with its associated applications. It must be emphasized that the mission of the NBTF is isotope production; training aspects will be focused in this area and not in the areas of accelerator design and operation. This facility will be an enormous boost to the educational mission but it will not be a panacea for all nuclear and radiochemistry training needs.

Target selection and development for production of the desired isotopes (or suite of isotopes) is an excellent educational opportunity in nuclear and radiochemistry. Many factors must be considered when making decisions regarding a target for production of an isotope. Of obvious importance is the efficiency with which the isotope of interest would be produced in the target. A fundamental knowledge of the chart of the nuclides is essential in evaluating a given target. Beyond this, the scientist must have a working understanding of particle transport concepts, cross-sections, recoil energies, and similar basic nuclear fundamentals. Research into target choice often begins with making nuclear reaction cross-section measurements on feasible target materials. Students involved in such research would receive outstanding hands-on training in nuclear chemistry. Another important consideration in selecting the target is encapsulation in the accelerator beam. Factors such as physical phase at operating temperature, cooling methods, target thickness and density, and radiation effects must be considered. Trainees would gain a practical knowledge in evaluating materials and hardware for production applications. A crucial consideration associated with target selection is the method that will be used to recover and purify the isotope. The methods of separation might be chemical or physical, depending upon the nature of the target. Thus the scientist making decisions regarding a target for production must have a fundamental knowledge of chemistry and physics. The post-irradiation physical and chemical states of both the target material and the radionuclides produced must be known in developing a cost effective and efficient recovery procedure. Since many of the targets conceived for accelerator production depend upon enriched materials, it will be important to think about methods of recovery of the target material for re-use. It is apparent that a trainee involved in isotope production targetry would learn a great deal about nuclear and radiochemistry that would have broad application in fields needing this expertise.

A major educational opportunity for the NBTF is in separations chemistry. There will be many opportunities to develop methods to separate and purify radioisotopes from the parent target materials. Future progress in fields as diverse as:

biotechnology,

hazardous and radioactive waste management,

environmental chemistry,

electronics,

nuclear power,

materials science and

medicine

depends heavily on the development of new separation technologies and radioanalytical procedures. These developments often depend upon, or can be greatly simplified, by the use of nuclear and radiochemical methods. Thus scientists, engineers, and technicians who are involved in the development and use of new separation methods (or the improvement of established methods such as solvent extraction, ion exchange, absorption, precipitation, volatilization, and electrochemical deposition) must also be skilled in the use of nuclear and radiochemical techniques. Unfortunately, most separation chemists receive little or no training in radiochemical techniques. This hampers the progress of separation science as well as the progress of fields that rely on improved separation technology for their developments. Separations skills and knowledge also have applications for the efficient production of PET isotopes from cyclotrons and reactor production of isotopes. Thus the development of separation chemistry to isolate and purify a desired radionuclide from the target material will provide many research and educational opportunities at the NBTF.

Radiolabeling chemistry, with its associated applications, is an area of great educational potential in conjunction with the NBTF. Incorporation of radioisotopes into other molecules yields radiolabeled compounds with significantly altered physical and biological properties, compared with the properties of the free radioisotopes. Labeling chemistry and its applications are vital parts of nuclear medicine and pharmaceutical research. Nuclear medicine is currently facing a severe shortage of organic and inorganic chemists and nuclear pharmacists who also have the advanced training in radiolabeling chemistry necessary to prepare radiolabeled compounds.

Ironically, this professional and technical personnel deficit is occurring in the face of rapid growth and technological advances that have made the practice of nuclear medicine an integral part of the modern health care system. This shortage of qualified professionals threatens to limit the availability of radiopharmaceuticals required in routine hospital procedures and to impede the development of new diagnostic and therapeutic agents. In pharmaceutical research radiolabeled drugs are used extensively in the study of drug metabolism, pharmacokinetics, drug biodistribution, drug delivery systems, bioavailability, and molecular pharmacology. These studies, intrinsic to drug discovery, development, and approval, require the expertise of synthetic chemists and pharmaceutical scientists who are knowledgeable in radiolabeling, radioanalytical techniques, and the basic properties of radioactive materials.

Future demands on these researchers will be even greater due to increased sophistication of pharmacologic studies requiring isotopic methods and new approaches by

PET or Single Photon Emission Computed Tomography (SPECT) in the study of dynamic factors in drug activities. The Pimentel Report (*Opportunities in Chemistry*, 1985) described the application of nuclear and radiochemistry in the practice of medicine and in biomedical research as one of the intellectual frontiers of chemistry related to the national well-being. Use of radiolabeling chemistry to provide radiolabeled compounds for the study of environmental chemistry and remediation will also be a benefit from training in radiolabeling methodologies. The NBTF will provide a large variety of radioisotopes, which can be used for radiolabeling research and associated applications. Thus radiolabeling chemistry will be a significant area for educational opportunities at the NBTF. It should be noted, however, that these educational opportunities will have little direct application to PET labeling with short-lived isotopes ($^{18}F$, $^{11}C$,...). This training role will likely continue to reside with the on-site cyclotrons at PET facilities.

## 9.3. Mechanism to Exploit the Educational Opportunities at the NBTF.

Los Alamos National Laboratory is managed by the University of California. There are numerous opportunities to collaborate with the UC campuses, and many programs that provide funding to encourage interaction between the campuses and the laboratories. These will provide mechanisms for development of educational programs focussed on the utilization of the NBTF. Los Alamos also enjoys excellent relations with state educational institutions, such as the University of New Mexico and the College of Pharmacy, Department of Radiopharmacy. This provides excellent possibilities for development of courses and curriculae that are focussed on the capabilities of the NBTF.

Los Alamos has a variety of special educational programs to provide opportunities for researchers, faculty, and students to have access to our unique capabilities and extensive facilities. Our postdoctoral program is extensive with several hundred postdocs in residence at any time. Many of these positions are funded by a Director's reserve fund, and are very competitive. There is a graduate research assistant (GRA) program where graduate students can complete all or part of their degree work at Los Alamos. Also there is an undergraduate student (UGS) program so that university and college students can spend part of their educational experience (usually summers and holiday breaks) at Los Alamos.

There are a variety of other funding sources to support educational opportunities at the NBTF. In addition to traditional support from federal agencies such as NIH, NSF, or DOE for students, postdoctoral fellows, faculty members and other researchers, there are other programs having strong university ties and collaborations. The National Physical Science Consortium for Minorities and Women (NPSC) provides stipends for graduate students; the National Consortium for Graduate Degrees for Minorities in Engineering, Inc. (GEM) supports graduate students in engineering or computer science. The DOE funds a number of programs that could be applicable for educational purposes at the NBTF: the Historically Black College and Universities (HBCU) program funds undergraduate students, graduate students, and faculty sabbaticals; the Science and Engineering Research Semester (SERS) supports undergraduate students; and the Science and Technology Alliance funds undergraduate students, graduate students and faculty sabbaticals for blacks, native Americans, and Hispanics. The Alexander Hollaender Award is funded by the DOE Office of Health and Environmental Research to support postdoctoral training in advanced energy research related to the life, biomedical, and environmental sciences and supporting disciplines.

In addition, there are the consortia of universities and national laboratories [e.g. Associated Western Universities (AWU), Oak Ridge Associated Universities (ORAU)], which fund graduate students, postdoctoral fellows, and faculty sabbaticals. These special programs should be viewed as complimentary to and not in lieu of direct support of students and postdocs from facility operating funds.

## 9.4. Vocational Training Programs at the Los Alamos National Laboratory.

*This information is abstracted from a 1990 report issued by NIS Division Safeguards Office. It is intended to illustrate the abilities and past experience of the Los Alamos National Laboratory in conducting a broad based and widely attended vocational training program.*

"The DOE Safeguards Technology Training Program is a major vehicle for technology transfer to both the domestic and foreign nuclear communities. Since 1973, the program has grown from a single course to the present curriculum (which includes 10 formal course offerings and a special lecture series) and has services nearly 2000 students. The program is very succcessful both in informing participants of the latest nuclear material control and measurement technology and in keeping the R&D program abreast of the needs and experiences of facility operators and safeguards inspectors. The training program enjoys an excellent reputation throughout the nuclear community.

The 1989 DOE Safeguards Technology Training Program comprised three formal courses and one workshop:

- Materials Accounting for Nuclear Safeguards
- Gamma Spectroscopy for Nuclear Materials Accounting
- Fundamentals of Nondestructive Assay of Nuclear Material

- Variance Propagation and Systems Analysis Workshop

The course participants included DOE employees from six regional centers, an NRC employee, and NRC licensee employee, and DOE contractor employees from 14 different sites.

The first presentation of the *Variance Propagation and Systems Analysis Workshop* occurred during the period October 24-26. Participation was by invitation only. Lecture topics included: Terms in the Materials Balance Equation, Theory and Application of Variance Propagation, Estimating Uncertainties, Problems with Variance Propagation, Detection Sensitivity and Decision Making, and Description of the Example Facility. Working groups derived variance equations for example materials balance terms and solved several problems applied to an example facility. The course was well-received.

The *Gamma-Ray Spectroscopy for Nuclear Materials Accounting* course was given on September 18-22, 1989 for 24 experienced students interested in becoming familiar with the advanced NDA techniques typically used in implant instruments. The course emphasized the use of high-resolution, computer-based gamma-ray spectroscopy systems in applications such as uranium and plutonium isotopics measurements, bulk and segmented transmission-corrected assay, absorption-edge densitometry, and x-ray fluorescence. The course concluded with three topical lectures:

- The Poor Man's Densitometer
- Cold Fusion Measurements in the Safeguards Assay Group
- A Summary of Gamma-Ray NDA Capabilities: A Comparison

The course, *Fundamentals of Nondestructive Assay of Nuclear Materials*, was held on November 13-17 for 32 students, most of whom had not been admitted to the October 1988 offering because of space limitations or had been scheduled for the March 1989 course that was cancelled. As usual, this course provided an introduction to neutron and gamma-ray NDA of nuclear materials. Although designed primarily for professional scientists and engineers with little or no background in NDA, the course also is useful to materials accounting supervisors, NRC inspectors, and NDA technicians. The course consisted of lectures and laboratories in gamma-ray and neutron interactions, uranium enrichment measurements, transmission-corrected gamma-ray assays, and neutron singles and coincidence counting. The course concluded with three lectures on

- Specialized Neutron Coincidence Counters for Verification of SNM in an Automated MOX facility
- Shufflers: History and Application
- The Rest of the Story: Other NDA Applications

The 1989 offering of the Fundamentals course also marked a new era in the physical facilities used for the Los Alamos/DOE Safeguards Technology Training Program. During 1989, we acquired additional, temporary classroom space that allowed us to continue certain courses under enhanced SNM physical security requirements. This new training space is within an existing security area where the proper physical security measures can continue during course sessions. This additional training space within an existing protected area has the added benefit that the SNM used in the class sessions is no longer transported with an escort to the classroom, over public roads. Instead, the material is brought to the training area, as needed, from secure vault storage within the same protected area. This space is, however, only temporary until our new Nuclear Safeguards Technology Laboratory is constructed at TA-55.

Table 9.1 summarizes the training course attendance for 1989. Although each training course has been given in previous years, the courses usually are updated each year to include the latest in measurement techniques, commercially available instruments, and materials accounting procedures.

Both the *Fundamentals* and the *Gamma Spectroscopy* courses have shown significantly increased demand in the past two years, to the point where a single offering of these courses satisfies only approximately half of the demand. In addition, we have received an increased number of requests for courses on neutron NDA techniques, inventory difference analysis, and in-plant holdup measurements.

The other courses, together with the NDA school for IAEA inspectors and the Nuclear Nonproliferation course on State Systems of Accounting and Control (SSAC) of Nuclear Materials accounted for six offerings in the 1989 training schedule.

The *Materials Accounting for Nuclear Safeguards* course was presented to 30 participants during the period April 10-14. A series of 17 lectures and 5 workshops constituted the core of this year's course. Topics of lectures ranged from fundamentals of materials accounting to site-specific MC&A systems. The use of measurement, analyses, records, and reports to maintain knowledge of the quantities of nuclear materials present in a defined area of a facility and the use of physical inventories and material balances to verify the presence of SNM were emphasized as key elements of good materials accounting for nuclear safeguards."

As evidenced by this program, the Laboratory has extensive experience in the design and implementation of technical training programs. This experience will be invaluable to the NBTF management as they determine the training programs that will enhance the ranks of nuclear-related health and other professionals.

## Table 9.1

## Summary of Attendance at LANL/DOE Safeguards Technology Training Courses, 1989

| Attendee Affiliation | Materials Accounting 4/10-14 | Gamma Spectroscopy 9/18-22 | Variance Propagation 10/24-26 | Fundamentals of NDA 11/13-17 | Totals |
|---|---|---|---|---|---|
| Argonne National Laboratory | 3 | | | | 3 |
| Babcock & Wilcox, Lynchburg | | | | 1 | 1 |
| Brookhaven National Laboratory | | | 1 | | 1 |
| DOE (All field offices) | 2 | | 1 | 3 | 6 |
| DOE Headquarters | 3 | | | | 3 |
| EG&G (Idaho) | | | | 1 | 1 |
| G.E. Wilmington | 1 | | | | 1 |
| LLNL | 2 | 1 | | | 3 |
| Los Alamos (Pu Facility) | 3 | 4 | 2 | 3 | 12 |
| Los Alamos (Other areas) | 1 | 2 | | 3 | 6 |
| Martin Marietta, Oak Ridge | 3 | 3 | | 1 | 7 |
| Martin Marietta, Piketon | 2 | 4 | 1 | | 7 |
| Mason & Hanger, Pantex | | | | 2 | 2 |
| New Brunswick Laboratory | 2 | | | | 2 |
| NFS, Irwin | | 1 | | | 1 |
| NRC | 1 | | | 1 | 2 |
| Rockwell, Golden | 3 | 1 | 1 | 2 | 7 |
| Sandia Labs, Albuquerque | 1 | 3 | | 2 | 6 |
| Westinghouse Hanford | | | 1 | 4 | 5 |
| Westinghouse Idaho | | | 1 | | 1 |
| Westinghouse Savannah River Co. | 2 | 4 | 1 | 6 | 13 |
| Westinghouse WID, Carlsbad | | | | 1 | 1 |
| Aldermaston/AWE (U.K.) | | | | 2 | 2 |
| CNEA, Argentina | | 1 | | | 1 |
| Japan | 1 | | | | 1 |
| TOTALS | 30 | 24 | 9 | 32 | 95 |

# APPENDIX A
# ISOTOPE RESEARCH, PRODUCTION, AND DISTRIBUTION
# LOS ALAMOS FACILITIES AND EXPERTISE

## INTRODUCTION

Throughout our fifty year history, the Los Alamos National Laboratory has conducted research and development directed at the production, isolation, purification, and enrichment of radioactive and stable isotopes. Los Alamos continues to be a major source of research, technology development, applications research, and supply for many isotope products and services. Initially, these efforts were developed to support the Laboratory's national security mission; however, they quickly evolved to support basic research studies in many diverse fields, including nuclear medicine, biomedical research, environmental studies, materials science, and the physical sciences. Los Alamos National Laboratory has a distinguished history and an international reputation in the isotope sciences. This has been made possible by our excellent facilities; many of the facilities currently used for research, technology development, production, and distribution of isotopes are a result of the requirements of the Laboratory's national security programs. As this Nation's requirements for national security evolve, Los Alamos has the opportunity to enhance our capabilities to continue addressing an important national need, that of stable and radioactive isotope availability for the both the commercial sector and the many research communities that require these materials. Tremendous opportunities to establish partnerships among Los Alamos, industry, and the academic community exist; we only have to encourage them to develop.

This appendix briefly describes the facilities and expertise that exist at Los Alamos to satisfy the Nation's requirements for isotope products and services. Equally important, but not discussed here, is the infrastructure that already exists at Los Alamos to support these endeavors.

## ACCELERATOR-PRODUCED RADIOISOTOPES

**Los Alamos Meson Physics Facility** - The LAMPF-Produced Medical Radioisotopes Program strives to maintain a balance between (1) production of radioisotopes of demonstrated or potential value in medicine and biomedical research, and (2) production concentrating on new radioisotopes. The production program attempts to meet the needs of the nuclear medicine research community and the commercial radiopharmaceutical manufacturers for radioisotopes by taking advantage of the unique opportunity afforded by the intense beam current (1.1 mA) and energy (800 MeV) of the LAMPF accelerator. We have developed an irradiation facility called the Isotope Production Facility (IPF) at LAMPF. Our program identifies radioisotopes with potential nuclear medicine applications; we develop the targeting and irradiation schedules to maximize production yields of the required isotopes; we develop the target dissolution and separations chemistry required to purify the desired isotope; and we collaborate with our own internal research programs and external customers to facilitate research, technology development, and technology transfer of radioisotopes for clinical trials and ultimately new nuclear medicine diagnostic and therapeutic procedures. We can produce in excess of 30 radioisotopes, for which we are the sole U.S. producer for 15, and a major supplier of several others. Even with this impressive array of radioisotopes we have not yet even begun to tap the potential of this national medical radioisotope production resource.

The IPF at LAMPF consists of an automated insertion and retrieval system at the LAMPF beam stop that allows for insertion of target materials, including metals, alloys, and salts. There are currently nine target stringers that can be inserted and irradiated simultaneously. After irradiation, the targets are highly radioactive (>50,000 R), therefore, they are remotely removed from the LAMPF beam and transported to our hot cell facility at the Los Alamos Radiochemistry Site (TA-48). This facility comprises 13 hot cells that are fitted with master/slave manipulators and shielded by 24-in. lead glass windows and 20-in. high-density concrete walls. Routinely irradiated targets are used to produce $^{82}Sr$, $^{68}Ge$, $^{109}Cd$, $^{22}Na$, $^{67}Cu$, and $^{88}Y$, which are used in nuclear medicine and commercial applications. Other radioisotopes produced when time and resources permit include: $^{73,74}As$, $^{26}Al$, $^{7}Be$, $^{207}Bi$, $^{148}Gd$, $^{172}Hf$, $^{194}Hg$, $^{92}Nb$, $^{83}Rb$, $^{72,75}Se$, $^{32}Si$, $^{85}Sr$, $^{95m}Tc$, $^{48}V$, $^{65}Zn$, and $^{88}Zr$.

**Los Alamos Ion Beam Facility** - This facility provides precision ion beams for a wide variety of users and experiments. The facility consists of a vertical Van de Graaff accelerator capable of operating over 11 MeV, and a NEC pelletron capable of operating at 1.7 MeV. These accelerators have provided positive ions from protons at energies of 0.5 to 28 MeV to heavy ions at energies up to 150 MeV and have been used to accelerate clumps of matter (femtograms to picograms) at velocities to more than 100 km/s. Specialized equipment on the tandem can provide the only source of polarized tritium in the world, and a buncher system allows users to generate sub-nanosecond pulses of the hydrogen isotopes at rates to a few megahertz.

We are currently investigating the production of a variety of medical radioisotopes and other isotopes that have commercial markets. For example, the IBF appears particularly well suited for the production of $^{18}F$. Regional distribution of this radioisotope could facilitate the expansion of positron emission tomography (PET) in the southwest. Other radioisotopes being investigated include $^{62}Zn$, $^{72}Se$, $^{186}Re$ and $^{76}As$. The first two isotopes have potential PET applications, while the second two have potential as therapy isotopes. Additional exploration of the production of short-lived radioisotopes for research applications is continuing.

## REACTOR-PRODUCED RADIOISOTOPES

Los Alamos continues to participate in the Department of Energy's Mo-99 and related reactor-produced isotope program in conjunction with Sandia National Laboratory. Los Alamos' role is to develop and implement the required target fabrication capability and to aid in the development and improvement of radioisotope process chemistry. Sandia continues to develop the capability to irradiate and process enriched U-235 targets for the recovery of Mo-99. Although the Omega West Reactor has been shutdown since December 1992 and is being prepared for decontamination and decommissioning, a short description of the facility follows. Although currently in a safe shutdown mode, Los Alamos personnel have not taken any actions that would preclude the restart of this facility if programmatic requirements necessitated such an effort.

**Omega West Reactor** - The OWR is a thermal, heterogeneous, closed-tank, 8 MW research reactor, that is light-water moderated and cooled, and uses aluminum-clad plate-type fuel elements. At 8 MW, the thermal neutron flux in the core is $9x10^{13}$ neutrons/cm$^2$s, and the fast neutron flux (>0.1 MeV) is $5.6x10^{13}$ neutrons/cm$^2$s. Our focus before shutdown was on the irradiation of enriched uranium-235 targets for the production of molybdenum-99 and related fission production radioisotopes. After irradiation in the OWR, the uranium targets were to be transported to the Chemistry and Metallurgy Research Wing-9 hot cells for chemical processing. These radioisotopes would then have been distributed to radiopharmaceutical manufacturers for use in their products. All manufacturing processes related to molybdenum-99 was to be done according to FDA Good Manufacturing Practices (GMP). Other radioisotopes, such as I-125 and P-32, were also to be produced in the OWR. As a result of dedicating the OWR to an isotope production mission, we were planning to also explore other radioisotope production of interest to the nuclear medicine and other research communities. These same activities are currently being carried out at Sandia National Laboratory, in collaboration with Los Alamos.

## ENRICHED STABLE ISOTOPES

**Los Alamos ICON Facility** - Historically, the function of the ICON Facility at Los Alamos was to isolate large quantities of individual isotopes of light elements, such as carbon, oxygen, and nitrogen - hence the facility's name. The separations were carried out using cryogenic distillation columns that vary in length from 180 to 700 ft. The separated isotopes or compounds containing these isotopes were used in research and medical activities at Los Alamos and many other institutions. For example, separated $^{18}O$ is used in the preparations of $^{18}F$, which is incorporated into fluorodeoxyglucose. This compound is the primary metabolic tracing agent used in PET. The isotopic materials from this facility were sold at cost to the general research community. The facility has been in the standby mode since October 1989. The DOE and Los Alamos investigated the possibility of leasing this facility to a private company for the commercial operation, but there was not sufficient industrial interest to pursue this concept further.

There are five cryogenic NO distillation columns for the separation of nitrogen and oxygen isotopes. The capacity of the facility for $^{15}N$ and $^{18}O$ is approximately 10 Kg/yr, for 98+ and 95+% enriched material respectively. There also is a cryogenic CO distillation column for production of separated carbon isotopes. The capacity of this column is in excess of 10 Kg/yr for 99+% of both $^{12}C$ and $^{13}C$. Lastly, there is a cryogenic distillation column for the separation of $^{22}Ne$. The capacity of this column is in excess of 3 Kg/yr for 90+% enriched material.

**Los Alamos Isotope Separator Facility** - This facility consists of three electromagnetic isotope separators, with the design and hardware available for a fourth instrument. The separators are fully instrumented and operate in an automated fashion. Each separator is capable of an approximately 1-mg/day (all isotopes) collection rate; each isotope is enhanced in purity by $\sim 10^4$ relative to the isotopic ratio in the feed material. Higher collection rates are possible for selected elements. Almost all elements in the periodic table can be separated but not with equal efficiency; the collected-mass/feed-material-mass efficiencies range from 0.1 to 50%. Alpha emitters and highly radioactive samples with long half-lives cannot be separated at this time, but conversion of an existing separator to meet this requirement is planned.

## ISOTOPICALLY LABELED COMPOUNDS

**Los Alamos National Stable Isotope Resource (SIR)** - This resource is funded by the National Institutes of Health to develop biomedical applications of the low -abundance stable isotopes of carbon, nitrogen, and oxygen. When enriched above their natural abundance, the stable isotopes $^{13}C$, $^{15}N$, and $^{17,18}O$ are used to follow complex chemical and biochemical processes. The power of these isotopes is derived in part from the NMR spectroscopic techniques used to detect them. These methods allow determination of not only the extent of labeling, but also the chemical identity of the labeled product. As describe above, Los Alamos pioneered the large-scale production of the stable isotopes of carbon, nitrogen, and oxygen. The major obstacle to the more general use of stable isotopes is the relatively poor availability of useful compounds incorporating these isotopes. Thus, the SIR carries out vigorous research and development of new methods for the synthesis of labeled compounds. Current research focuses in three areas: (1) stereoselective synthesis of labeled L-amino acids, (2) site specific labeling of nucleosides and nucleotides, and (3) biosynthesis of symmetrically labeled porphyrins.

**Los Alamos Medical Radioisotopes Research Program** - One of the goals of this program is the development of biomedical generators to provide short-lived PET and therapeutic radioisotopes for clinical applications. A biomedical generator is a system that has an immobilized long-lived parent radioisotope that decays into a shorter-lived daughter radioisotope that has a nuclear medicine or biomedical applications. Past research in this program has contributed to the commercial success of the $^{82}Sr/^{82}Rb$ generator. We currently are conducting research on several generator systems including $^{72}Se/^{72}As$, $^{194}Hg/^{194}Au$, and $^{47}Ca/^{47}Sc$.

Another of the goals for this program is the development of radiolabeled compounds that may have utility in nuclear medicine and biomedical applications. Design goals for compounds include: (1) ultrastability for *in vivo* applications; (2) biochemical specificity for targeting specific organs or diseased tissues; and (3) applicability to radiopharmaceutical synthesis. Additional efforts are directed at the radioisotopic labeling of biomolecules either directly or through attachment of radiolabeled compounds. These efforts extend the range of utility of radioisotopes produced in our reactors and accelerators.

## ISOTOPE MARKETING AND DISTRIBUTION

Los Alamos National Laboratory produces and distributes radioisotopes, and in the past stable isotopes, on a cost recovery basis. This is done under the auspices of the Department of Energy, Office of Nuclear Energy, Office of Isotope Production and Distribution. During a typical fiscal year, we will distribute a total of 17 Ci of 15 radioisotopes to over 45 organizations worldwide. Details of our shipments to customers in FY 1994 is given in a separate appendix. These customers included research institutions, hospitals, other national laboratories, and industry. We have developed a reputation as a reliable supplier of both research and commercial radioisotopes. Our current isotope distribution efforts are focused on LAMPF-produced materials, but in the past we considered the distribution of OWR-produced products. In addition, a change in the status of the ICON facility was considered to alleviate the severe shortage of enriched isotopes of carbon, nitrogen, and oxygen. Los Alamos National Laboratory continues to explore the requirements of the U. S. industry and the research community, and continues to examine what facilities and expertise are available to meet these requirements. Whenever appropriate additional products and services are added to our isotope portfolio. We continue to research new isotopes, new isotope separation processes, and new isotope applications. We want to aggressively pursue collaborations that involve partnerships among Los Alamos, the U. S. academic community, and the U. S. commercial sector.

# APPENDIX B
# LOS ALAMOS NATIONAL LABORATORY
## FY94 Medical Radioisotopes Shipments

| Isotope | Customer | No. of Shipments | mCi Shipped | mCi Received |
|---|---|---|---|---|
| $^{26}Al$ | Institut fur Allgemeine, Germany | 2 | 0.000280 | 0.00280 |
| $^{73}As$ | Commissione Delle Com., Italy<br>Isotopen Dienst, Germany<br>LANL/INC-12<br>New York Univ. Med. Ctr<br>Old Dominion University<br>State University of New York<br>U.S. EPA/RSO<br>UC, San Diego<br>University of Arizona<br>Wayne State University<br>White Sands Research Center | 17 | 68.33 | 67.00 |
| $^{7}Be$ | Isotope Products Laboratory | 2 | 3.32 | 3.32 |
| $^{109}Cd$ | North American Scientific<br>Teledyne Isotope, Inc. | 7 | 345.50 | 345.10 |
| $^{67}Cu$ | Hazleton Wisconsin, Inc.<br>Purdue University<br>Texas A & M University<br>UC, Davis<br>University of Florida<br>University of Utah<br>Washington University | 8 | 368.61 | 246.00 |
| $^{148}Gd$ | Isotope Products Laboratory<br>North American Scientific<br>UMDNJ | 3 | 0.02 | 0.02 |
| $^{68}Ge$ | CTI Services, Inc.<br>McMaster University, Canada<br>North American Scientific<br>Washington University | 20 | 939.22 | 935.70 |
| $^{22}Na$ | E.I. Dupont<br>Japan Radioisotope Association<br>LANL/INC-12 | 5 | 1516.20 | 1505.20 |

| Isotope | Customer | No. of Shipments | mCi Shipped | mCi Received |
|---|---|---|---|---|
| $^{83}Rb$ | Idaho National Engineering Lab<br>UC, Lawrence Berkeley Lab | 4 | 6.52 | 6.52 |
| $^{75}Se$ | Boyce Thompson Institute<br>Idaho National Engineering Lab | 2 | 2.04 | 2.04 |
| $^{32}Si$ | Amersham Buchler, Germany<br>Institut d'Etudes Marines, France<br>UC, Santa Barbara<br>Isotope Products Laboratory | 4 | 0.02 | 0.02 |
| $^{95m}Tc$ | Atomic Energy of Canada<br>Battelle/U.S. DOE<br>Freie Universitat Berlin, Germany<br>Harwell Laboratory, UK<br>Isotope Products Laboratory | 5 | 7.56 | 7.00 |
| $^{44}Ti$ | Commissione Delle Com., Italy<br>Cornell University | 2 | 0.02 | 0.02 |
| $^{48}V$ | Ben Gurion Univ. Israel | 1 | 1.84 | 1.00 |
| $^{49}V$ | Univ. De Coimbra, Portugal | 1 | 1.04 | 1.00 |
| $^{88}Y$ | Amersham International, UK<br>Analytics, Inc.<br>ANSTO, Australia<br>Center for Molecular Medicine<br>Idaho National Engineering Lab<br>Immunomedics, Inc.<br>Isotope Products Laboratory<br>National Institute of Health<br>Societe Gondrand, France<br>University of Missouri | 22 | 83.00 | 79.13 |
| $^{65}Zn$ | E. I. Dupont/NEN Products | 1 | 50.00 | 50.00 |
| $^{88}Zr$ | Idaho National Engineering Lab<br>Oak Ridge National Laboratory | 2 | 2.15 | 2.15 |
| TOTALS | | 116 | 6402.72 | 6176.35 |

# APPENDIX C
# LOS ALAMOS NATIONAL LABORATORY
# CUSTOMER LIST

** denotes nuclear medicine isotope purchaser

**Amersham Buchler GmbH & Co KG
Gieselweg 1
38110 Braunschweig, Germany

**Amersham International
Amersham Laboratories
White Lion Road
Amersham, United Kingdom
Bucks HP7 9LL

**Analytics, Inc.
1380 Seaboard Industrial Blvd.
Atlanta, GA 30318

Atomic Energy of Canada
Whiteshell Laboratories
Pinawa, Manitoba, Canada ROE 1LO

**Australian Nuclear Science
& Technology Organization (ANSTO)
Lucas Heights Research Lab
Bldg. 23A
New Illawarra Road
Menai, NSW 2234 Australia

Argonne National Laboratory
9700 South Cass Avenue
Bldg. 5
Argonne, IL 60439

Battelle Memorial Institute
Pacific Northwest Laboratory
c/o Westinghouse Hanfrod Company
2355 Stevens Drive Bldg 1162
Richland, WA 99352

Ben Gurion University of the Negev
1, Henrietta Sold Street
Beer-Sheva
Israel

Boyce Thompson Institute for
Plant Reserach
Office of Environmental Health
118 Maple Avenue
Ithaca, NY 14853

**Brookhaven National Laboratory
Bldg 801, T-89
Upton, NY 11973

**California State University
Research/Instructural Safety, RM MH55
800 N. State, College Blvd.
Fullerton, CA 92634

**Center for Molecular Medicine
and Immunology
Corner of W. Market & Bruce Str.
Newark, NJ 07103

Cell Research Pty Ltd
99-101 Buckingham St.
Surry Hills NSW 2010
AUSTRALIA

Clark University
Department of Chemistry
950 Main Street
Worcester, MA 01610

Commissione Delle Comunita
Europee-Centro Comune Di Ricerca
Istituto Dell Ambiente
21020 Ispra-Varese ITALY

**Computer Technology & Imaging
830 Corridor Park Blvd.
Suite 400
Knoxville, TN 37932

Cornell University
Radiation Safety Office
Office of Environmental Health
118 Maple Ave.
Ithaca, NY 14850

Cyclotron Biomedical De Caen
L.M.R.I.
BP 21
91190 GIF SUR YVETTE, FRANCE

**E.I. Dupont
331 Treble Cove Road
North Billerica, MA 01862

**E.R. Squibb & Sons
(Bristol Myers Squibb)
1 Squibb Drive
New Brunswick, NJ 08903

Freie Universitat, Berlin
Fachrichtung Umweltgeologie
matleserstr. 74-100 Haus E

**German Cancer Research Center
Im Neuenheimer Feld 280
D-69120 Heidelberg
Federal Republic of Germany

**Groningen University Hospital
Department of Nuclear Medicine
Osstersingel 59
9713 EZ Groningen, Netherlands

Harvard School of Public Health
665 Huntington Ave.
Bldg. 11, Room 237
Boston, MA 02115

Harwell Laboratory
Rad Waste Disposal Division
Bldg 20
Oxfordshire, OX11 ORA
United Kingdom

**Hazleton Wisconsin
3301 Kinsman Blvd.
Madison, WI 53707

Idaho National Engineering Lab
EG&G Idaho Nuclear/U.S.D.O.E.
CF 601
Scoville, ID 83415

**Immunomedics, Inc.
300 American Road
Morris Plains, NJ 07950

**Indiana University
Medical Center
Radiation Safety Room 159
541 Clinical Drive
Indianapolis, IN 46202

Institut fur Allgemeine Metallurgie
TU Clausthal
Robert-koch-str. 42
38678 Clausthal-Zellerfeld
Germany

Institut d'Estudes Marines
Universite de Bretagne Occidentale
6 Avenue Le Gorgeu, BP 452
29285 Brest Cedex-France

Institutt for Energiteknikk
Instituttevein 18
N-2207 Kjeller
Norway

**Isotope Products Laboratory
1800 N. Keystone Street
Burbank, CA

Isotopen Dienst Benelux B.V.
Weverstraat 17
5111 PV Baarle-Nassau
Netherlands

Isotopen Dienst D-A-Ch
Gebaeude 458, Zimmer 2177
Frankfurt/Main Flughafen
Fracht-Zentrum, Germany

Institute for Reference Materials
and Measurements (IRMM)
Sample Preparation
Joint Research Centre
Retiwseweg B-2440 GEEL BELGIUM

Japan Radioisotope Association
28-45, Hon-Komagome 2-chome
Bunkyo-ku, Tokyo, Japan

**Laboratoire De Metallurgie, URA 443
Faculte Des Sciences of Techniques
St. Jerome, Case 511
Av. Bacadrille Normadndie-Niemen
13397 Marseille Cedex 13, France

**Lovelace Biomedical
Bldg 9217 Area Y
Kirtland Air Force Base
Albuquerque, NM 87115

Management Technology
U.S. EPA/RSO
Chemical Facility, Bldg R
Alexander Drive
Research Triangel Park, NC 27711

**McMaster University
Chedoke-McMaster Hospitals
1200 Main Street West
Forsyth Avenue Receiving
Hamilton, Ontario, Canada L8N 3Z5

Montana State University
Dept. of Plant and Soil Science
Leon Johnson Hall
Bozeman, MT 59717

**National Institutes of Health
Radiation Safety Officer
Bldg. 21, Room 116
Bethesda, MD 20892

**New York Univ. Med. Ctr.
A.J. Lanza Labs
Sterling Lake Road
Tuxedo, NY 10987

North American Scientific
7435 Greenbush Avenue
North Hollywood, CA 91605

NRD Inc.
2937 Alt Blvd.
Grand Island, NY 14072

Nuclear Sources and Services (NSSI)
(Gammatron)
5711 Ethridge Street
Houston, TX 77087

Oak Ridge National Laboratory
Martin Marietta Energy Systems, Inc.
Bldg. 3038
Oak Ridge, TN 37831

Oklahoma State Univ. (SE)
Math & Science Bldg. Room 203
Durant, OK 74701

**Old Dominion University
Environmental Health &
Safety Office
1300 West 49th Street
Norfolk, VA 23529

Oregon State University
c/o Radiation Safety
Radiation Center A-124
35 th & Jefferson
Corvallis, OR 97331-5904

Oriental Scientific Instruments
I/E Corp. Shanghai Branch
445 Jian-Guo Road (W)
Shanghai 200031 P.R. China

**Paul Scherrer Institut
Wurenlingen und Villigen
Ch-5232 Villigen PSI
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Princeton University
Physics Department
Jadwin Hall, Washington Road
Princeton, NJ 08544-0708

**Purdue University
Radiological Control Office
Civil Engr., Bldg. Rm. B201
West Lafayette, IN 47907

Rensselaer Polytechnic Institute
Dept. of Earth & Environmental Science
West Hall, Room G17
Troy, NY 12180-3590

Societe Gondrand
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CDG Roissy Airport
FRANCE

State University of New York
College of Environmental
Science and Forestry
307 Stadium Place
Syracuse, NY 13210

Suny at Stony Brook
Central Receiving
Stony Brook, NY 11794

**Texas A & M University
Radiological Safety Office
Corner of Houston and Bush Streets
College Station, TX 77843

**Triumf
4004 Wesbrook Mall
Vancounver, B.C. V6T 2A3
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U.S. Bureau of Mines
729 Arapeen Drive
Salt Lake City, UT 84108

**UC, Davis
Radiodiagnosis Therapy
1508 Alhambra Blvd.
Sacramento, CA 95816

UC, Irvine
19182 Jamboree Blvd.
Irvine, CA 92717

UC, Lawrence Berkeley Lab
Bldg. 75, Room 113
1 Cyclotron Road
Berkeley, CA 94720

**UC, Los Angeles
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650 Circle Drive South
Los Angeles, CA 90024

**UC, San Diego
Receiving/EH&S
8655 Production Avenue
San Diego, CA 92121

UC, Santa Barbara
Central Receiving
Santa Barbara, CA 93106

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Radiation Safety
221 14th Street South
Birmingham, AL 35294

University of Arizona
Health Science Center
c/o Radiation Control Office
Tucson, AZ 85721

Univ. De Coimbra
Departamento de Fisica
Rua Larga da Universidade
Coimbra 3000 Portugal

Univ. Libre De Bruxelles
Groupe De Microbiologie Des Milieux
Aquatiques, CP 221, Campus Plaine,
Boulevard de Triomphe,
B-1050 Bruxelles, Belgium

University of Chicago
Radiation Protection
5835 So. Cottage Grove
Chicago, IL 60637

**University of Florida
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Bldg. 175
Gainesville, FL 32611

University of Greenwich
Dept. of Biological & Chemical Sciences
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**University of Illinois at Chicago
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Chicago, IL 60612

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**University of Medicine and
Dentistry of NJ
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185 South Orange Avenue
Newark, NJ 07103

**University of Missouri
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Research Park, Room 241
Columbia, MO 65211

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G-7 Parran Hall, GSPH
Pittsburgh, PA 15261

**University of Southern California
Radiation Safetly
1540 Alcazal St. Room 107
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USDA-ARS-NPA
Grand Forks Human Nutr. Res. Ctr
2420 2nd Avenue North
Grand Forks, ND 58203

Walther-Straub-Institute
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D-8000 Munich 2
Germany

**Washington University
Radiation Safety-Room 2242
724 South Euclid
St. Louis, MO 63110

Wayne State University
Department of Biochemistry
540 East Canfield Avenue
Room 5324 Scott Hall
Detroit, MI 48201

White Sands Research Center
1300 LaVelle Road
Alamorgordo, NM 88310

Yale University
Boyer Center Receiving Room
297 Congress Avenue
New Haven, CT 06510

## APPENDIX D

## CREDENTIALS OF LOS ALAMOS PERSONNEL RECENT PUBLICATIONS, PATENTS, AND PRESENTATIONS

Our policy on publications is to obtain the necessary patent disclosures and subsequent applications prior to publication of results in the open literature. This facilitates any future technology transfer opportunities for the unique and novel targeting, production, processing, and applications research we perform on this project. This policy necessarily delays publications in the open literature for a short period following the intellectual property disclosure process.

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D. A. Cole, J. A. Mercer-Smith, S. A. Schreyer, J. K. Norman and D. K. Lavallee (1990). "The Biological Characteristics of a Water Soluble Porphyrin in Rat Lymph Nodes," Int. J. Nucl. Med. Biol., 17, 457-464.

J. A. Mercer-Smith, D. A. Cole, J. C. Roberts, D. Lewis, M. J. Behr, and D. K. Lavallee (1990). "The Biodistribution of Radiocopper-Labeled Compounds," in Copper Bioavailability and Metabolism, Vol. 258 of Advances in Experimental Medicine and Biology (C. Kies, ed.), Plenum Press, New York, NY, pp. 103-121.

D. A. Cole, J. A. Mercer-Smith, J. K. Norman, S. A. Schreyer, K. P. Bullington, J. C. Roberts, and D. K. Lavallee (1990). "Copper-67 Labeled Porphyrin Localization in Inflamed Tissues," in Copper Bioavailability and Metabolism, Vol. 258 of Advances in Experimental Medicine and Biology (C. Kies, ed.), Plenum Press, New York, NY, pp. 259-272.

W. A. Taylor, A. N. Herring, R. M. Lopez, D. C. Moody, D. R. Phillips, and R. C. Staroski, "Production of Mono-Isotopic $^{88}$Y from the Decay of $^{88}$Zr," Appl. Radiat. Isot., Int. J. Radiat. Appl. Instrum. Part A 42, 208 (1991).

J. A. Mercer-Smith, J. C. Roberts, D. Lewis, D. A. Cole, S. L. Newmyer, L. D. Schulte, P. L. Mixon, S. A. Schreyer, S. D. Figard, T. P. Burns, D. J. McCormick, V. A. Lennon, M. Hayashi, and D. K. Lavallee "Radiometallating Antibodies and Autoantigenic Peptides," in *New Trends in Radiopharmaceutical Synthesis, Quality Assurance and Regulatory Control.*, A. Emran, Ed., (Plenum Press, New York, NY, 1991) pp.129-152.

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R. C. Heaton, D. J. Jamriska, W. A. Taylor, J. B. Garcia, and D. R. Phillips, "Recent Developments of Zinc Oxide Target Chemistry," *Journal of Radioanalytical and Nuclear Chemistry, Articles*, Vol. 195, No. 2 (1995).

W. A. Taylor, D. J. Jamriska, V. T. Hamilton, R. C. Heaton, D. R. Phillips, R. C. Staroski, J. B. Garcia, J. G. Garcia, "Waste Minimization in the Los Alamos Radioisotope Development Program," *Journal of Radioanalytical and Nuclear Chemistry, Articles*, Vol. 195, No. 2 (1995).

D. A. Cole, D. C. Moody, E. Ellinwood, G. Klein, R. Michels, J. Becktal, and G. Saccomanno, "Detection of Lung Cancer Sputum Cells with a Water Soluble Porphyrin: Part I. Localization of Porphyrin in Sputum Cells from Cancer Patients, Journal *of the National Cancer Institute*, submitted.

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D. A. Cole, "Method of Treating Cancers of the Lung with Radiolabeled 5,10,15,20-Tetrakis (4-carboxyphenyl) Porphine," WO Patent # 9119978 A1, October, 1991.

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R. C. Heaton, D. J. Jamriska, W. A. Taylor, "Process for $^{82}$Sr Separation", U. S. Patent #5,167,938, December, 1992.

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D. R. Phillips, "Production of Selenium-72 and Arsenic-72," U. S. Patent # 5,204,072 April 20, 1993.

D. R. Phillips, V. T. Hamilton, D. J. Jamriska, "Recovery of Germanium-68 from Irradiated Targets", U.S. Patent # 5,296,203 (Divisional on Related U.S. Patent #5,190,735), March 22, 1994.

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D. R. Phillips and M. A. Brzezinski, "Production of High Specific Activity Silicon-32", U.S. Patent #5,346,678, Issued September 13, 1994.

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D. R. Phillips, "Production of Selenium-72 and Arsenic-72," U.S. Patent #5,405,589 (Divisional on Related U.S. Patents #5,204,072 and #5,371,372), Issued April 11, 1995.

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D. J. Jamriska, W. A. Taylor, M. A. Ott, M. M. Fowler, and R. C. Heaton, "Production of High Specific Activity Copper-67," (Pending, LANL Docket Number S-80,427).

**Presentations at Major Meetings with Published Abstracts**

J. A. Mercer-Smith, T. P. Burns, D. Lewis, S. Newmyer, J. C. Roberts, L. Schulte, and D. K. Lavallee, "Radiometallating Antibodies Using Porphyrins as Chelating Agents", invited presentation at the 200th National Meeting of the American Chemical Society, International Symposium on New Trends in Radiopharmaceutical Synthesis, Quality Assurance and Regulatory Control, Washington, D.C., August 26-31, 1990.

J. A. Mercer-Smith, J. C. Roberts, D. Lewis, S. L. Newmyer, L. D. Schulte, T. P. Burns, P. L. Mixon, A. L. Jeffrey, S. A. Schreyer, D. A. Cole, S. D. Figard, V. A. Lennon, M. Hayashi, and D. K. Lavallee, "Radiometallating Antibodies and Biologically Active Peptides,"invited presentation at the 200th National Meeting of the American Chemical Society, International Symposium on New Trends in Radiopharmaceutical Synthesis, Quality Assurance and Regulatory Control, Washington, D.C., August 26-31, 1990.

Ali M. Emran and Dennis R. Phillips, "Biomedical Use of Arsenic Radioisotopes," invited presentation at the 200th ACS National Meeting, International Symposium on New Trends in Radiopharmaceutical Synthesis, Quality Assurance and Regulatory Control, Washington, D.C., August 26-31, 1990.

Dennis R. Phillips, David A. Nix, Wayne A. Taylor, Timothy P. Burns, and Ali M. Emran, "The Chemistry and Concept for an Automated $^{72}Se/^{72}As$ Generator," invited presentation at the 200th ACS National Meeting, International Symposium on New Trends in Radiopharmaceutical Synthesis, Quality Assurance and Regulatory Control, Washington, D.C., August 26-31, 1990.

D. Erb, R. Atcher, J. Beaver, L. Mausner, and E. Peterson, "The Future of Accelerator Production of Radioisotopes in the United States," invited presentation at the 200th ACS National Meeting, International Symposium on New Trends in Radiopharmaceutical Synthesis, Quality Assurance and Regulatory Control, Washington, D.C., August, 1990.

T. P. Burns and J. A. Mercer-Smith, "Design of a Paramagnetic Contrast Imaging Agent Through the Use of Molecular Modeling," 200th American Chemical Socety National Meeting, Washington, D.C., August 26-31, 1990.

D. J. Jamriska, W. A. Taylor, R. C. Heaton, V. T. Hamilton, R. C. Staroski, D. R. Phillips, "Isolation and Recovery of $^{82}Sr$ and Other Spallation Products from Proton Irradiated Molybdenum," Presented at the 205th ACS National Meeting, Symposium on Radioisotope Production and Radiochemical Separations, Denver, Colorado, March 28-April 2, 1993.

D. J. Jamriska, W. A. Taylor, R. C. Heaton, V. T. Hamilton, and R. C. Staroski, "Isolation and Recovery of $^{88}Zr$, $^{88}Y$, $^{83}Rb$, and $^{65}Zn$ from Proton Irradiated Molybdenum," Presented at the 205th ACS National Meeting, Symposium on Radioisotope Production and Radiochemical Separations, Denver, Colorado, March 28-April 2, 1993.

M. M. Fowler, D. J. Jamriska, and W. A. Taylor, "Determination of the Ratio of $^{82}Sr$ to $^{85}Sr$ by High Resolution Gamma-ray Counting," Presented at the 205th ACS National

Meeting, Symposium on Radioisotope Production and Radiochemical Separations, Denver, Colorado, March 28-April 2, 1993.

V. T. Hamilton, D. R. Phillips, and D. J. Jamriska, "Recovery of $^{68}Ge$ and $^{95m}Tc$ from Proton Irradiated Molybdenum," Presented at the 205th ACS National Meeting, Symposium on Radioisotope Production and Radiochemical Separations, Denver, Colorado, March 28-April 2, 1993.

W. A. Taylor, D. J. Jamriska, M. M. Fowler, and R. C. Heaton, "Production of Beryllium-7 and Vanadium Isotopes from Proton Irradiated Zinc Oxide," Presented at the 205th ACS National Meeting, Symposium on Radioisotope Production and Radiochemical Separations, Denver, Colorado, March 28-April 2, 1993.

D. R. Phillips, V. T. Hamilton, D. J. Jamriska, and M. A. Brzezinski, "Recovery of Al-26 and Si-32 from Proton Irradiated KCl Targets," Presented at the 205th ACS National Meeting, Symposium on Radioisotope Production and Radiochemical Separations, Denver, Colorado, March 28-April 2, 1993.

D. J. Jamriska, W. A. Taylor, M. A. Ott, R. C. Heaton, and D. R. Phillips, "Activation Rates and Chemical Recovery of $^{67}Cu$ Produced with Low Energy Proton Irradiation on Enriched $^{70}Zn$ Targets," Presented at the American Nuclear Society International Topical Conference on Methods and Applications of Radioanalytical Chemistry-III, Kailua-Kona, Hawaii, April, 1994.

D. R. Phillips, V. T. Hamilton, D. J. Jamriska, and M. A. Brzezinski, "Application of Sephadex to Radiochemical Separations," Presented at the American Nuclear Society International Topical Conference on Methods and Applications of Radioanalytical Chemistry-III, Kailua-Kona, Hawaii, April, 1994.

R. C. Heaton, D. J. Jamriska, W. A. Taylor, J. B. Garcia, and D. R. Phillips, "Recent Developments of Zinc Oxide Target Chemistry," Presented at the American Nuclear Society International Topical Conference on Methods and Applications of Radioanalytical Chemistry-III, Kailua-Kona, Hawaii, April, 1994.

W. A. Taylor, D. J. Jamriska, V. T. Hamilton, R. C. Heaton, D. R. Phillips, R. C. Staroski, J. B. Garcia, J. G. Garcia, "Waste Minimization in the Los Alamos Radioisotope Development Program," Presented at the American Nuclear Society International Topical Conference on Methods and Applications of Radioanalytical Chemistry-III, Kailua-Kona, Hawaii, April, 1994.

world, and a buncher system allows users to generate sub-nanosecond pulses of the hydrogen isotopes at rates to a few megahertz.

We are currently investigating the production of a variety of medical radioisotopes and other isotopes that have commercial markets. For example, the IBF appears particularly well suited for the production of $^{18}F$. Regional distribution of this radioisotope could facilitate the expansion of positron emission tomography (PET) in the southwest. Other radioisotopes being investigated include $^{62}Zn$, $^{72}Se$, $^{186}Re$ and $^{76}As$. The first two isotopes have potential PET applications, while the second two have potential as therapy isotopes. Additional exploration of the production of short-lived radioisotopes for research applications is continuing.

## REACTOR-PRODUCED RADIOISOTOPES

Los Alamos continues to participate in the Department of Energy's Mo-99 and related reactor-produced isotope program in conjunction with Sandia National Laboratory. Los Alamos' role is to develop and implement the required target fabrication capability and to aid in the development and improvement of radioisotope process chemistry. Sandia
continues to develop the capability to irradiate and
recovery of Mo-99. Although the Omega West
December 1992 and is being prepared for decontam
description of the facility follows. Although curre
Alamos personnel have not taken any actions that wo
if programmatic requirements necessitated such an eff

**Omega West Reactor** - The OWR is a the
MW research reactor, that is light-water moderated a
plate-type fuel elements. At 8 MW, the thermal
neutrons/cm$^2$s, and the fast neutron flux (>0.1 MeV
focus before shutdown was on the irradiation of en
production of molybdenum-99 and related fission
irradiation in the OWR, the uranium targets were to be transported to the Chemistry and Metallurgy Research Wing-9 hot cells for chemical processing. These radioisotopes would then have been distributed to radiopharmaceutical manufacturers for use in their products. All manufacturing processes related to molybdenum-99 was to be done according to FDA Good Manufacturing Practices (GMP). Other radioisotopes, such as I-125 and P-32, were also to be produced in the OWR. As a result of dedicating the OWR to an isotope

after 142 starts over w/126-142

Extra pages

production mission, we were planning to also explore other radioisotope production of interest to the nuclear medicine and other research communities. These same activities are currently being carried out at Sandia National Laboratory, in collaboration with Los Alamos.

## ENRICHED STABLE ISOTOPES

**Los Alamos ICON Facility** - Historically, the function of the ICON Facility at Los Alamos was to isolate large quantities of individual isotopes of light elements, such as carbon, oxygen, and nitrogen - hence the facility's name. The separations were carried out using cryogenic distillation columns that vary in length from 180 to 700 ft. The separated isotopes or compounds containing these isotopes were used in research and medical activities at Los Alamos and many other institutions. For example, separated $^{18}O$ is used in the preparations of $^{18}F$, which is incorporated into fluorodeoxyglucose. This compound is the primary metabolic tracing agent used in PET. The isotopic materials from this facility were sold at cost to the general research community. The facility has been in the standby mode since October 1989. The DOE and Los Alamos investigated the possibility of leasing this facility to a private company for the commercial operation, but there was not sufficient industrial interest to pursue this concept further.

There are five cryogenic NO distillation columns for the separation of nitrogen and oxygen isotopes. The capacity of the facility for $^{15}N$ and $^{18}O$ is approximately 10 Kg/yr, for 98+ and 95+% enriched material respectively. There also is a cryogenic CO distillation column for production of separated carbon isotopes. The capacity of this column is in excess of 10 Kg/yr for 99+% of both $^{12}C$ and $^{13}C$. Lastly, there is a cryogenic distillation column for the separation of $^{22}Ne$. The capacity of this column is in excess of 3 Kg/yr for 90+% enriched material.

**Los Alamos Isotope Separator Facility** - This facility consists of three electromagnetic isotope separators, with the design and hardware available for a fourth instrument. The separators are fully instrumented and operate in an automated fashion. Each separator is capable of an approximately 1-mg/day (all isotopes) collection rate; each isotope is enhanced in purity by $\sim 10^4$ relative to the isotopic ratio in the feed material. Higher collection rates are possible for selected elements. Almost all elements in the periodic table can be separated but not with equal efficiency; the collected-mass/feed-material-mass efficiencies range from 0.1 to 50%. Alpha emitters and highly radioactive samples with long half-lives cannot be separated at this time, but conversion of an existing separator to meet this requirement is planned.

## ISOTOPICALLY LABELED COMPOUNDS

**Los Alamos National Stable Isotope Resource (SIR)** - This resource is funded by the National Institutes of Health to develop biomedical applications of the low -abundance stable isotopes of carbon, nitrogen, and oxygen. When enriched above their natural abundance, the stable isotopes $^{13}C$, $^{15}N$, and $^{17,18}O$ are used to follow complex chemical and biochemical processes. The power of these isotopes is derived in part from the NMR spectroscopic techniques used to detect them. These methods allow determination of not only the extent of labeling, but also the chemical identity of the labeled product. As describe above, Los Alamos pioneered the large-scale production of the stable isotopes of carbon, nitrogen, and oxygen. The major obstacle to the more general use of stable isotopes is the relatively poor availability of useful compounds incorporating these isotopes. Thus, the SIR carries out vigorous research and development of new methods for the synthesis of labeled compounds. Current research focuses in three areas: (1) stereoselective synthesis of labeled L-amino acids, (2) site specific labeling of nucleosides and nucleotides, and (3) biosynthesis of symmetrically labeled porphyrins.

**Los Alamos Medical Radioisotopes Research Program** - One of the goals of this program is the development of biomedical generators to provide short-lived PET and therapeutic radioisotopes for clinical applications. A biomedical generator is a system that has an immobilized long-lived parent radioisotope that decays into a shorter-lived daughter radioisotope that has a nuclear medicine or biomedical applications. Past research in this program has contributed to the commercial success of the $^{82}Sr/^{82}Rb$ generator. We currently are conducting research on several generator systems including $^{72}Se/^{72}As$, $^{194}Hg/^{194}Au$, and $^{47}Ca/^{47}Sc$.

Another of the goals for this program is the development of radiolabeled compounds that may have utility in nuclear medicine and biomedical applications. Design goals for compounds include: (1) ultrastability for *in vivo* applications; (2) biochemical specificity for targeting specific organs or diseased tissues; and (3) applicability to radiopharmaceutical synthesis. Additional efforts are directed at the radioisotopic labeling of biomolecules either directly or through attachment of radiolabeled compounds. These efforts extend the range of utility of radioisotopes produced in our reactors and accelerators.

## ISOTOPE MARKETING AND DISTRIBUTION

Los Alamos National Laboratory produces and distributes radioisotopes, and in the past stable isotopes, on a cost recovery basis. This is done under the auspices of the Department of Energy, Office of Nuclear Energy, Office of Isotope Production and Distribution. During a typical fiscal year, we will distribute a total of 17 Ci of 15 radioisotopes to over 45 organizations worldwide. Details of our shipments to customers in FY 1994 is given in a separate appendix. These customers included research institutions, hospitals, other national laboratories, and industry. We have developed a reputation as a reliable supplier of both research and commercial radioisotopes. Our current isotope distribution efforts are focused on LAMPF-produced materials, but in the past we considered the distribution of OWR-produced products. In addition, a change in the status of the ICON facility was considered to alleviate the severe shortage of enriched isotopes of carbon, nitrogen, and oxygen. Los Alamos National Laboratory continues to explore the requirements of the U. S. industry and the research community, and continues to examine what facilities and expertise are available to meet these requirements. Whenever appropriate additional products and services are added to our isotope portfolio. We continue to research new isotopes, new isotope separation processes, and new isotope applications. We want to aggressively pursue collaborations that involve partnerships among Los Alamos, the U. S. academic community, and the U. S. commercial sector.

APPENDIX B
LOS ALAMOS NATIONAL LABORATORY
FY94 Medical Radioisotopes Shipments

| Isotope | Customer | No. of Shipments | mCi Shipped | mCi Received |
|---|---|---|---|---|
| $^{26}Al$ | Institut fur Allgemeine, Germany | 2 | 0.000280 | 0.00280 |
| $^{73}As$ | Commissione Delle Com., Italy<br>Isotopen Dienst, Germany<br>LANL/INC-12<br>New York Univ. Med. Ctr<br>Old Dominion University<br>State University of New York<br>U.S. EPA/RSO<br>UC, San Diego<br>University of Arizona<br>Wayne State University<br>White Sands Research Center | 17 | 68.33 | 67.00 |
| $^{7}Be$ | Isotope Products Laboratory | 2 | 3.32 | 3.32 |
| $^{109}Cd$ | North American Scientific<br>Teledyne Isotope, Inc. | 7 | 345.50 | 345.10 |
| $^{67}Cu$ | Hazleton Wisconsin, Inc.<br>Purdue University<br>Texas A & M University<br>UC, Davis<br>University of Florida<br>University of Utah<br>Washington University | 8 | 368.61 | 246.00 |
| $^{148}Gd$ | Isotope Products Laboratory<br>North American Scientific<br>UMDNJ | 3 | 0.02 | 0.02 |
| $^{68}Ge$ | CTI Services, Inc.<br>McMaster University, Canada<br>North American Scientific<br>Washington University | 20 | 939.22 | 935.70 |
| $^{22}Na$ | E.I. Dupont<br>Japan Radioisotope Association<br>LANL/INC-12 | 5 | 1516.20 | 1505.20 |

| Isotope | Customer | No. of Shipments | mCi Shipped | mCi Received |
|---|---|---|---|---|
| $^{83}Rb$ | Idaho National Engineering Lab<br>UC, Lawrence Berkeley Lab | 4 | 6.52 | 6.52 |
| $^{75}Se$ | Boyce Thompson Institute<br>Idaho National Engineering Lab | 2 | 2.04 | 2.04 |
| $^{32}Si$ | Amersham Buchler, Germany<br>Institut d'Etudes Marines, France<br>UC, Santa Barbara<br>Isotope Products Laboratory | 4 | 0.02 | 0.02 |
| $^{95m}Tc$ | Atomic Energy of Canada<br>Battelle/U.S. DOE<br>Freie Universitat Berlin, Germany<br>Harwell Laboratory, UK<br>Isotope Products Laboratory | 5 | 7.56 | 7.00 |
| $^{44}Ti$ | Commissione Delle Com., Italy<br>Cornell University | 2 | 0.02 | 0.02 |
| $^{48}V$ | Ben Gurion Univ. Israel | 1 | 1.84 | 1.00 |
| $^{49}V$ | Univ. De Coimbra, Portugal | 1 | 1.04 | 1.00 |
| $^{88}Y$ | Amersham International, UK<br>Analytics, Inc.<br>ANSTO, Australia<br>Center for Molecular Medicine<br>Idaho National Engineering Lab<br>Immunomedics, Inc.<br>Isotope Products Laboratory<br>National Institute of Health<br>Societe Gondrand, France<br>University of Missouri | 22 | 83.00 | 79.13 |
| $^{65}Zn$ | E. I. Dupont/NEN Products | 1 | 50.00 | 50.00 |
| $^{88}Zr$ | Idaho National Engineering Lab<br>Oak Ridge National Laboratory | 2 | 2.15 | 2.15 |
| TOTALS | | 116 | 6402.72 | 6176.35 |

## APPENDIX C
## LOS ALAMOS NATIONAL LABORATORY
## CUSTOMER LIST

** denotes nuclear medicine isotope purchaser

**Amersham Buchler GmbH & Co KG
Gieselweg 1
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1380 Seaboard Industrial Blvd.
Atlanta, GA 30318

Atomic Energy of Canada
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**Australian Nuclear Science
& Technology Organization (ANSTO)
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Argonne National Laboratory
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Battelle Memorial Institute
Pacific Northwest Laboratory
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New Haven, CT 06510

## APPENDIX D

## CREDENTIALS OF LOS ALAMOS PERSONNEL
## RECENT PUBLICATIONS, PATENTS, AND PRESENTATIONS

Our policy on publications is to obtain the necessary patent disclosures and subsequent applications prior to publication of results in the open literature. This facilitates any future technology transfer opportunities for the unique and novel targeting, production, processing, and applications research we perform on this project. This policy necessarily delays publications in the open literature for a short period following the intellectual property disclosure process.

**Publications in Journals and Book Volumes (1990-Present)**

J. C. Roberts, Y. E. Adams, D. Tomalia, J. A. Mercer-Smith, and D. K. Lavallee (1990). "Using Starburst Dendrimers as Linker Molecules to Radiolabel Antibodies," Bioconjugate Chem., 2, 305-308.

D. A. Cole, J. A. Mercer-Smith, S. A. Schreyer, J. K. Norman and D. K. Lavallee (1990). "The Biological Characteristics of a Water Soluble Porphyrin in Rat Lymph Nodes," Int. J. Nucl. Med. Biol., 17, 457-464.

J. A. Mercer-Smith, D. A. Cole, J. C. Roberts, D. Lewis, M. J. Behr, and D. K. Lavallee (1990). "The Biodistribution of Radiocopper-Labeled Compounds," in Copper Bioavailability and Metabolism, Vol. 258 of Advances in Experimental Medicine and Biology (C. Kies, ed.), Plenum Press, New York, NY, pp. 103-121.

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J. A. Mercer-Smith, J. C. Roberts, D. Lewis, D. A. Cole, S. L. Newmyer, L. D. Schulte, P. L. Mixon, S. A. Schreyer, S. D. Figard, T. P. Burns, D. J. McCormick, V. A. Lennon, M. Hayashi, and D. K. Lavallee "Radiometallating Antibodies and Autoantigenic Peptides," in *New Trends in Radiopharmaceutical Synthesis, Quality Assurance and Regulatory Control.*, A. Emran, Ed., (Plenum Press, New York, NY, 1991) pp.129-152.

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A. M. Emran and D. R. Phillips, "Biomedical Use of Arsenic Radioisotopes: Overview," in *New Trends in Radiopharmaceutical Synthesis, Quality Assurance, and Regulatory Control*, A. M. Emran, Ed., (Plenum Press, New York, NY), 153-168, (1991).

D. A. Cole, D. C. Moody, L. E. Ellinwood, M. G. Klein, J. A. Mercer-Smith, A. Brumbaugh, R. O. Eikleberry, D. Lewis, G. Saccomanno, J. J. Bechtel, and D. K. Lavallee, "A Synthetic Porphyrin with High Affinity for Lung Cancer Cells and Inflamed Lymphatic Tissue," in *New Trends in Radiopharmaceutical Synthesis, Quality Assurance and Regulatory Control.*, A. Emran, Ed., (Plenum Press, New York, NY, 1991) pp.109-118.

D. Erb, D. Moody, E. Peterson, L. Mausner, and R. Atcher, "A National Biomedical Tracer Facility," in *New Trends in Radiopharmaceutical Synthesis, Quality Assurance and Regulatory Control.*, A. Emran, Ed., (Plenum Press, New York, NY, 1991) pp.201-211.

D. R. Phillips, V. T. Hamilton, M. D. Taylor, J. E. Farnham, A. M. Emran, R. W. Rowe, and D. Pattel, "Generator-Produced Arsenic-72 in Positron Emission Tomography," *Radioactivity and Radiochemistry*, 3(4), 53-58 (1992).

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R. C. Heaton, D. J. Jamriska, W. A. Taylor, J. B. Garcia, and D. R. Phillips, "Recent Developments of Zinc Oxide Target Chemistry," *Journal of Radioanalytical and Nuclear Chemistry, Articles*, Vol. 195, No. 2 (1995).

W. A. Taylor, D. J. Jamriska, V. T. Hamilton, R. C. Heaton, D. R. Phillips, R. C. Staroski, J. B. Garcia, J. G. Garcia, "Waste Minimization in the Los Alamos Radioisotope Development Program," *Journal of Radioanalytical and Nuclear Chemistry, Articles*, Vol. 195, No. 2 (1995).

D. A. Cole, D. C. Moody, E. Ellinwood, G. Klein, R. Michels, J. Becktal, and G. Saccomanno, "Detection of Lung Cancer Sputum Cells with a Water Soluble Porphyrin: Part I. Localization of Porphyrin in Sputum Cells from Cancer Patients, Journal *of the National Cancer Institute*, submitted.

D. A. Cole, D. C. Moody, E. Ellinwood, G. Klein, R. Michels, M. Tockman, J. Becktal, and G. Saccomanno, "Detection of Lung Cancer Sputum Cells with a Water Soluble Porphyrin: Part II. Identification of Sputum Cells with Computerized Image Analysis," *Journal of the National Cancer Institute*, submitted.

**Patents and Patent Disclosures (1990-present)**

F. J. Steinkruger and D. R. Phillips, "Production of Aluminum-26", U.S. Patent # 5,057,269, October 15, 1991.

D. A. Cole, "Method of Treating Cancers of the Lung with Radiolabeled 5,10,15,20-Tetrakis (4-carboxyphenyl) Porphine," WO Patent # 9119978 A1, October, 1991.

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D. R. Phillips, "Production of Selenium-72 and Arsenic-72," U. S. Patent # 5,204,072 April 20, 1993.

D. R. Phillips, V. T. Hamilton, D. J. Jamriska, "Recovery of Germanium-68 from Irradiated Targets", U.S. Patent # 5,296,203 (Divisional on Related U.S. Patent #5,190,735), March 22, 1994.

R. C. Heaton, D. J. Jamriska, W. A. Taylor, "Process for Zr-88, Y-88 and Rb-83 Separation from Molybdenum," U. S. Patent # 5,330,731, Issued July 1, 1994.

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D. R. Phillips, "Production of Selenium-72 and Arsenic-72," U.S. Patent #5,371,372 (Divisional on Related U.S. Patent #5,204,072), Issued December 6, 1994.

D. R. Phillips, "Production of Selenium-72 and Arsenic-72," U.S. Patent #5,405,589 (Divisional on Related U.S. Patents #5,204,072 and #5,371,372), Issued April 11, 1995.

W. A. Taylor, R. C. Heaton, D. J. Jamriska, "Production of Na-22 from Proton Irradiated Aluminum," (Pending, LANL Docket #S-78320).

D. J. Jamriska, W. A. Taylor, M. A. Ott, M. M. Fowler, and R. C. Heaton, "Production of High Specific Activity Copper-67," (Pending, LANL Docket Number S-80,427).

## Presentations at Major Meetings with Published Abstracts

J. A. Mercer-Smith, T. P. Burns, D. Lewis, S. Newmyer, J. C. Roberts, L. Schulte, and D. K. Lavallee, "Radiometallating Antibodies Using Porphyrins as Chelating Agents", invited presentation at the 200th National Meeting of the American Chemical Society, International Symposium on New Trends in Radiopharmaceutical Synthesis, Quality Assurance and Regulatory Control, Washington, D.C., August 26-31, 1990.

J. A. Mercer-Smith, J. C. Roberts, D. Lewis, S. L. Newmyer, L. D. Schulte, T. P. Burns, P. L. Mixon, A. L. Jeffrey, S. A. Schreyer, D. A. Cole, S. D. Figard, V. A. Lennon, M. Hayashi, and D. K. Lavallee, "Radiometallating Antibodies and Biologically Active Peptides,"invited presentation at the 200th National Meeting of the American Chemical Society, International Symposium on New Trends in Radiopharmaceutical Synthesis, Quality Assurance and Regulatory Control, Washington, D.C., August 26-31, 1990.

Ali M. Emran and Dennis R. Phillips, "Biomedical Use of Arsenic Radioisotopes," invited presentation at the 200th ACS National Meeting, International Symposium on New Trends in Radiopharmaceutical Synthesis, Quality Assurance and Regulatory Control, Washington, D.C., August 26-31, 1990.

Dennis R. Phillips, David A. Nix, Wayne A. Taylor, Timothy P. Burns, and Ali M. Emran, "The Chemistry and Concept for an Automated $^{72}Se/^{72}As$ Generator," invited presentation at the 200th ACS National Meeting, International Symposium on New Trends in Radiopharmaceutical Synthesis, Quality Assurance and Regulatory Control, Washington, D.C., August 26-31, 1990.

D. Erb, R. Atcher, J. Beaver, L. Mausner, and E. Peterson, "The Future of Accelerator Production of Radioisotopes in the United States," invited presentation at the 200th ACS National Meeting, International Symposium on New Trends in Radiopharmaceutical Synthesis, Quality Assurance and Regulatory Control, Washington, D.C., August, 1990.

T. P. Burns and J. A. Mercer-Smith, "Design of a Paramagnetic Contrast Imaging Agent Through the Use of Molecular Modeling," 200th American Chemical Socety National Meeting, Washington, D.C., August 26-31, 1990.

D. J. Jamriska, W. A. Taylor, R. C. Heaton, V. T. Hamilton, R. C. Staroski, D. R. Phillips, "Isolation and Recovery of $^{82}Sr$ and Other Spallation Products from Proton Irradiated Molybdenum," Presented at the 205th ACS National Meeting, Symposium on Radioisotope Production and Radiochemical Separations, Denver, Colorado, March 28-April 2, 1993.

D. J. Jamriska, W. A. Taylor, R. C. Heaton, V. T. Hamilton, and R. C. Staroski, "Isolation and Recovery of $^{88}Zr$, $^{88}Y$, $^{83}Rb$, and $^{65}Zn$ from Proton Irradiated Molybdenum," Presented at the 205th ACS National Meeting, Symposium on Radioisotope Production and Radiochemical Separations, Denver, Colorado, March 28-April 2, 1993.

M. M. Fowler, D. J. Jamriska, and W. A. Taylor, "Determination of the Ratio of $^{82}Sr$ to $^{85}Sr$ by High Resolution Gamma-ray Counting," Presented at the 205th ACS National

Meeting, Symposium on Radioisotope Production and Radiochemical Separations, Denver, Colorado, March 28-April 2, 1993.

V. T. Hamilton, D. R. Phillips, and D. J. Jamriska, "Recovery of $^{68}$Ge and $^{95m}$Tc from Proton Irradiated Molybdenum," Presented at the 205th ACS National Meeting, Symposium on Radioisotope Production and Radiochemical Separations, Denver, Colorado, March 28-April 2, 1993.

W. A. Taylor, D. J. Jamriska, M. M. Fowler, and R. C. Heaton, "Production of Beryllium-7 and Vanadium Isotopes from Proton Irradiated Zinc Oxide," Presented at the 205th ACS National Meeting, Symposium on Radioisotope Production and Radiochemical Separations, Denver, Colorado, March 28-April 2, 1993.

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D. R. Phillips, V. T. Hamilton, D. J. Jamriska, and M. A. Brzezinski, "Application of Sephadex to Radiochemical Separations," Presented at the American Nuclear Society International Topical Conference on Methods and Applications of Radioanalytical Chemistry-III, Kailua-Kona, Hawaii, April, 1994.

R. C. Heaton, D. J. Jamriska, W. A. Taylor, J. B. Garcia, and D. R. Phillips, "Recent Developments of Zinc Oxide Target Chemistry," Presented at the American Nuclear Society International Topical Conference on Methods and Applications of Radioanalytical Chemistry-III, Kailua-Kona, Hawaii, April, 1994.

W. A. Taylor, D. J. Jamriska, V. T. Hamilton, R. C. Heaton, D. R. Phillips, R. C. Staroski, J. B. Garcia, J. G. Garcia, "Waste Minimization in the Los Alamos Radioisotope Development Program," Presented at the American Nuclear Society International Topical Conference on Methods and Applications of Radioanalytical Chemistry-III, Kailua-Kona, Hawaii, April, 1994.