ORNL/TM-11027

OAK RIDGE NATIONAL LABORATORY

MARTIN MARIETTA

Final Report on Seed Money Project 3210-0346: Feasibility Study for Californium Cold Neutron Source

R. G. Alsmiller
D. L. Henderson
B. H. Montgomery

OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
NTIS price codes—Printed Copy: A05 Microfiche A01

ORNL/TM-11027
Dist. Category UC-400

Engineering Technology Division

Final Report on Seed Money Project 3210-0346: Feasibility Study for Californium Cold Neutron Source

Principal Authors

R. G. Alsmiller D. L. Henderson
B. H. Montgomery

October 1988

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-84OR21400

Contributing Authors

B. H. Montgomery C. D. West
Engineering Technology Division

F. F. Dyer L. Robinson
Analytical Chemistry

C. W. Alexander
Chemical Technology Division

R. G. Alsmiller D. L. Henderson
Engineering Physics and Mathematics Division

K. K. Chipley T. J. McManamy
C. L. Hahs T. L. Ryan
J. K. Jones D. E. Welch
Martin Marietta Energy Systems Engineering

R. E. Pawel
Metals and Ceramics Division

J. B. Hayter
Solid State Division

CONTENTS

Page

EXECUTIVE SUMMARY

Based on an idea conceived by F. F. Dyer of the Oak Ridge National Laboratory (ORNL) Analytical Chemistry Division, a study has been completed on the feasibility and cost of building a cold neutron source that is not dependent on a reactor or accelerator. The neutron source is provided by up to ten ^{252}Cf capsules, each containing 50 mg isotope produced in the High-Flux Isotope Reactor (HFIR). The new facility would be located in the "D" and "E" cells of the Radiochemical Engineering Development Center, Building 7930 (formerly called Thorium-Uranium Reprocessing Facility): the californium capsules are fabricated in 7930 and can be transferred to different cells through hydraulic transport lines without the need of shielded carriers.

The neutron sources presently used for the type of experiment discussed here are very large (and costly) nuclear reactors or accelerator spallation sources. These facilities require a long source-to-detector distance to isolate the detector from the interfering fast neutrons and gamma rays; much shorter distances will be possible in the proposed new facility.

Liquid nitrogen-15 and liquid deuterium (LD_2) were suggested as possible moderators in the original proposal; neutronic calculations from this seed money project show that of those two moderators, only LD_2 is capable, in practice, of attaining a peak cold neutron flux (flux below 10 meV) of 1.4×10^{13} neutrons/($m^2 \cdot s$), which is within the range of the desired flux presented in the same proposal.

The estimate for the overall facility cost — approximately \$6.5M — was very much higher than expected; over one-half of the total cost was TURF cell modifications. A possible alternative to the TURF cells would be a pool facility like the Oak Ridge Research Reactor or Bulk Shielding Reactor, which could reduce this estimate; however, other factors — such as transporting the sources, beam tube placement, and containment — would add significantly to the total cost if a location other than TURF is chosen. At any rate, the total cost would certainly have an impact on a decision by private industries or universities to build a facility of this nature. In addition, and surprisingly, the

cost estimate is higher than the cost estimate for a proposal (see Sect. 8.4) to install a small hydrogenated cold source in one of the Engineering Slant Facilities at HFIR: the HFIR cold source would, therefore, be a better option for ORNL than the californium one. For other laboratories without a reactor in-house, the Californium source would be the only option.

Another major concern in proposing a californium source facility is the availability of the source isotope; the only reactor that produces this isotope is the HFIR. In the past, the HFIR produced ~400 mg per campaign, normally one campaign per year. There have been recent discussions to upgrade this program because of the backlog and current downtime problems of the HFIR. The future of the HFIR is unsettled.

The final decision will depend on the scientific communities' interests and needs for this facility. Individual scientists are excited about this proposed facility (see Sect. 3). Of course, the funding is of primary interest; a rather large investment for this facility would weigh heavily on an individual program; therefore multi-program funding might be required.

FEASIBILITY STUDY FOR CALIFORNIUM COLD NEUTRON SOURCE

R. G. Alsmiller D. L. Henderson
B. H. Montgomery

ABSTRACT

A study has been completed of the feasibility and cost of building a cold neutron source that is not dependent on a reactor or accelerator. The neutron source is provided by up to ten ^{252}Cf capsules, each containing 50 mg of the isotope produced in the High-Flux Isotope Reactor. The neutrons are moderated by heavy water and liquid deuterium to attain, in practice, a peak cold neutron flux of 1.4×10^{13} neutrons/ $(m^2 \cdot s)$. The new facility would be located in the TURF Californium Facility. The estimated cost of the Californium Cold Neutron Source Facility is $6.5 million.

1. INTRODUCTION

Based on an idea conceived by Frank Dyer of the Analytical Chemistry Division, a feasibility study of a Californium Cold Neutron Source (CCNS) has been completed; this would be a cold neutron source that is not dependent on a reactor or accelerator. It would be located in the Oak Ridge National Laboratory (ORNL) TURF Californium Facility. This source facility, utilizing the ^{252}Cf produced in the High-Flux Isotope Reactor (HFIR), would offer opportunities to the neutron research community in the applications of capture gamma-ray analysis (CGA), neutron depth profiling (NDP), medical research studies, low temperature moderator development, and training.

The neutron absorption cross sections of many nuclei are inversely proportional to the neutron velocity. At low energies, the cross section may be very high, leading to more efficient use of the available neutrons. This is particularly important to the use of neutrons in highly sensitive chemical analyses and to the detection and measurement of elements present in very dilute forms (parts per million or below) and in small samples.

In the design studied, ten capsules, each with 50 mg of ^{252}Cf, will be located in a heavy-water vessel surrounding a vacuum-jacketed cryostat containing liquid deuterium (LD_2). The neutrons are initially moderated by the room-temperature heavy water and further moderated, to lower energies and therefore longer wavelengths, by the LD_2.

Simple one-dimensional (i.e., spherically symmetric) neutron transport calculations have been performed for the CCNS experimental facility (Appendix A). The computations indicate that a peak cold neutron flux (flux below 10 meV) of 1.4×10^{13} neutrons/($m^2 \cdot s$) can be attained for a 500-mg californium neutron source. This value exceeds the recommended design criterion for the peak cold neutron flux of 5×10^{12} neutrons/($m^2 \cdot s$) by almost a factor of 3. The cold neutron exit (leakage) current from the spherical LD_2 cryostat is calculated to be ~2.2×10^{12} neutrons/($m^2 \cdot s$).

A beam tube with its origin at the center of the cryostat (the point of highest flux) will provide the neutron path for the experimenters' guide tube.

2. CCNS DESCRIPTION

The following is a description of the CCNS and the TURF modifications required to accommodate the experimental device. The facility description also includes some alternate site discussion. Additional drawings and sketches are shown in Sect. 8.3.

2.1 CCNS DESIGN

As shown in Fig. 2.1 the CCNS design consists of a LD_2 cryostat, a deuterium oxide (D_2O) tank, the californium sources, the holding tube assemblies, the neutron beam tubes, primary gaseous deuterium (GD_2) containment, secondary GD_2 containment, a helium refrigerator, a vacuum system, and other instrument and controls (I&C) required for operating this facility.

The LD_2 cryostat consists of an inner cryostat pressure vessel with a helium-cooled heat exchanger for initially condensing the LD_2 and then removing the steady state heat conducted to the vessel. Inside this vessel are void-producing cavities to optimize the neutron flux produced along the beam tubes. The remainder of the cryostat consists of an exterior vacuum vessel that also serves as secondary containment for the deuterium in the cryostat.

The LD_2 cryostat is suspended in the D_2O tank that holds the heavy-water moderator for the californium-source-produced neutrons. The tank also serves as a structural support for the californium sources and for the beam tubes. This is a very simple, straightforward pressure vessel. No appreciable amount of heat will be produced in the vessel, and it is not anticipated that any cooling system or temperature control will be required. The liquid level and inventory will be monitored.

The californium sources are contained within individual holding tube assemblies and suspended in the D_2O tank. This allows location of each source in such a manner as to optimize the neutron flux entering the LD_2 cryostat. An analysis shows that this proposed concept produces the highest flux of cold neutrons. The sources will be attached to rods that will allow remote manipulators to install and remove them individually.

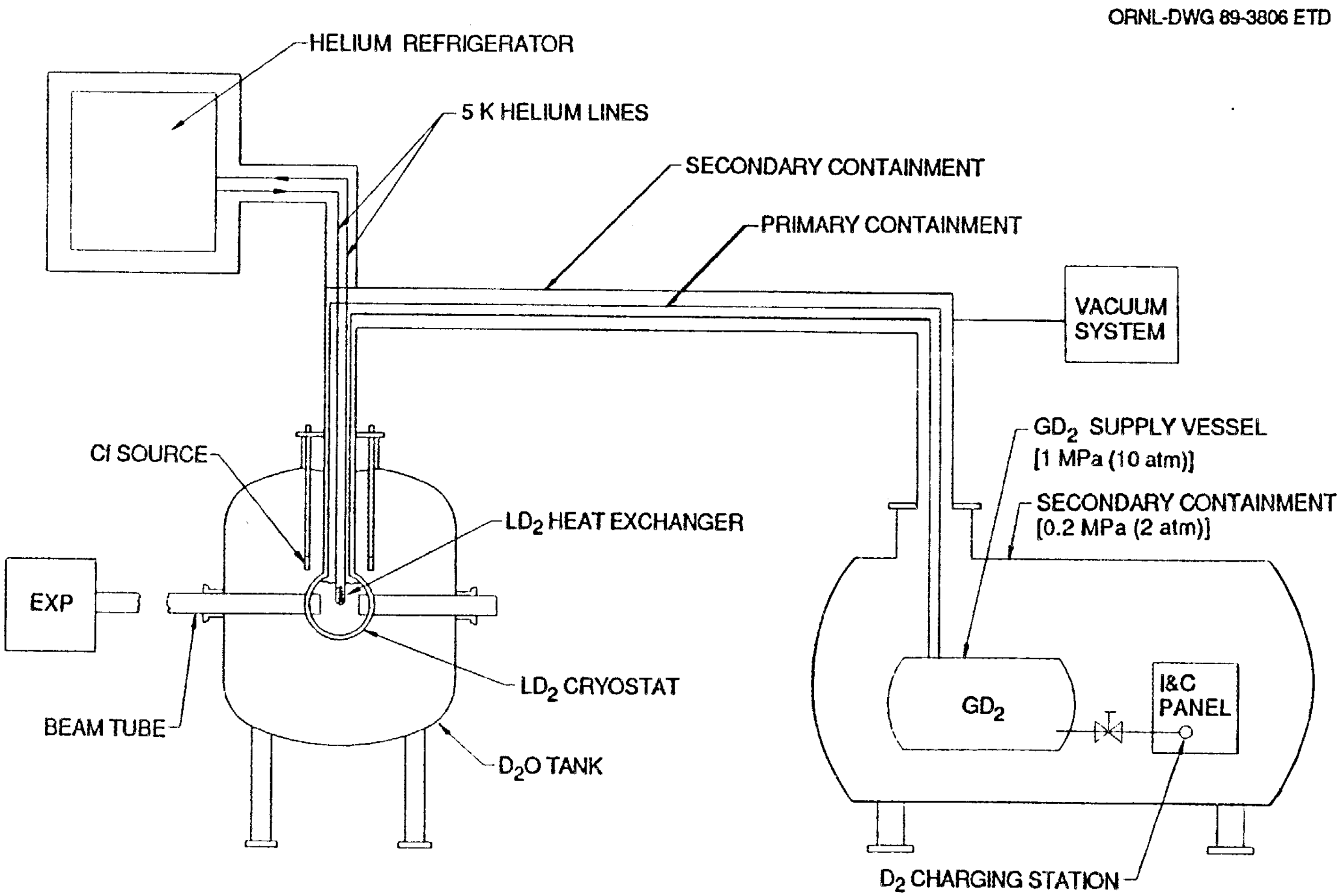


Fig. 2.1. Californium cold neutron source.

The heavy-water tank will have provisions for mounting the beam tubes. The guide tubes were not costed as a part of this concept because they will be provided by the experimenters.

The primary GD_2 containment consists of the inner cryostat pressure vessel, the GD_2 supply vessel, and the connecting pipe between them. The primary containment system is so designed that when the deuterium has been condensed in the cryostat, the entire deuterium inventory (including that within the supply vessel) is at 0.101 MPa (1 atm). Therefore, no valves are required in the primary containment, thus eliminating potential leaks, valve failures, and operator errors. Furthermore, in the event of loss of cooling or even a complete loss of power, the inventory will safely rise to the design pressure of 1.01 MPA (10 atm).

The secondary gaseous containment consists of the outer vacuum shell on the cryostat, the vacuum connecting lines around the primary containment, and the secondary containment vessel. This entire volume is normally under vacuum. The volume is sized so that if the entire inventory of deuterium leaked into the secondary containment, the pressure would not exceed 0.2 MPa (2 atm) at ambient temperature. The vacuum within the secondary containment provides a means to detect even very small leaks in primary containment. It also allows the operators to take corrective action, and if necessary to remove the GD_2.

2.2 CCNS OPERATION

Before initial operation, the D_2O tank will be filled. Operation of the CCNS will consist of first evacuating the primary containment, purging and backfilling with an inert gas, and then evacuating the secondary containment. Once this has been accomplished, the primary containment volume will be charged to 1 MPa (10 atm) of GD_2 from high-pressure bottles. At this point, the helium refrigerator will cool down the gas in the cryostat. As the gas in the cryostat is cooled, it will begin to condense deuterium on the heat exchanger and cool the walls of the inner vessel. The cryostat will begin to fill with liquid until the primary containment has reached a pressure of 0.1 MPa (1 atm). At this point, the appropriate liquid level will have been achieved and the refrigerator cooling will be adjusted to maintain the level within the cryostat.

The sources will be transferred into Cell D one at a time by the extended rabbit tube system. Operators, using remotely operated manipulators and a table located in the cell, will attach that source to its support rod and insert it into the holding tube assembly in the heavy-water tank. This operation will continue until as many as ten californium capsules are in place.

A remote control panel will allow operation and monitoring of the CCNS. Electrical power will be required for instrumentation and the helium refrigerator.

2.3 CCNS SAFETY CONSIDERATIONS

Of primary concern in the design of the CCNS are the safety aspects of handling the californium and the containment of the LD_2 and GD_2 (possibly contaminated with tritium). The radioactive sources require remote handling; this will be achieved by extending the existing TURF rabbit tube system and by installing remote manipulators in Cell D. This approach provides the same degree of safety and control as is currently being used in the handling of californium in the TURF and brings with it all of the established procedures and operating experience. Safe handling of the potentially explosive deuterium has been accomplished by adopting the industry standard concept of double containment with monitoring of the secondary containment for leaks in the primary containment. Removal of any deuterium from the secondary containment in a failure mode will be achieved by getter pumps. The deuterium will be stored in a solid solution for removal from TURF.

2.4 SUMMARY OF FACILITY ALTERNATIVES

The following paragraphs briefly discuss the installation of the CCNS and the TURF with possible alternate sites for operation of the facility.

For this study, TURF Cells D and E were selected as the most desirable location for operation of the CCNS. The main benefit of TURF is that the californium source capsules are fabricated there and can be transferred through an extension of the rabbit tube system to the CCNS. Use of the TURF also has the advantage of existing safety and operating procedures and personnel with experience in the type of operations required by the CCNS. The CCNS is located in Cell D with the beam tube penetrating the wall between D and E. This allows the neutron experimental apparatus to be located in Cell E.

A major portion of the CCNS cost is for the TURF modifications. As a result of this high cost, other facility concepts might be considered. An obvious consideration for an alternate site is a dedicated facility. The advantages would be better experimental access and a better design to accommodate deuterium. For example, in normal hydrogen facilities, there would be a low-pressure building release system.

Another alternative would be to use an existing reactor pool such as in the Oak Ridge Research Reactor (ORR) or the Bulk Shielding Reactor (BSR). The primary advantage is that, with the current concept for the CCNS, it would be possible simply to lower the assembly into the reactor pool, charge it with GD_2, and then install the californium sources. This eliminates some of the high-cost items such as the zinc bromide windows and manipulators that are required in the TURF; however, additional costs would be incurred for transporting the sources and instrument access to beam tubes.

An important part of the conceptual design for the CCNS will be to evaluate alternate site concepts; the goal is to provide reduced facility costs and greater experimental access than are currently available with the use of the TURF.

3. JUSTIFICATION

A limited number of facilities in the United States and the world conduct research utilizing cold neutrons. Neutrons for the existing cold sources are produced either by fission (at nuclear reactors) or by a spallation reaction (at accelerators). Because of the high background radiation generated by these modes of production, neutrons for some experiments (e.g., prompt gamma materials analysis measurements) must be taken up to 50 m away from the source, through guide tubes, before they are isolated enough from beta, gamma, and fast neutron radiation to be useful. Nevertheless, the existing facilities generally are in high demand. The high demand for beams at existing facilities has precluded the use of the best sources for training and development; training and development has provided the justification for many small- and medium-flux sources overseas. [Note, for example, that essentially all of the innovations at Institute Laue Langevin (ILL), Grenoble, were invented and developed at small reactor centers.] The CCNS could offer some similar opportunities to the neutron scattering community in the United States.

Some of the problems associated with cold sources that the CCNS will address are safety, expense, availability, distance from cold source to experiment, and accessibility of the cold source.

The idea to develop a nonreactor-, nonaccelerator-based cold neutron source stemmed from interest in capture gamma-ray analysis (CGA) and neutron depth profiling (NDP). Although the primary interest is in the application of cold neutrons to these analytical methods, the development of the CCNS would increase the opportunities for scientists to conduct research in areas such as nuclear medicine and low-temperature moderator development. The latter application is particularly intriguing; at temperatures below 22 K, neutrons lose energy primarily via their interaction with rotational energy states of the moderator. Solid compounds such as frozen methane, propane, etc., appear to be quite suitable. The CCNS, in which moderators could be interchangeable with minor modifications, will allow studies to be performed with a variety of compounds.

One of the most important uses of ^{252}Cf is as implants in the treatment of hypoxic external cancerous tumors, such as cervical cancers. One of the leading medical centers in the United States using the implants is the Albert B. Chandler Medical Center at the University of Kentucky. Impressive success by the University of Kentucky in this particular application and continued research into neutron brachytherapy by other laboratories and institutions have led to a renewed interest in the use of neutron beam and boron capture therapy. The CCNS should be able to provide a neutron beam of sufficient intensity for investigation of both types of therapy. Very preliminary discussions with the University of Kentucky and the Thompson Cancer Survival Center, Knoxville, Tennessee, indicated an interest in using the proposed facility for exploratory studies and possibly building additional sources if the investigations prove fruitful.

4. SYSTEM DEFINITION

Located in the modified cell of the TURF, the CCNS consists of ten californium sources remotely manipulated and suspended in a pool of heavy water surrounding a cryostat containing LD_2. The supply of deuterium is stored in the gaseous phase. The gas is condensed with a helium refrigerator. The entire deuterium inventory is enclosed in an evacuated secondary containment, and the refrigerator is in an inert gas containment.

The facility consists of eight subsystems to be defined with respect to functional, performance, and technology requirements; operational considerations; constraints; and interfaces. The major components are shown in Fig. 4.1: (1) cryostat, (2) heavy-water tank,

ORNL-DWG 89-3807 ETD

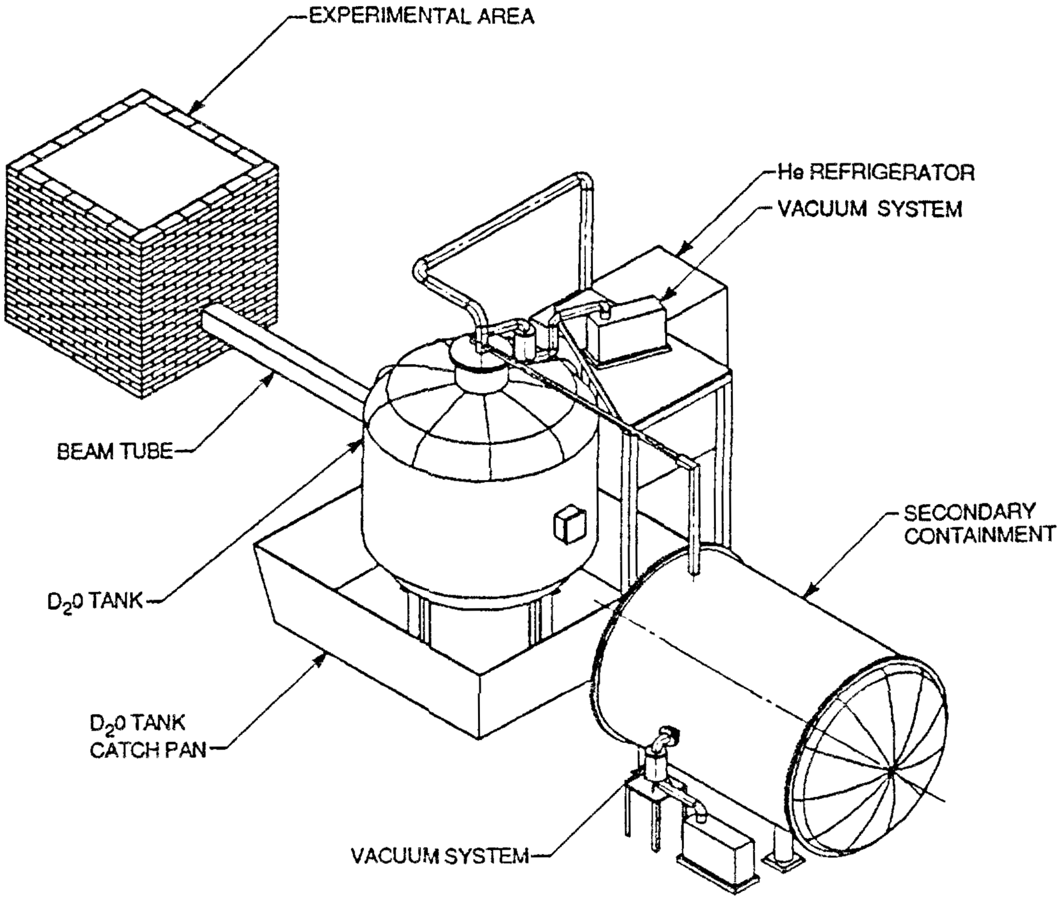


Fig. 4.1. Major components.

(3) refrigerator, (4) deuterium supply, (5) secondary containment, (6) vacuum system, (7) safety systems, and (8) facility modifications. Additional drawings and sketches of the CCNS are shown in Sect. 8.3.

4.1 CRYOSTAT

The cryostat will function to contain and insulate the LD_2. It will also be outfitted with heaters to create and maintain a deuterium bubble at the surface area of the sphere closed by the beam tube intersection. The vacuum space will be instrumented with thermocouples (see Fig. 4.2).

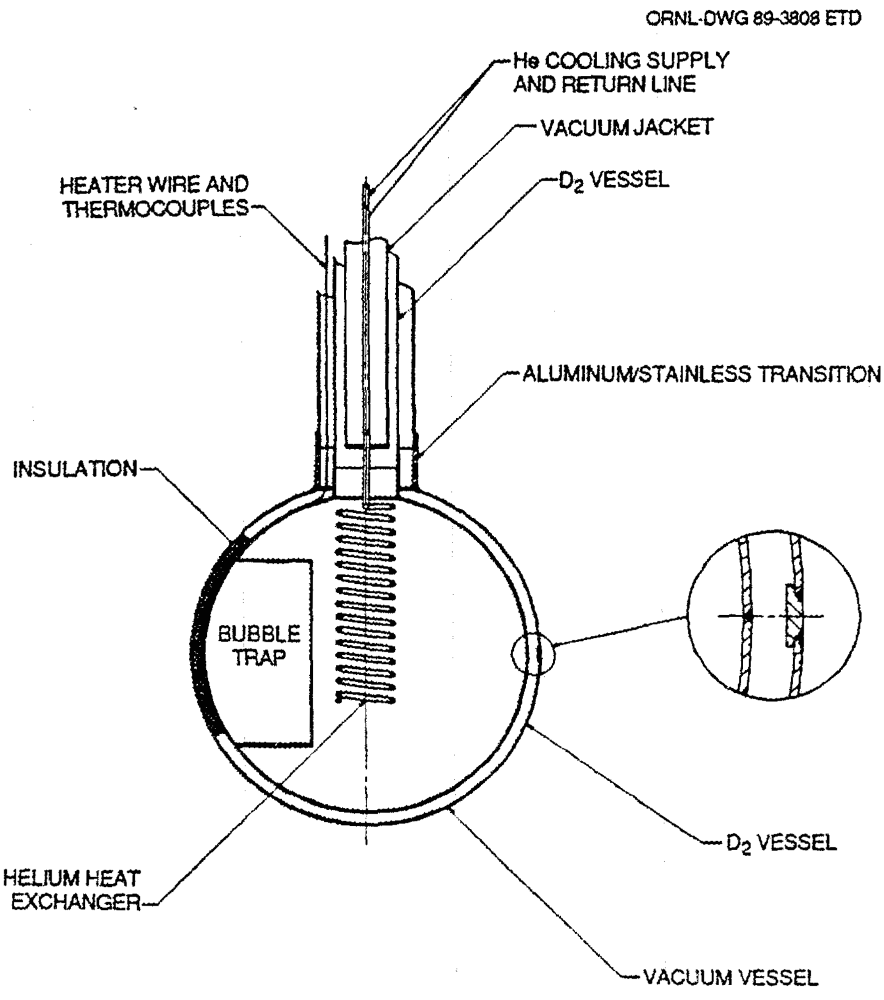


Fig. 4.2. Cryostat.

The cryostat will be of all welded construction and will be designed according to the American Society of Mechanical Engineers *ASME Boiler and Pressure Vessel Code* for a maximum internal pressure of 1.01 MPa (10 atm). Neutronic requirements dictate that the cryostat be constructed of aluminum. The vessel must interface with the D_2O tank, the beam tube, and the refrigerator.

4.2 HEAVY-WATER TANK

The heavy-water tank will contain the D_2O pool and support the beam tube and californium sources (see Fig. 4.3). It will be designed and fabricated in accordance with *ASME Boiler and Pressure Vessel Code*.

ORNL- DWG 89-3809 ETD

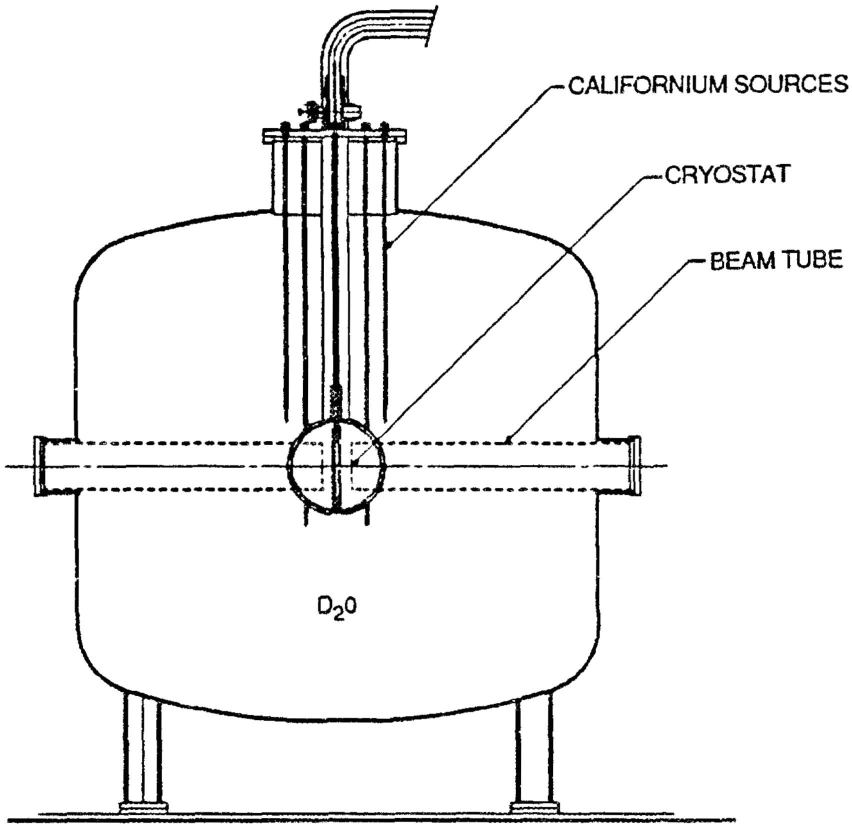


Fig. 4.3. D_2O tank.

4.3 REFRIGERATOR

The refrigerator will liquify the deuterium within 3 days and maintain the correct liquid level by absorbing the steady state heat transferred across the vacuum space and down the support tube of the cryostat. The steady-state heat load is ~5 W, and a commercially available refrigerator has been identified. The heat exchanger will be extended into the cryostat and will be fully removable. The entire refrigerator will be explosion-proof and surrounded by an inert gas.

4.4 DEUTERIUM SUPPLY

The deuterium supply tank will function to supply the cryostat with GD_2 (see Fig. 4.4). The vessel will be structurally designed for 1.01 MPa (10 atm) and shall be in accordance with the *ASME Boiler and Pressure Vessel Code*. It will incorporate supply lines, pump-out and purge lines, a pressure gage, and necessary safety equipment. It will

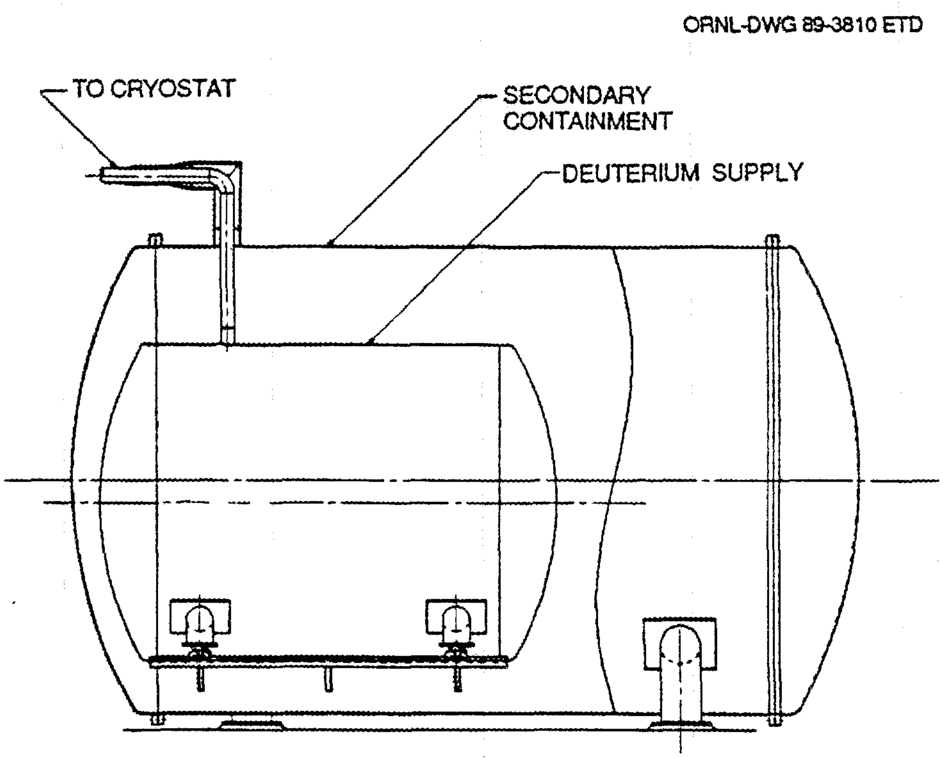


Fig. 4.4. Secondary containment.

supply GD_2 to the cryostat through an insulated line that is not restricted by valves.

4.5 SECONDARY CONTAINMENT

The secondary containment prevents an explosive mixture of hydrogen from occurring in the environment in the event of a breach of the primary containment. It shall be structurally designed for 0.202 MPa (2 atm) and will be in accordance with the *ASME Boiler and Pressure Vessel Code*. The vessel will have vacuum pump-out, purge lines, pressure gages, a hydrogen monitor, and safety equipment as required. Feedthroughs for all lines and valve stems for the deuterium supply will be assembled on a common flange on the secondary containment. Assembly of the two containments will consist of rolling the deuterium supply vessel inside the secondary containment and using an orbital welder to join the supply vessel lines to the feedthroughs and the cryostat supply line to the jacketed line.

Vacuum gages and a hydrogen monitor, located in the secondary containment, will make the operator aware of a possible breach of containment. In the event of a leak in the primary containment, the deuterium will be removed from the secondary containment by a getter pump.

4.6 VACUUM SYSTEM

For the secondary containment, the vacuum system provides an evacuated environment that includes the insulating jacket of the cryostat. The system will be designed to evacuate the secondary containment within 8 hours and to maintain an ultimate pressure of 10^{-3} Pa. After evacuation, the secondary containment will be sealed and monitored. Maintenance and repair of the pumps will not be necessary at times that would require remote handling, and the pumps will be protected from tritium contamination.

4.7 SAFETY SYSTEMS

The safety systems will ensure that deuterium cannot form an explosive mixture with air during any operating or failure mode. Furthermore, it will provide for handling tritium contamination.

The two purposes of the safety features of the primary containment are to provide a monitor and prevent leakage pressure boundary for the deuterium, and to prevent deuterium leakage into the environment through the feedthroughs. The first is achieved by an all welded design of monitoring the pressure in the primary containment, and the second is achieved by self-sealing disconnects on all feedthroughs. A rupture disk from the primary containment to an alarmed pressure gage and relief valve notifies the operator that the pressure is rising and allows him to take corrective action. Leakage into the environment is prevented by using double valves in all of the lines that feed through the secondary containment. The volume between the two valves is pressurized with an inert gas so that a leak in the valve will cause seepage of the inert gas into the vessel rather than air. To contain a leak in the heavy-water tank, a catch pan that can hold the total inventory will be located beneath the tank.

4.8 FACILITY MODIFICATIONS

The modifications to the TURF are necessary to make the two proposed Cells D and E capable of providing for safe handling of the radioactive and hazardous materials of the CCNS. To transport the californium sources that are processed at the TURF, the existing rabbit tube system will be extended from Cell C to Cell D. The rabbit tube will travel through the C-to-D cell wall and across the north and east sides of cell D to the southeast corner. Two Series E manipulators that can access an area of 2.4×4.9 m^2 and are centered on the heavy-water tank will be installed on the east wall of cell D. A source preparation table for attaching and removing the sources from the support rods will be located in the manipulator area.

The remote handling features will accommodate all required operation for the CCNS. Two zinc bromide windows are required to allow operation of the manipulators. The other window locations in the cell will be filled with barytes brick. For other remotely operated components, such as air-actuated valves, an instrument air system will be installed. A new penetration in the wall between cells D and E will be necessary for the beam tube. Radiation detectors and interlock controls will be installed in both D and E Cells, as well as hydrogen monitors and flame detectors. The monitoring systems will be located in a local control station outside the hot cells.

5. PRELIMINARY ASSESSMENT

5.1 PROJECT RISK

Three primary hazards were identified in the hazard analysis of this project:

1. neutron-radiation exposure hazard,
2. deuterium fire/explosion hazard, and
3. airborne release and ingestion of tritium.

In the absence of a quantitative hazard and probability analysis, the consequences of these hazards and their associated probabilities will be estimated with guidance from DOE Order 5481.1B to assess the total project risk.

The neutron-radiation exposure hazard would affect primarily the operators for the project, as well as operating personnel in adjacent cells. Therefore, the hazard rating for this case would probably be low. By use of suitable shielding, the probability of excessive neutron irradiation can be made extremely low ($10^{-6} < p < 0.001$), leading to a total risk category of "extremely low."

The deuterium fire/explosion hazard, with the potential explosive power of 81 kg (180 lb) of TNT, would affect the total building population, as well as other on-site and possibly off-site personnel, by causing structural damage to the building and by release of tritium and ^{252}Cf into the air. Therefore, the hazard rating for this scenario would be either "high" or "extremely high." By the use of secondary containment for the deuterium and the provision for adequate ventilation and fire prevention measures, the probability of a deuterium fire/explosion can be made low ($0.001 < p < 0.01$), leading to a total risk category of "low."

The tritium exposure and ingestion hazard would consist of either tritium gas or tritiated water vapor and would affect primarily the on-site operators; therefore, the hazard rating for this situation would probably be "low." By the same measures taken for containment and ventilation to prevent the fire/explosion hazard, the probability for this hazard can be made "extremely low" ($10^{-6} < p < 0.001$), leading to a total risk category of "extremely low."

Thus, the total project risk is governed by the deuterium fire/explosion hazard and is estimated to be "low."

5.2 SAFETY, FIRE, AND HEALTH

As a preliminary to ensuring the safety of this project, the requirements of DOE Order 6430.1A, *General Design Criteria*, must be met. In addition to the general requirements for all DOE facilities, the criteria applicable to "special facilities" found in Div. 13, Sect. 1300, and, in particular, the criteria found in Sect. 1325, "Laboratory Facilities (Including Hot Laboratories)" must also be met. The primary requirements of this section are for three levels of material confinement; for control and monitoring of solid, liquid, and gaseous waste; and for decommissioning plans for the facility.

During the design phase of the project, a "safety assessment" for the project must be completed according to the requirements of DOE Order 5481.1B and Sect. 1300-2 of DOE Order 6430.1A. This analysis will quantify the hazards inherent in the project, and determine the appropriate level of safety documentation required for the project. If the project hazard level is determined to be "medium" or "high," a Preliminary Safety Analysis (PSAR) must be completed during the design phase before the start of construction that identifies the safety class items in the design and estimates the overall project risk. Then, at completion of construction and before the start of operation, a Final Safety Analysis (FSAR) must be prepared and approved.

The requirements for fire protection are listed in Sect. 1530 of DOE Order 6430.1A and DOE Order 5480.7. The criterion for fire protection design is an "improved risk" level of fire protection. An automatic fire suppression system will be required by Criterion I, Sect. 1530-2.3.2, because the "maximum possible fire loss" would exceed $1 million. Additional fire protection requirements may be specified by ORNL Fire Protection Engineering.

Adequate shielding against neutron-radiation exposure will be required, both to protect the facility operators and to protect operators in adjacent cells.

5.3 QUALITY ASSURANCE

Quality assurance (QA) will be addressed by the QA Checklist and the QA Assessment/Plan. This documentation will serve to address the impact of quality failures on the project and identify safeguards that should be in place to prevent them. The plan will conform to the ORNL QA Manual, which addresses the ANSI/ASME Quality Standard NQA-1.

5.4 ENVIRONMENT

Environmental documentation will be prepared in accordance with the Atomic Energy Act of 1954 as amended. Compliance will be achieved through the use of the Environmental ALARA (As Low As Reasonable Achievable) Memorandum.

5.5 RELIABILITY, AVAILABILITY, AND MAINTENANCE

A reliability, availability, and maintenance (RAM) plan will be implemented. The objective of the plan will be to ensure that the proper emphasis is placed on reliability during the design and operation of the CCNS. Applicable issues are that the components and systems

1. will work when needed,
2. will work long enough to perform the intended function,
3. will be designed so that the operator can compensate for failures or malfunctions and accomplish the functional objective or shut down safely in spite of malfunction,
4. will have the cost and penalties associated with failure weighed against the increased cost and time required to reduce failure probability, and
5. will have routine maintenance schedules that are not difficult or time-consuming and are at intervals that allow for maximum safe operating periods.

The reliability of the components shall be confirmed by calculations (stress and heat transfer), by testing (leak and pressure), and by specification.

6. PROJECT SCHEDULE

The project schedule is shown in Fig. 6.1. This schedule reflects a 3-year effort from beginning of the project to facility operation based on the necessary funding for support as called for in the cost estimate (Sect. 7). The schedule is very preliminary; part of the conceptual design effort should be to refine the schedule and introduce a Work Breakdown Structure.

One of the largest uncertainties about the schedule is the time required to obtain safety and environmental approvals. A considerable effort has been scheduled in these areas, but the evolving nature of the regulations creates concern and uncertainty.

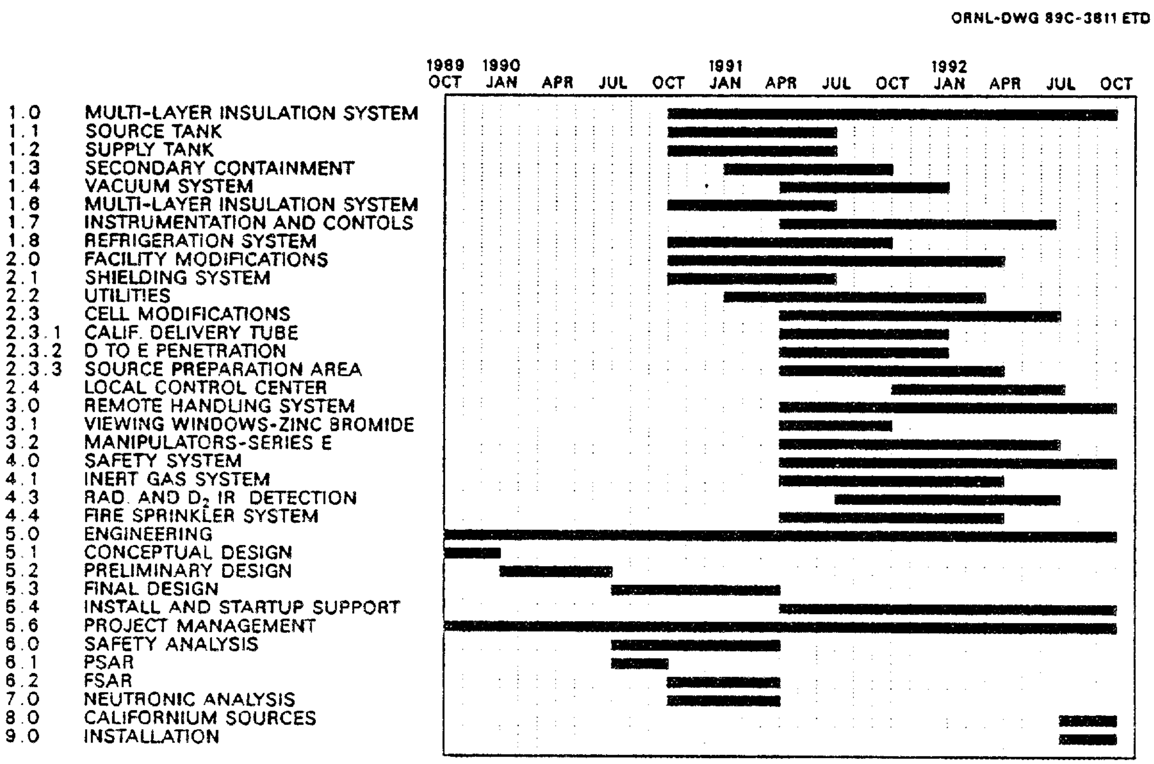


Fig. 6.1. CCNS schedule.

7. SUMMARY OF COST ESTIMATE

A feasibility level cost estimate has been prepared to demonstrate some of the cost considerations for the CCNS. This estimate was based on listings by several of the design disciplines and compiled by Engineering Estimating. The results are summarized in Table 7.1, and the memorandum is attached as reference data in Appendix B.

Table 7.1. Summary of cost estimate for CCNS at TURF

CCNS device	$1,281,000
Modifications to facility (biological shielding)	750,000
Operational facility modifications	970,000
Refrigerator systems piping[a]	65,000
	$3,066,000
Allow for uncertainties	250,000
TOTAL	$3,316,000
Engineering (35%)	1,160,000
Contingency (35%)	1,566,000
FSAR	300,000
Neutronic calculations	180,000
Californium sources	30,000
GRAND TOTAL	$6,552,000

[a]Note: Reference AES BM - J. P. Schubert

The total cost resulting from this study is $6.6M. The CCNS device cost is approximately $2.2M, including engineering and contingency. The balance of the costs is associated with TURF modifications, a helium refrigerator, and required analysis and documentation.

A major portion of the costs associated with the facility will be the modifications to the enclosure for the experiment. Use of the TURF seems to be logical, because of the proximity of the sources, availability of personnel and procedures, and existing containment. However, during the conceptual design, the cost impact of locating the facility in a new dedicated building, or possibly in a reactor pool, should be addressed.

APPENDIX A

D. L. Henderson, R. G. Alsmiller, *Preliminary One-Dimensional Neutronics Scoping Study for Californium-252 Cold Neutron Source Moderating Device*, Letter Report, September 1988.

Preliminary One-Dimensional Neutronics Scoping Study for a Californium-252 Cold Neutron Source Moderating Device

D. L. Henderson
R. G. Alsmiller, Jr.

Engineering Physics and Mathematics Division

September 1988

ABSTRACT

One-dimensional neutron transport calculations have been performed for a proposed Californium Cold Neutron Source experimental facility. The computations indicate that a peak cold neutron flux (flux below 10 meV) of 1.4×10^{13} neutrons/m^2-s can be attained from a 500 mg Californium neutron source. The cold neutron exit (leakage) current from the spherical cryostat containing the liquid deuterium is approximately 2.2×10^{12} neutrons /m^2-s.

1. INTRODUCTION

The Californium-252 Cold Neutron Source (CCNS) is a proposed experimental facility based on nonreactor and nonaccelerator technology for the purpose of producing cold neutrons for possible applications to: a) capture gamma-ray analysis (CGA) and neutron depth profiling (NDP), b) basic research in the areas of neutron optics (neutron focussing, beam guide tubes) and low temperature moderator development (solid and liquid moderators), c) a cold neutron user's training facility, and d) a development facility for new innovative cold neutron source designs (geometry, distance from cold source to experiments.)[1] The spontaneous fission neutrons from Californium-252 (Cf-252) serve as the neutron source for the facility. The proposed design calls for up to 500 mg of Cf-252, which would generate approximately 10^{12} neutrons/s.

The preliminary design of the CCNS facility has a liquid deuterium (LD_2) filled, vacuum-jacketed, cryostat submerged within a cylindrical shaped heavy water (D_2O) moderator/reflector tank as portrayed in Fig. 1. During operation the LD_2 will be maintained at a temperature of 20 K and the D_2O thermal moderator at room temperature. Penetrating the reflector tank will be one, or perhaps two radially oriented rectangular neutron guide tubes which will extend to the surface of the liquid deuterium cryostat. Ten 50 mg Cf-252 sources encapsuled in standard platinum and stainless steel capsules are arranged on two levels around the cryostat, five to a level. The Cf-252 capsules will be housed within sleeves or will be attached to the end of rods. This allows for easy removal of the capsules for reduction of the source intensity, storage and the exchange of capsules. The preliminary design has a spherical shaped LD_2 cryostat which may or may not have a cavity region positioned before the radial neutron guide tubes as is the case for the second cold source in operation at the Institute Max Von Laue-Paul Langevin (ILL) facility in Grenoble, France.[2,3] Figure 1 depicts the LD_2 cryostat with a cavity region, two neutron guide tubes and the Cf-252 neutron source positions.

The organization of this paper is as follows: Sect. 2 contains a brief description of the transport codes, data libraries, and calculational model used for the one-dimensional computations. A discussion of the results is presented in Sect. 3. A brief summary with concluding remarks is given in Sect. 4. Results computed for an alternative Californium Cold Neutron Source configuration using both light water (H_2O) and heavy water (D_2O) thermal moderators are contained in Appendix A of this report.

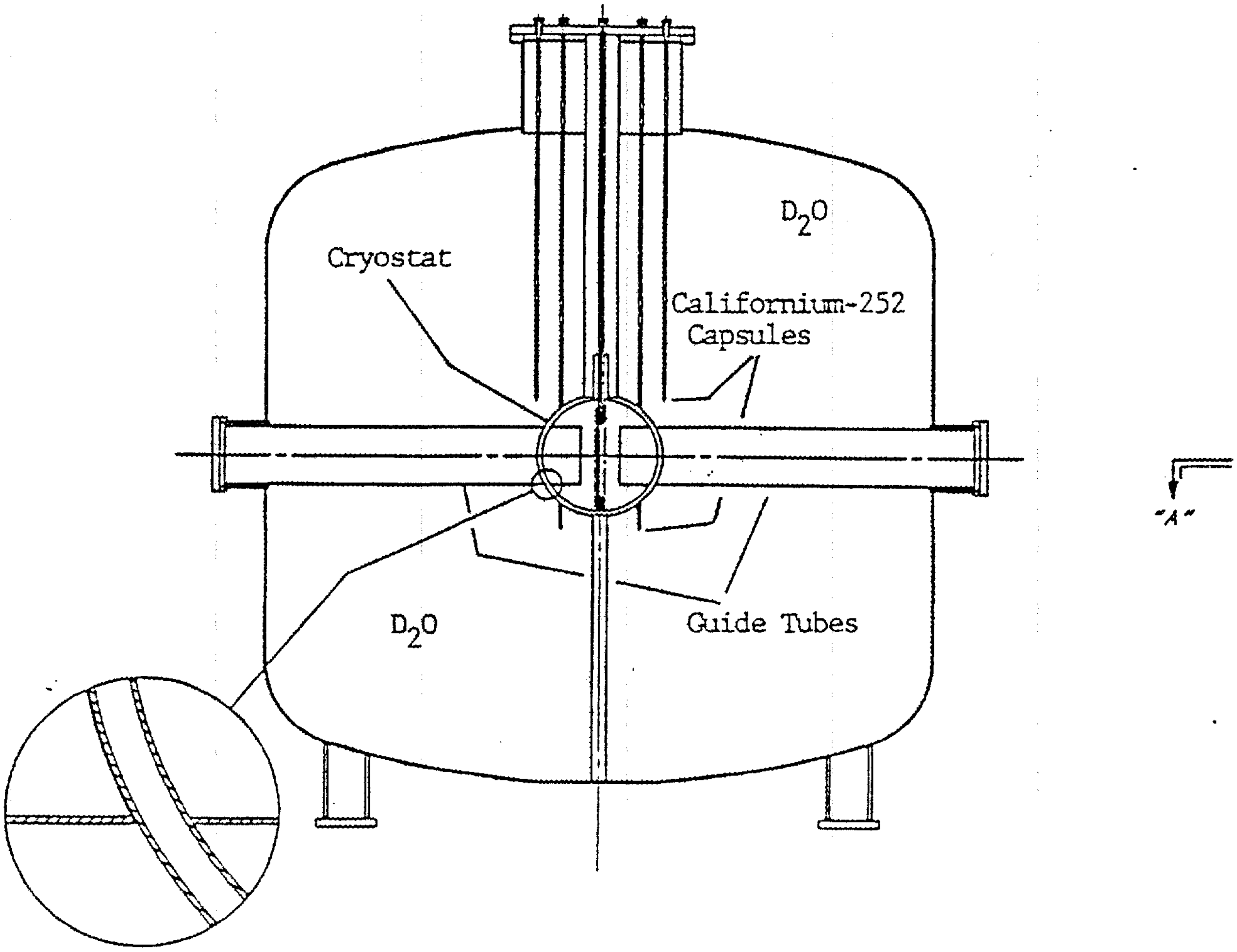


Fig 1. A sketch of the D_2O moderator/reflector tank, liquid deuterium cryostat, neutron guide tubes and Californium-252 neutron source capsules (housed within sleeves or attached to the end of rods).

2. CALCULATIONAL MODEL

The transport of neutrons from the Cf-252 neutron source was performed with the one-dimensional, multigroup, diffusion accelerated, neutral particle transport code, ONEDANT.[4] The cylindrical shaped D_2O moderator/reflector tank and LD_2 cryostat were modelled in spherical geometry. A cavity region within the LD_2 cold source moderator was not considered (an off-center asymmetric cavity region cannot be modelled in one-dimensional geometry). The Cf-252 source capsules are modelled as a 10 mm thick spherical shell source positioned 100 mm from the cryostat within the D_2O thermal moderator/reflector which surrounds the LD_2 moderator. A schematic of the Cf-252 cold neutron source calculational model is depicted in Fig. 2. The neutron transport was performed using a 39-neutron energy group ANSL-V data cross section library.[5,6] There are 18 groups below 0.397 eV and 22 of the liquid deuterium cross section groups contain upscattering data. A P_3 Legendre expansion of the differential scattering cross section and a S_{16} angular quadrature are used in the computations. The energy boundaries of the 39-energy group data library are given in Table B.1 of Appendix B. The spontaneous fission spectrum for the Cf-252 source neutrons was computed from the evaluated fission spectrum data given in Ref. 7. A density of 0.1713 g/cm^3 and a 20% void fraction to account for nuclear heating (presence of deuterium vapor) were used in the calculations for LD_2 and a density of 1.105 g/cm^3 for D_2O. Table B.2 in Appendix B gives the composition of the Aluminum-6061-T6 used in the calculations.

The primary quantities of interest in the calculations are the peak cold neutron flux within the LD_2 moderator, the cold neutron flux in and cold neutron exit (leakage) current from the aluminum cryostat walls. Also of interest is the position of the peak thermal neutron flux relative to the LD_2 cryostat. The calculations are normalized to one source neutron. Thus, to obtain the values corresponding to 500 mg of Cf-252, the results must be multiplied by the source strength of 10^{12} neutrons/s.

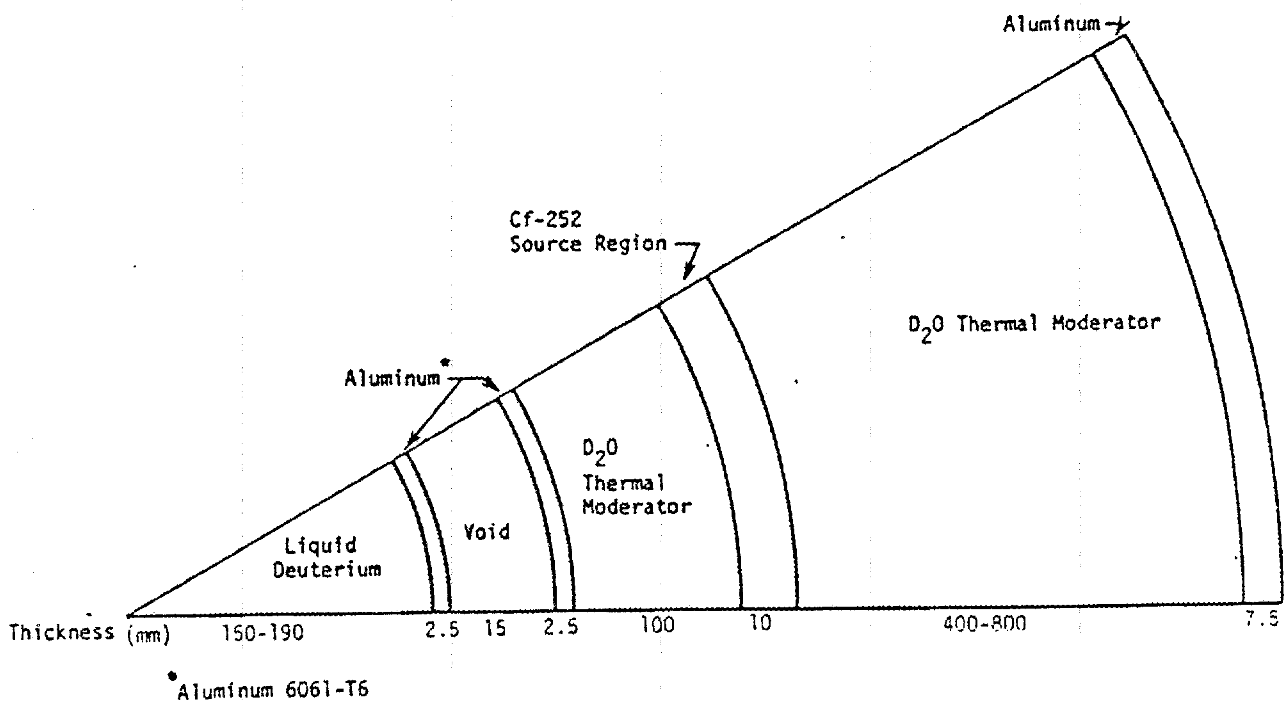


Fig. 2. A schematic of the Californium-252 Cold Neutron Source Calculational Model for a LD_2-D_2O-Cf-252 source-D_2O configuration.

3. DISCUSSION OF RESULTS

Three cases using different combinations of D_2O thermal moderator/reflector and LD_2 moderator thicknesses are considered. Case 1 has a 0.19 m radius LD_2 region and a total D_2O thickness of 0.50 m. For Case 2 the total D_2O reflector thickness is increased to 0.90 m. Case 3 has a 0.15 m radius LD_2 region and a total D_2O reflector thickness of 0.50 m. For all cases the Cf-252 spherical shell source region is positioned 0.10 m from the cryostat wall.

Figure 3 shows the neutron fluxes for several energy groups in the thermal energy range, 400 meV < E < 10 meV, for Case 2. We note that the thermal neutron fluxes peak within the 0.10 m D_2O region between the LD_2 moderator (cold neutron source region) and the Cf-252 source shell. That is, the thermal neutron fluxes peak near the LD_2 moderator. This is desirable as the more efficient the thermal neutron moderator is in thermalizing neutrons and the higher the thermal neutron intensity near the LD_2 moderator, the greater the cold neutron exit current (leakage) intensity from the LD_2 moderator. This is in contrast to an alternative Cf-252 cold neutron source configuration (see Fig. A2 in Appendix A) where the thermal neutron fluxes peak further from the LD_2 cold neutron source region which in turn results in a lower flux within and neutron exit current (leakage) from the LD_2 moderator. Thus, the positioning of the LD_2 moderator relative to the peak thermal neutron fluxes is quite important. The neutron fluxes for several energy groups in the cold energy range (below 10 meV) are shown in Fig. 4. The cold fluxes peak at the center of the LD_2 moderator. This is as one would expect given that the cold source is surrounded by a spherical symmetric thermal neutron source.

Table 1 presents the integrated cold neutron flux (integration over all energy groups below 10 meV) and cold-to-fast flux ratio results per source neutron at the center of the LD_2 cold neutron source region. The cold-to-fast ratio is defined as

$$\text{Ratio} = \frac{\sum_{g=N+1}^{39} \phi_g}{\sum_{g=1}^{N} \phi_g} \qquad (1)$$

where N = group index for which the energy $E \geq 10$ meV. (Note: increasing group number corresponds to a decrease in energy.) One notes that the peak cold neutron flux and peak cold-to-fast ratio is obtained for an LD_2 moderator radius of 0.19 m and a total D_2O moderator/reflector thickness of 0.90 m (Case 2). Multiplying the peak cold neutron flux by the 500 mg Cf-252 source strength of 10^{12} neutrons/s, we obtain a peak cold neutron flux within the LD_2 cold neutron source region of 1.4×10^{13} neutrons/m^2-s. The cold neutron flux and cold-to-fast ratio results for the cryostat wall (i.e. near the entrance to the guide tube) per source neutron are given in Table 2. The cold neutron flux has dropped over the value at the cold source center by a factor of approximately 2.7 to 2.9. An indication of this drop in the cold neutron flux is given by the group cold neutron fluxes shown in Fig. 4. The flux values both for the peak flux and the flux within the cryostat wall are approximately a factor of 10 larger than for the values given in Appendix A for the alternative CCNS configuration. Table 3 gives the neutron exit current (leakage) from the cryostat and the cold-to-fast current ratio results. Provided the guide tubes are in contact with the LD_2 cryostat, the neutron exit current values give an estimate of the neutron flow into the guide tube(s). Multiplying the current value by the Cf-252 source strength of 10^{12} neutrons/s, we obtain a cold neutron exit (leakage) current of 2.2×10^{12} neutrons/m^2-s.

Figure 5 displays the individual group cold-to-fast exit current ratios versus wavelength for all three cases. The individual group cold-to-fast ratio is defined as

$$\text{Ratio} = \frac{\phi_g}{\sum_{g=1}^{N} \phi_g} \qquad (2)$$

where N = group index for which the energy E $\geq$ 10 meV. These values are quite low as are the integrated values given in Tables 1 through 3. These low values are the result of modelling the Cf-252 as a spherical shell. As we note from Fig. 1, the Cf-252 50 mg neutron sources are not in alignment with the neutron beam guide(s) (whether directly or positioned behind the LD_2 moderator in direct alignment). Thus, we expect the cold-to-fast current ratios to be larger than the values presented in Tables 1 through 3 and displayed in Fig. 5. To obtain a more accurate estimate of the current ratios, multidimensional transport calculations would be required.

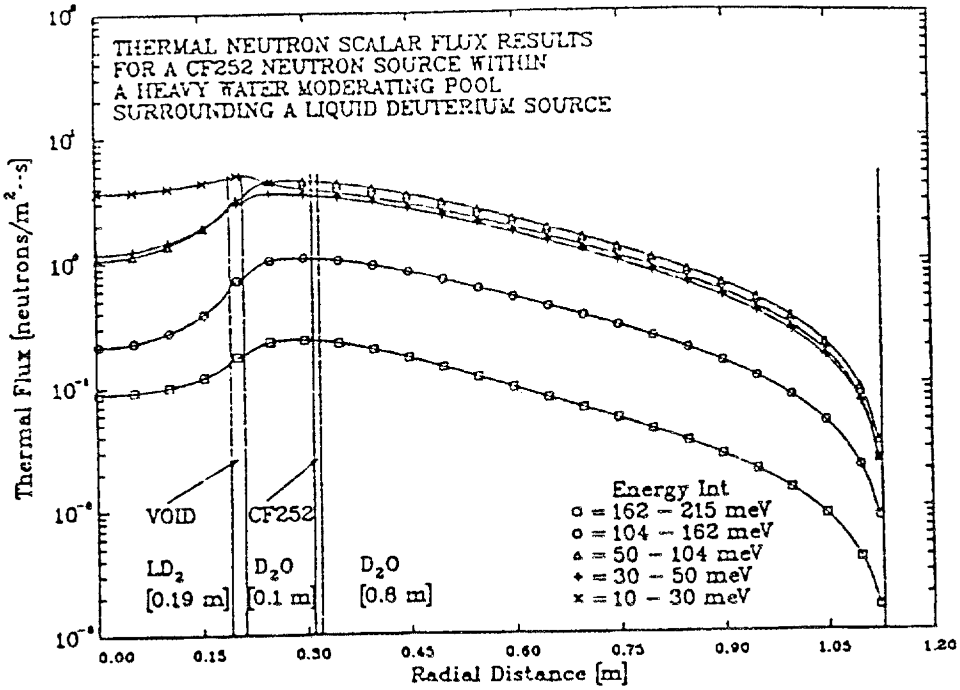


Fig. 3. The neutron fluxes for several energy groups in the thermal energy range, 400 meV to 10 meV, for Case 2.

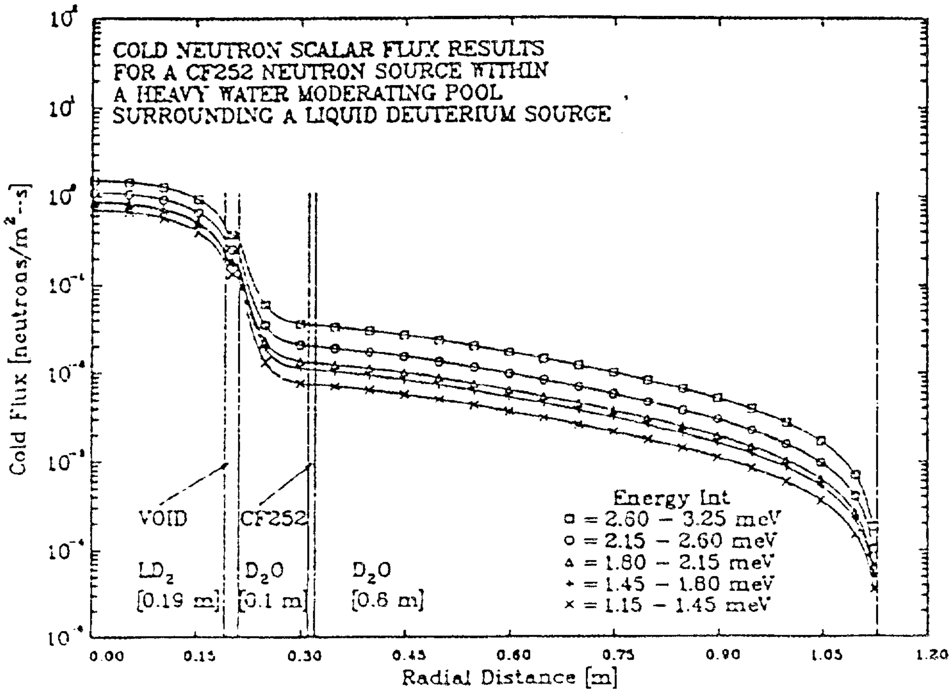


Fig. 4. The neutron fluxes for several energy groups in the cold energy range (less than 10 meV) for Case 2.

Table 1

Cold Neutron Flux and Cold-to-Fast Flux Ratio Results at the Center of the Cold Source (per Source Neutron)

Case	Cold Flux (neutrons/m^2-s)	Cold/Fast Ratio
1) LD_2[0.19m]-D_2O[0.50m]	11.05	1.58
2) LD_2[0.19m]-D_2O[0.90m]	14.32	1.72
3) LD_2[0.15m]-D_2O[0.50m]	10.65	1.05

Table 2

Cold Neutron Flux and Cold-to-Fast Flux Ratio Results Within the Cryostat Wall (per Source Neutron)

Case	Cold Flux (neutrons/m^2-s)	Cold/Fast Ratio
1) LD_2[0.19m]-D_2O[0.50m]	3.85	0.34
2) LD_2[0.19m]-D_2O[0.90m]	4.99	0.36
3) LD_2[0.15m]-D_2O[0.50m]	3.97	0.28

Table 3

Cold Neutron Current and Cold-to-Fast Current Ratio Results for the Current Exiting the Cryostat (per Source Neutron)

Case	Cold Current (neutrons/m^2-s)	Cold/Fast Ratio
1) LD_2[0.19m]-D_2O[0.50m]	1.68	0.83
2) LD_2[0.19m]-D_2O[0.90m]	2.19	0.89
3) LD_2[0.15m]-D_2O[0.50m]	1.76	0.64

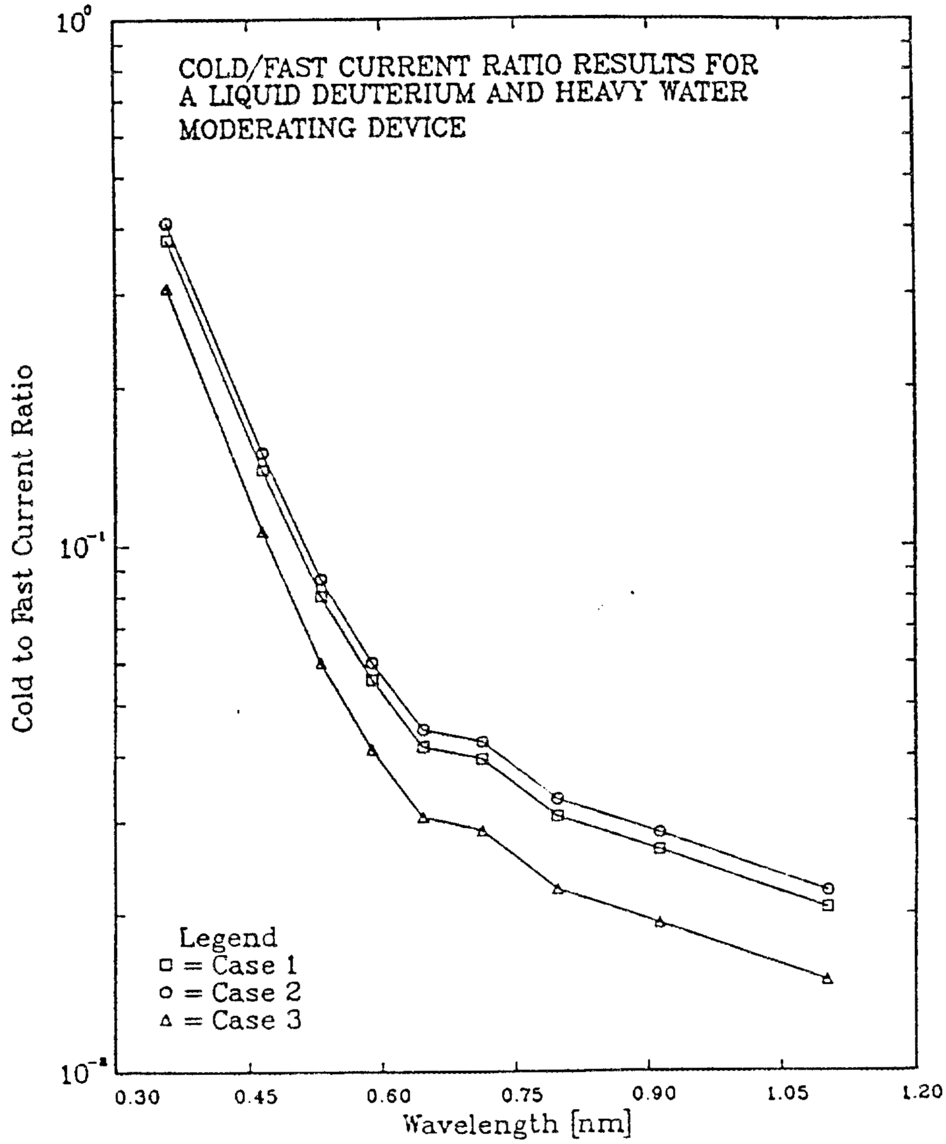


Fig. 5. The individual group cold-to-fast exit current ratios versus wavelength for all three cases.

4. SUMMARY AND REMARKS

In support of the Californium Cold Neutron Source proposal, one-dimensional neutron transport calculations have been performed on the preliminary design of the experimental facility in order to determine the peak cold neutron flux (flux below 10 meV) within the LD_2 moderator (cold neutron source). The computations indicate that a peak cold neutron flux of 1.4×10^{13} neutrons/m^2-s can be attained for a 500 mg Californium source and for the case of a 0.19 m radius spherical LD_2 moderator and a total D_2O thickness of 0.90 m. The cold neutron flux within the cryostat wall is 5×10^{12} neutrons/m^2-s. The cold neutron exit (leakage) current from the cryostat is approximately 2.2×10^{12} neutrons/m^2-s. These values are approximately a factor of 10 larger than for the results of an alternative CCNS calculational model examined in Appendix A.

The following are a few general remarks regarding the calculations:

a) The distance between the Californium-252 neutron source and the LD_2 cryostat has not been optimized. We are assuming that there is an optimum distance that will enhance the thermal neutron flux near the LD_2 cryostat and lead to an increase in the cold neutron flux and current. Thus, optimization calculations should be performed.

b) The optimum shape of the LD_2 moderator may not be a sphere or cylinder due to the asymmetry of the LD_2 moderating device to guide tube alignment.

c) The Cf-252 cold neutron source problem can basically be considered as a problem in neutron slowing down. A simplified view of the problem is: we have a MeV source whose emitted neutrons must be converted to neutrons (cold neutrons) in the less than 10 meV energy range. Thus, we are looking for materials which have excellent moderation properties in the MeV, keV, eV and meV energy ranges. Figure 6 depicts a simple illustration of the slowing down process. Perhaps we need to reexamine the materials used. An addition of another material or combination of materials may enhance the fraction of cold neutrons.

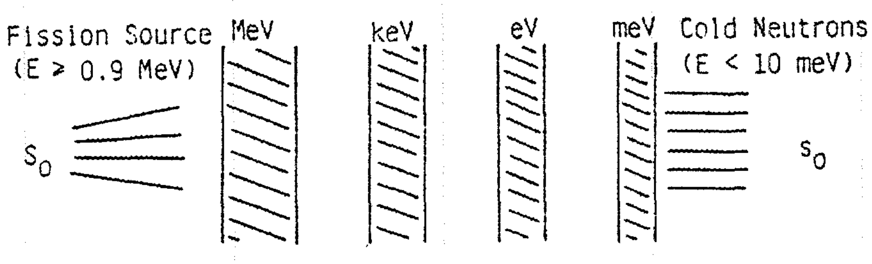


Fig. 6. Simplified illustration of the slowing down process for MeV neutrons to cold neutrons (less than 10 meV).

5. Appendix A

In the main body of this paper, the CCNS was modelled by placing a Cf-252 spherical shell neutron source 0.10 m from a 0.19 m radius LD_2 moderator. The source region was surrounded by a D_2O reflector region (see Fig. 2). In this Appendix we will examine the cases of a Cf-252 source region surrounded by a D_2O or H_2O thermal moderator which in turn is surrounded by a LD_2 moderator shell. The D_2O thermal moderator shells examined are 0.21 m and 0.27 m thick. For the H_2O thermal moderator, the thicknesses are 60 mm and 90 mm. Liquid deuterium moderator shells of 0.12, 0.15, 0.18, 0.21 and 0.24 m thickness are examined. A schematic of the calculational model is depicted in Fig. A1.

The neutron fluxes for several energy groups in the thermal energy range for the case of a 0.21 m thick D_2O shell and a 0.21 m thick LD_2 shell are depicted in Fig. A2. We note that the thermal fluxes peak at the D_2O - void region boundary. As mentioned in Results, we prefer having the peak thermal flux near the LD_2 moderator as this enhances the cold neutron flux and exit (leakage) current. The neutron fluxes for several cold energy groups (below 10 meV) are displayed in Fig. A3. The thermal and cold neutron fluxes for the case of a 60 mm thick H_2O shell and a 210 mm thick LD_2 shell are depicted in Figs. A4 and A5. Table A1 presents the peak integrated cold neutron flux (integration over all energy groups below 10 meV) and cold-to-fast flux ratio results for all the D_2O and H_2O moderator cases. In general, the peak flux values are approximately a factor of 10 lower than the flux values presented in Table 1. The cold neutron flux and cold-to-fast flux ratios within the cryostat walls are given in Table A2. The cold neutron current and cold-to-fast current ratio results are given in Table A3. One notes that the D_2O results are approximately a factor 18.5 to 21 lower than the 0.19 m radius LD_2 and 0.90 m total D_2O moderator results of Table 3. A comment on the use of H_2O as a moderator; though H_2O is an excellent moderator, its large absorption cross section at low energies limits its use in large quantities for neutron thermalization in the CCNS.

The cold-to-fast neutron exit (leakage) current ratio results versus wavelength for the D_2O and H_2O moderator cases are depicted in Figs. A6 through A9. For the calculational model of Fig. 2 used for the CCNS analysis in the main body of this paper, it was mentioned that the cold-to-fast current ratio results are overestimated, that is, the fast neutron component that the guide tubes would see is overestimated due to the Cf-252 source being modelled as a spherical shell. For the values presented in Figs. A6-A9 this is not the case as the Cf-252 source is located at the center of the CCNS device.

As the above results indicate, the peak neutron flux results for the calculational model considered in Fig. A1 are approximately a factor of 10 lower than the values computed from the model depicted in Fig. 2. In addition, the neutron exit (leakage) current are approximately a factor of 20 lower than those computed from the model in Fig. 2. Thus, the CCNS configuration depicted in Fig. 2 is preferred.

The CCNS configuration depicted in Fig. 2 also has several other advantages: a) easier to manufacture a spherical cryostat than a spherical shell cryostate, b) the inventory of LD_2 is reduced, and c) the more compact spherical cryostat design allows for easy removal and exchange of the cryostat.

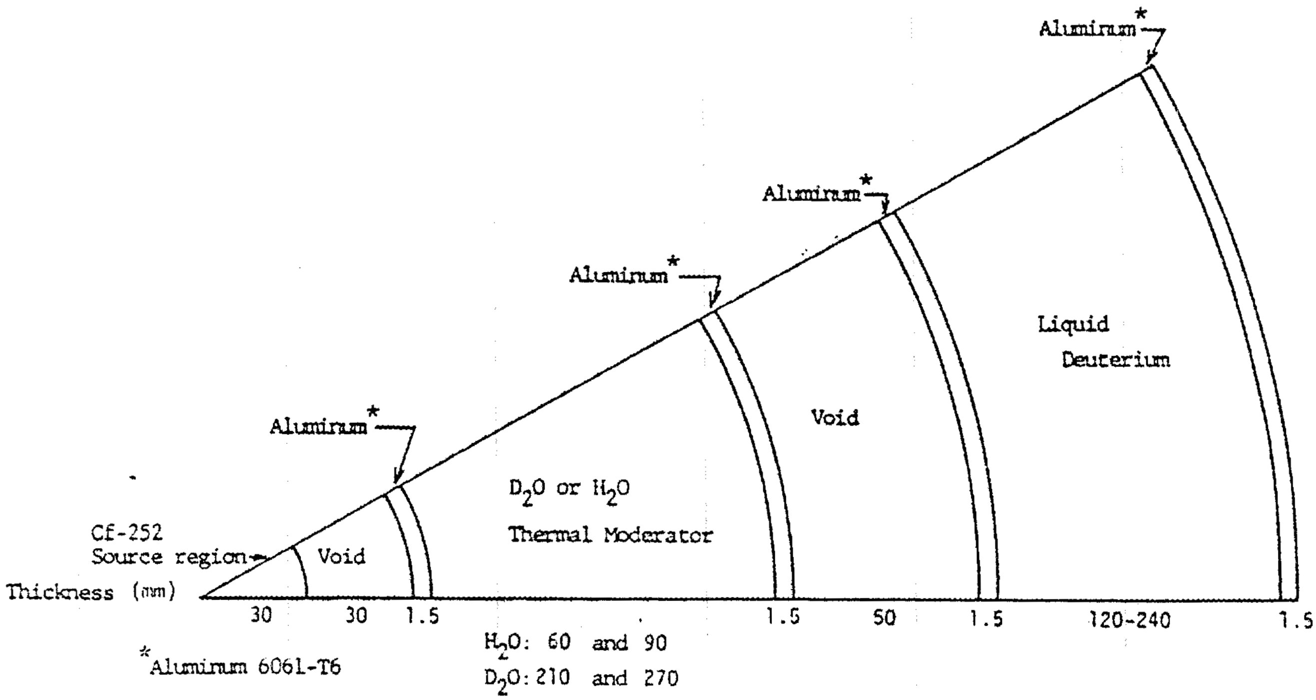


Fig. A1. A schematic of the Californium-252 Cold Neutron Source Calculational Model for a Cf-252-D_2O-(H_2O)-LD_2 configuration.

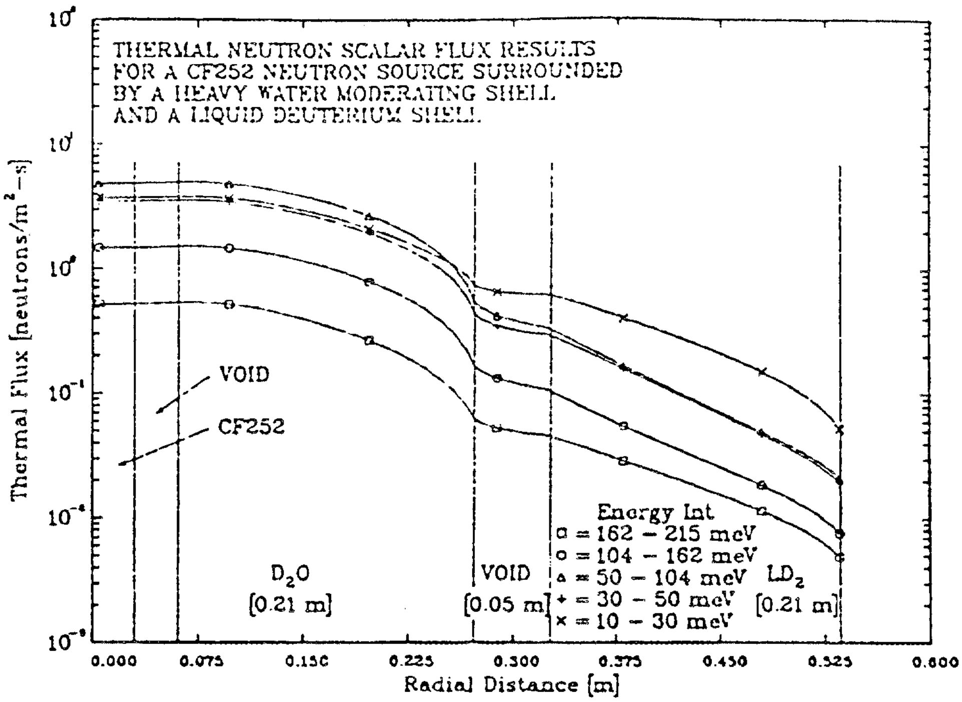
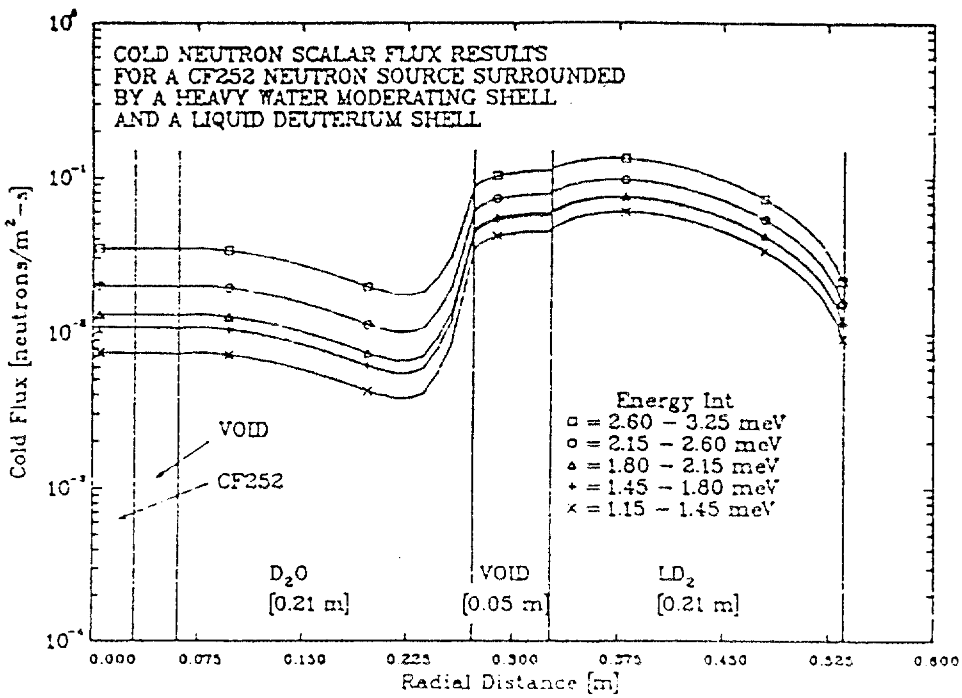
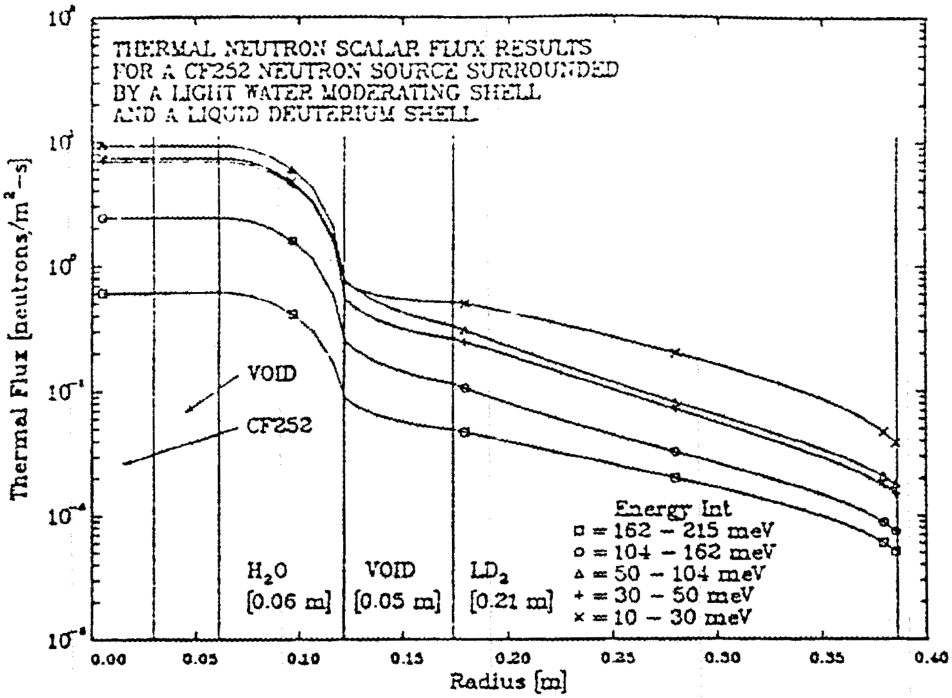


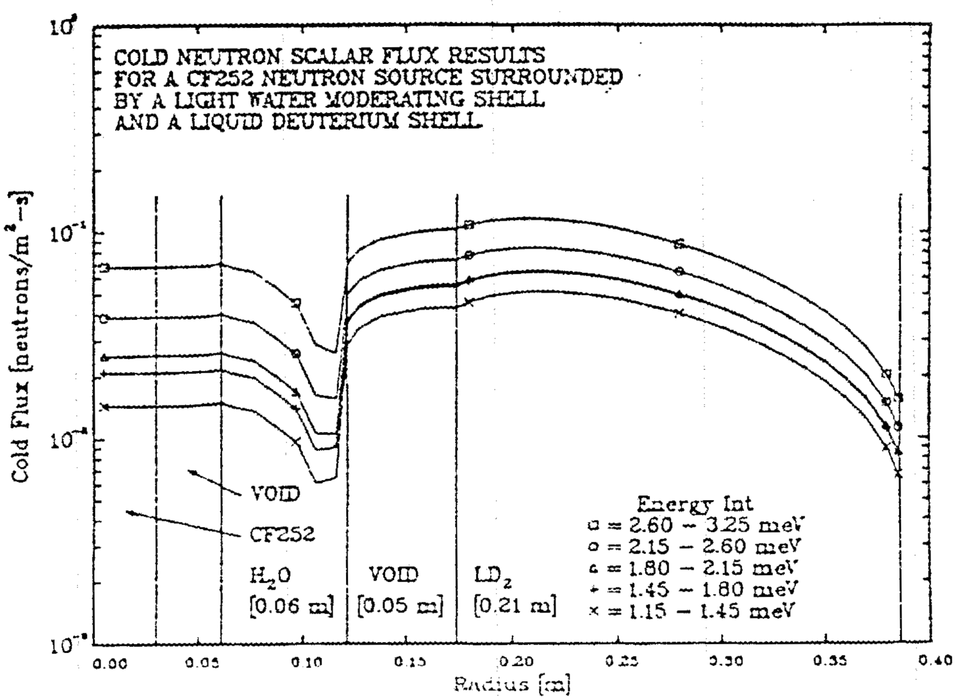
Fig. A2. The neutron fluxes for several energy groups in the thermal energy range, 400 meV to 10 meV, for the case of 0.21 m thick D_2O and 0.21 m thick LD_2 shells.



A3. The neutron fluxes for several energy groups in the cold energy range (less than 10 meV) for the case of 0.21 m thick D_2O and 0.21 m thick LD_2 shells.



A4. The neutron fluxes for several energy groups in the cold energy range (400 meV to 10 meV) for the case of 0.06 m thick H_2O and 0.21 m thick LD_2 shells.



A5. The neutron fluxes for several energy groups in the cold energy range (less than 10 meV) for the case of 0.06 m thick H_2O and 0.21 m thick LD_2 shells.

Table A1

Peak Cold Neutron Flux and Cold-to-Fast Flux Ratio Results Within the LD_2 Moderator (per Source Neutron)

Case	Cold Flux [neutrons/m^2-s]	Cold/Fast Ratio
1) D_2O[0.21m]-LD_2[0.12m]	0.68	0.41
2) D_2O[0.21m]-LD_2[0.15m]	0.89	0.49
3) D_2O[0.21m]-LD_2[0.18m]	1.10	0.63
4) D_2O[0.21m]-LD_2[0.21m]	1.22	0.72
5) D_2O[0.21m]-LD_2[0.24m]	1.53	0.88
6) D_2O[0.27m]-LD_2[0.12m]	0.67	0.58
7) D_2O[0.27m]-LD_2[0.15m]	0.87	0.69
8) D_2O[0.27m]-LD_2[0.18m]	1.06	0.88
9) D_2O[0.27m]-LD_2[0.21m]	1.26	0.98
10) D_2O[0.27m]-LD_2[0.24m]	1.45	1.19
11) H_2O[0.06m]-LD_2[0.12m]	0.62	0.15
12) H_2O[0.06m]-LD_2[0.15m]	0.80	0.18
13) H_2O[0.06m]-LD_2[0.18m]	0.98	0.23
14) H_2O[0.06m]-LD_2[0.21m]	1.17	0.27
15) H_2O[0.06m]-LD_2[0.24m]	1.36	0.33
16) H_2O[0.09m]-LD_2[0.12m]	0.48	0.21
17) H_2O[0.09m]-LD_2[0.15m]	0.61	0.27
18) H_2O[0.09m]-LD_2[0.18m]	0.74	0.32
19) H_2O[0.09m]-LD_2[0.21m]	0.87	0.39
20) H_2O[0.09m]-LD_2[0.24m]	1.01	0.44

Table A2

Peak Cold Neutron Flux and Cold-to-Fast Flux Ratio Results at the Edge of the Cold Source (per Source Neutron)

Case	Cold Flux [neutrons/m^2-s]	Cold/Fast Ratio
1) D_2O[0.21m]-LD_2[0.12m]	0.17	0.39
2) D_2O[0.21m]-LD_2[0.15m]	0.19	0.53
3) D_2O[0.21m]-LD_2[0.18m]	0.20	0.69
4) D_2O[0.21m]-LD_2[0.21m]	0.20	0.86
5) D_2O[0.21m]-LD_2[0.24m]	0.20	1.06
6) D_2O[0.27m]-LD_2[0.12m]	0.17	0.59
7) D_2O[0.27m]-LD_2[0.15m]	0.19	0.81
8) D_2O[0.27m]-LD_2[0.18m]	0.19	1.05
9) D_2O[0.27m]-LD_2[0.21m]	0.20	1.32
10) D_2O[0.27m]-LD_2[0.24m]	0.19	1.62
11) H_2O[0.06m]-LD_2[0.12m]	0.13	0.15
12) H_2O[0.06m]-LD_2[0.15m]	0.14	0.19
13) H_2O[0.06m]-LD_2[0.18m]	0.14	0.24
14) H_2O[0.06m]-LD_2[0.21m]	0.15	0.30
15) H_2O[0.06m]-LD_2[0.24m]	0.15	0.36
16) H_2O[0.09m]-LD_2[0.12m]	0.11	0.20
17) H_2O[0.09m]-LD_2[0.15m]	0.11	0.26
18) H_2O[0.09m]-LD_2[0.18m]	0.12	0.33
19) H_2O[0.09m]-LD_2[0.21m]	0.12	0.40
20) H_2O[0.09m]-LD_2[0.24m]	0.12	0.48

Table A3

Cold Neutron Exit Current and Cold-to-Fast Flux Ratio Results (per Source Neutron)

Case	Cold Exit Current [neutrons/m^2-s]	Cold/Fast Ratio
1) D_2O[0.21m]-LD_2[0.12m]	0.10	0.35
2) D_2O[0.21m]-LD_2[0.15m]	0.11	0.48
3) D_2O[0.21m]-LD_2[0.18m]	0.12	0.63
4) D_2O[0.21m]-LD_2[0.21m]	0.12	0.79
5) D_2O[0.21m]-LD_2[0.24m]	0.12	0.98
6) D_2O[0.27m]-LD_2[0.12m]	0.10	0.52
7) D_2O[0.27m]-LD_2[0.15m]	0.11	0.73
8) D_2O[0.27m]-LD_2[0.18m]	0.11	0.96
9) D_2O[0.27m]-LD_2[0.21m]	0.11	1.22
10) D_2O[0.27m]-LD_2[0.24m]	0.11	1.50
11) H_2O[0.06m]-LD_2[0.12m]	0.08	0.13
12) H_2O[0.06m]-LD_2[0.15m]	0.08	0.17
13) H_2O[0.06m]-LD_2[0.18m]	0.09	0.22
14) H_2O[0.06m]-LD_2[0.21m]	0.09	0.27
15) H_2O[0.06m]-LD_2[0.24m]	0.09	0.33
16) H_2O[0.09m]-LD_2[0.12m]	0.06	0.18
17) H_2O[0.09m]-LD_2[0.15m]	0.07	0.28
18) H_2O[0.09m]-LD_2[0.18m]	0.07	0.30
19) H_2O[0.09m]-LD_2[0.21m]	0.07	0.37
20) H_2O[0.09m]-LD_2[0.24m]	0.07	0.44

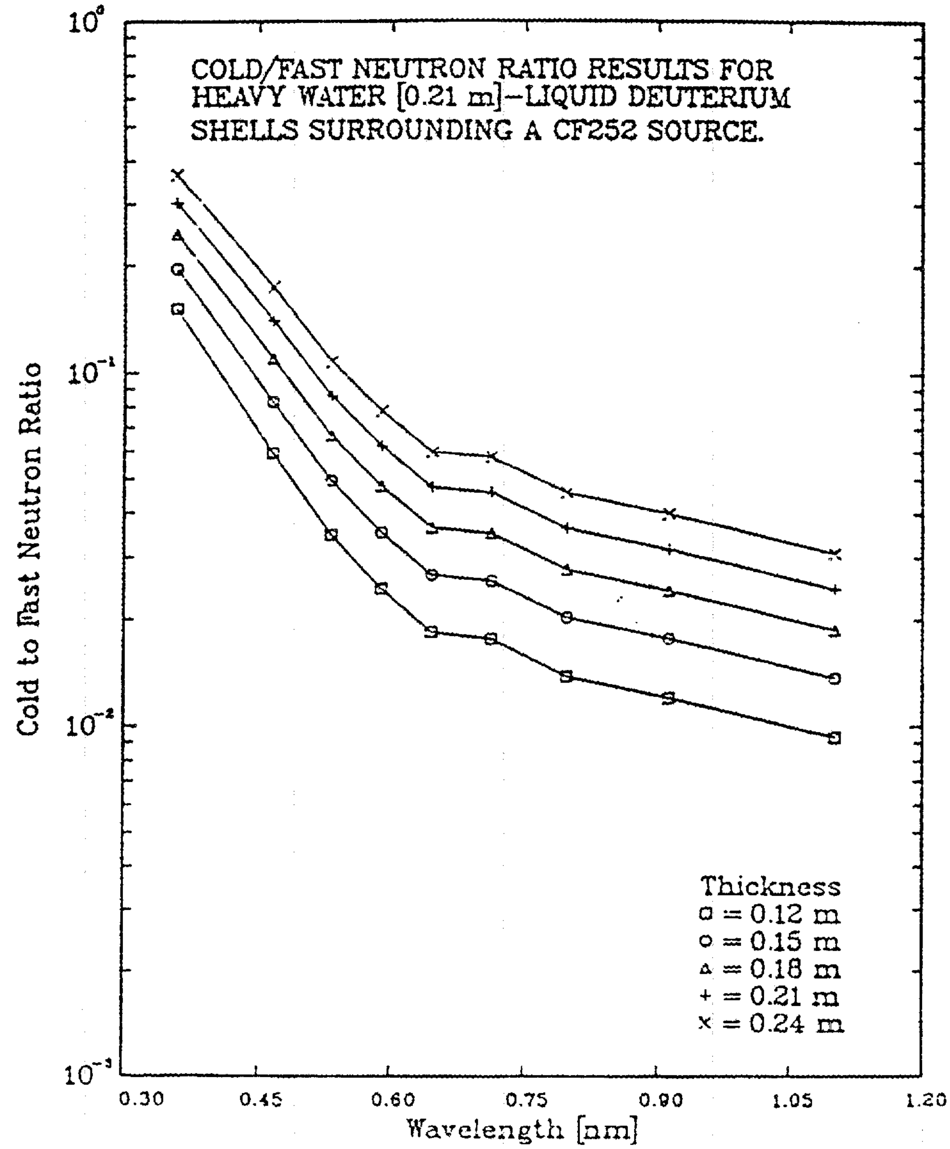


Fig. A6. The individual group cold-to-fast exit current ratios versus wavelength for the case of a 0.21 m thick D_2O shell and for LD_2 thicknesses of 0.12 m to 0.24 m.

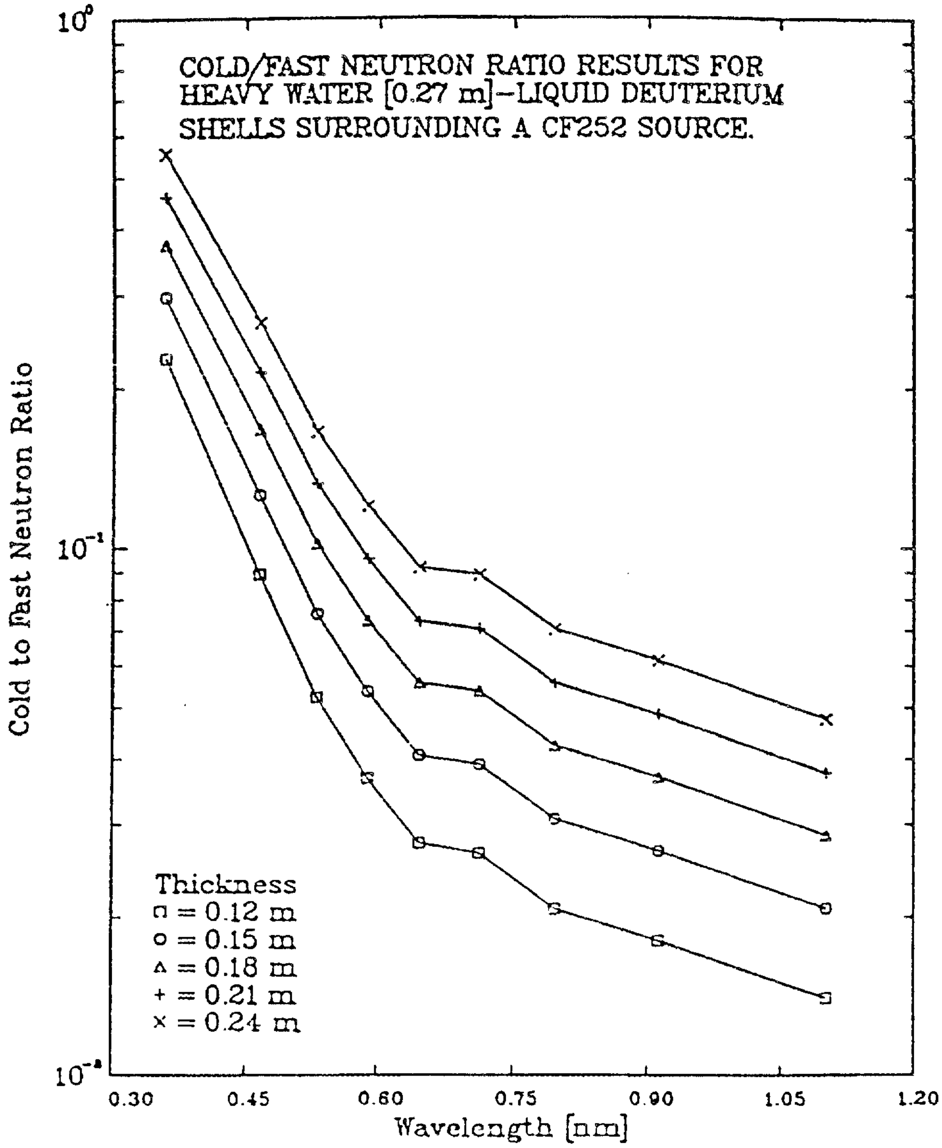


Fig. A7. The individual group cold-to-fast exit current ratios versus wavelength for the case of a 0.27 m thick D_2O shell and for LD_2 thicknesses of 0.12 m to 0.24 m.

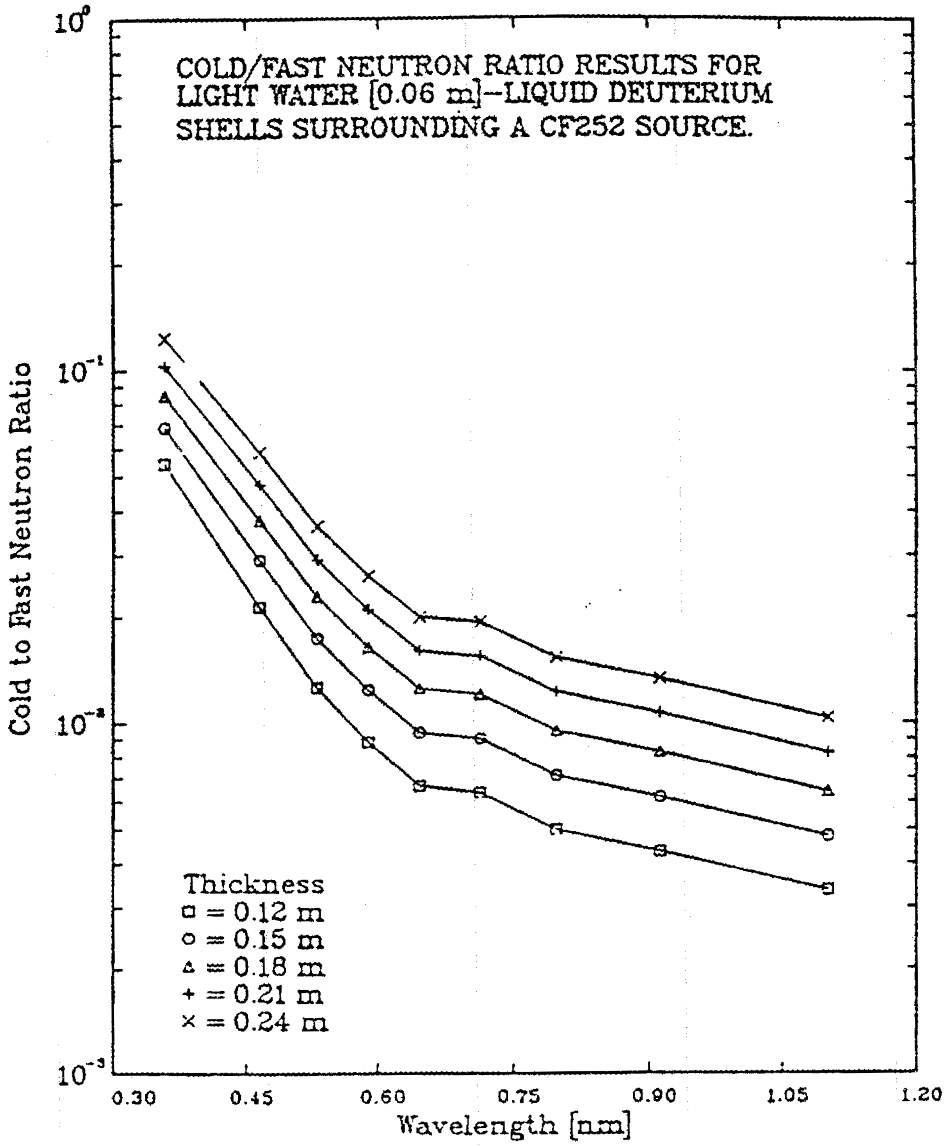


Fig. A8. The individual group cold-to-fast exit current ratios versus wavelength for the case of a .06 m thick H_2O shell and for LD_2 thicknesses of 0.12 m to 0.24 m.

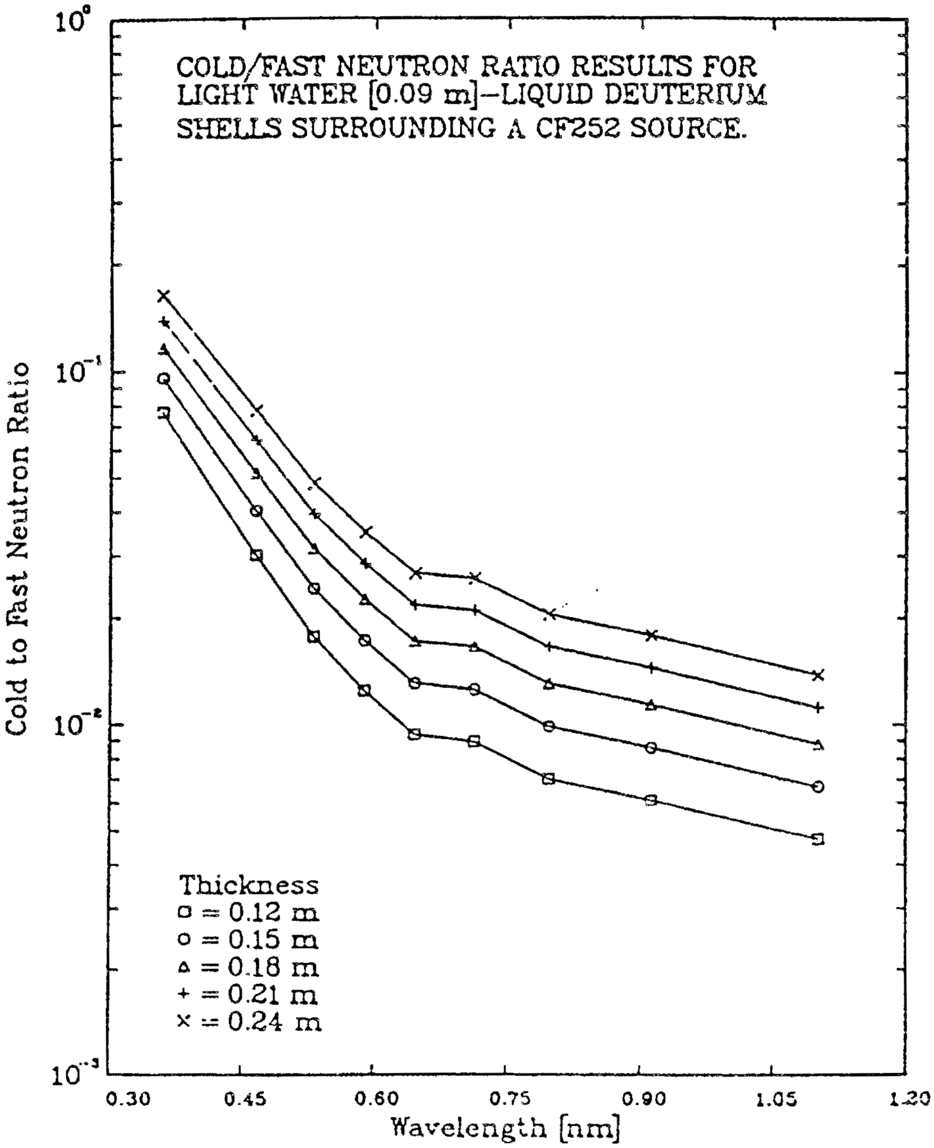


Fig. A9. The individual group cold-to-fast exit current ratios versus wavelength for the case of a 0.09 m thick H_2O shell and for LD_2 thicknesses of 0.12 m to 0.24 m.

6. APPENDIX B

Table B.1
39-Group ANSL-V Library Neutron Energy Group Structure

Group	High (eV)	Low (eV)
1	20.0×10^{6}	6.434×10^{6}
2	6.434×10^{6}	3.00×10^{6}
3	3.00×10^{6}	1.85×10^{6}
4	1.85×10^{6}	1.40×10^{6}
5	1.40×10^{6}	9.00×10^{5}
6	9.00×10^{5}	4.00×10^{5}
7	4.00×10^{5}	1.00×10^{5}
8	1.00×10^{5}	1.70×10^{4}
9	1.70×10^{4}	3.00×10^{3}
10	3.00×10^{3}	5.50×10^{2}
11	5.50×10^{2}	1.00×10^{2}
12	1.00×10^{2}	3.00×10^{1}
13	3.00×10^{1}	1.00×10^{1}
14	1.00×10^{1}	3.00×10^{0}
15	3.00×10^{0}	1.77×10^{0}
16	1.77×10^{0}	1.30×10^{0}
17	1.30×10^{0}	1.00×10^{0}
18	1.00×10^{0}	7.65×10^{-1}
19	7.65×10^{-1}	5.88×10^{-1}
20	5.88×10^{-1}	4.79×10^{-1}
21	4.79×10^{-1}	3.97×10^{-1}
22	3.97×10^{-1}	3.30×10^{-1}
23	3.30×10^{-1}	2.70×10^{-1}
24	2.70×10^{-1}	2.15×10^{-1}
25	2.15×10^{-1}	1.62×10^{-1}
26	1.62×10^{-1}	1.04×10^{-1}
27	1.04×10^{-1}	5.00×10^{-2}
28	5.00×10^{-2}	3.00×10^{-2}
29	3.00×10^{-2}	1.00×10^{-2}
30	1.00×10^{-2}	4.45×10^{-3}
31	4.45×10^{-3}	3.25×10^{-3}
32	3.25×10^{-3}	2.60×10^{-3}
33	2.60×10^{-3}	2.15×10^{-3}
34	2.15×10^{-3}	1.80×10^{-3}
35	1.80×10^{-3}	1.45×10^{-3}
36	1.45×10^{-3}	1.15×10^{-3}
37	1.15×10^{-3}	8.50×10^{-4}
38	8.50×10^{-4}	5.50×10^{-4}
39	5.50×10^{-4}	1.00×10^{-5}

Table B.2
Composition of the Aluminum-6061 T6 Used as the Structural Material for the Cryostat and Reflector Tank

Element	(wt. %)
Mg	1.00
Al	96.55
Si	0.60
Ti	0.15
Cr	0.30
Mn	0.15
Fe	0.70
Cu	0.30
Zn	0.25

Density of Al-6061-T6 $\rho = 2.7\ g/cm^3$

REFERENCES

1. Letter to Distribution from B. H. Montgomery (May 16, 1988).

2. P. Ageron, "Neutron Flux Calculations for the Deuterium Cold Sources in Siloette and HFR," Institute Max Von Laue-Paul Langevin, DTE-781650-PA/ngd (1978).

3. T. Springer, "The Installation of a Second Cold Source in the High Flux Reactor at the Institute Laue-Langevin," Institute Max Von Laue-Paul Langevin, 81SP49S, Grenoble, France (September 1981).

4. R. D. O'Dell, F. W. Brinkley, Jr. and D. R. Marr, "User's Manual for ONEDANT: A Code Package for One-Dimensional, Diffusion Accelerated, Neutral Particle Transport," Los Alamos National Laboratory Report LA-9184-M (February 1982).

5. J. W. Arwood et al., "Preparation and Benchmarking of ANSL-V Cross Sections for the Advanced Neutron Source Reactor Studies," Trans. Am. Nucl. Soc., 55, 615 (November 1987).

6. R. T. Primm, III, private communication.

7. Compendium of Benchmark and Test Region Neutron Fields for Pressure Vessel Irradiation Surveillance, 'Standard Neutron Field Entry: Fission Neutron Spectra; Part I: Cf-252 Spontaneous Fission,' National Bureau of Standards.

APPENDIX B

Letter to T. J. McManamy from D. E. Brashears, *Study Estimate for A Californium Cold Source Experiment at the TURF Facility*, October 19, 1988.

Internal Correspondence

MARTIN MARIETTA ENERGY SYSTEMS, INC.

October 19, 1988

T. J. McManamy

Study Estimate for A Californium Cold Source Experiment at the TURF Facility

Attached is the study estimate for a Californium Cold Source Experiment at the TURF Facility at ORNL. This facility is a part of the ongoing studies for the A.N.S. project. The estimate is very preliminary in nature and much more detailed design is needed to produce a "hard" conceptual design estimate.

Estimate dollars are stated in FY89.1 dollars including engineering and contingency. Dollars have been included for FSAR, neutronic calculations, and fabrication of ten (10) californium sources.

If any questions arise, please feel free to contact the undersigned.

D. E. Brashears, ORGDP, K1550V, MS-7234 (4-3275)

DEB:shb

Attachments

cc - w/att: M. M. Brown
K. K. Chipley
C. L. Hahs
C. E. Oldham
T. L. Ryan
File - NoRC

Californium Cold Source at TURF in Cells E & D

o	Equipment as listed on on Page 2	1,281,000	
o	Mods to Facility i.e. filling windows with S.S. shot	750,000	- Based on CWDD estimate
o	Other Facility Mods as listed on Page 3	970,000	
o	Refrig. Sys. Piping Note: Reference AES BM from J. P. Schubert	65,000	
		3,066,000	
	Allow for Uncertainties	250,000	
	TOTAL	3,316,000	
	Engineering 35%	1,160,000	
	Contingency 35%	1,566,000	
	TOTAL FY89.1 $	6,042,000	
	FSAR	300,000	
	Neutronic Calc.	180,000	
	Sources	30,000	
		6,552,000	
	USE	**6,600,000**	

D. E. Brashears 10/19/88

ITEM NO.	QTY	DESCRIPTION	DWG. NO. X2E-16420-	
1	1 EA	D2O TANK WELDMENT	0006	225,000
2	1 EA	D2 SUPPLY TANK	0004	45,000
3	1 EA	D2 SECONDARY CONTAINMENT VESSEL	0004	100,000
4	1 EA	KOCH 1200 HELIUM REFRIGERATOR	0005	134,000
5	2 EA	LEYBOLD-HERAEUS TMP450 TURBO PUMPS	0001	25,000
6	2 EA	LEYBOLD-HERAEUS D60A ROUGHING PUMPS	0001	6,300
7	4 EA	LEYBOLD-HERAEUS KF40 BELLOWS	0001	400
8	4 EA	LEYBOLD-HERAEUS KF40 ELBOWS	0001	400
9	1 EA	D2O PRIMARY DRIP PAN	0002	25,000
10	1 EA	D2O SECONDARY DRIP PAN	0002	25,000
11	10 EA	CALIFORNIUM SOURCES, ALLOW	0005	50,000
12	7 EA	VATRING 1" IN-LINE MANUAL VALVES	0004	10,500
13	7 EA	18-INCH LONG FLEXIBLE SHAFTS WITH COUPLINGS	0004	35,000
14	10 EA	VARIAN ROTARY FEEDTHROUGHS	0004	4,480
15	1 EA	1" RELIEF VALVES	0004	300
16	1 EA	8 PSI RUPTURE DISK	0004	150
17	10 EA	3/8" WHITEY MANUAL VALVES	0004	1,000
18	1 EA	HYDROGEN MONITOR	0004	25,000
19	2 EA	PRESSURE GAUGES	0004	200
20	1 EA	ALARMED PRESSURE GAUGES	0004	500
21	4 EA	1" SWAGELOK FITTINGS	0004	400
22	1 EA	INERT CONTAINER FOR REFRIGERATION SYSTEM, ALLOW	0005	15,000
23	1 EA	SUPPORT STRUCTURE FOR COLD SOURCE VACUUM SYSTEM	0001	20,000
24	1 EA	COLD SOURCE VESSEL	0003	30,000
25	1 EA	SET OF MULTI-LAYER INSULATION FOR THE COLD SOURCE	0003	50,000
26	1 LOT	PIPING BETWEEN COMPONENTS, ALLOW	0002	50,000
27	2 EA	INERT GAS K-BOTTLES	0004	2,000
28	1 LOT	D2O - 1600 GALLONS (NO ESTIMATE)		0
29	1 LOT	DEUTERIUM (NO ESTIMATE)		0
30	2 EA	VACUUM GAGES		700
		SUBTOTAL EQUIPMENT		881,330
		INSTRUMENTATION MAT'L AND LABOR		200,000
		INSTALLATION OF EQUIPMENT		200,000
		TOTAL EQUIPMENT		1,281,330

Listing by Carolyn Hahs

Estimate by D. E. Brashears

FACILITY MODIFICATIONS

		MATERIAL & LABOR
1.	INSTALL TWO ZINC BROMIDE WINDOWS ($100K EACH)	200,000
2.	INSTALL TWO SERIES E MANIPULATORS ($46K EACH)	100,000
3.	EXTEND THE RABBIT TUBE SYSTEM FROM C TO D CELL, ALLOW	125,000
4.	MAKE A NEW PENETRATION FROM D TO E FOR THE BEAM LINE, ALLOW	0*
5.	PROVIDE INERT GAS LINES FOR REMOTE ACTUATED COMPONENTS, ALLOW	100,000
6.	INSTALL RADIATION DETECTORS AND INTERLOCK CONTROLS, ALLOW	50,000
7.	INSTALL O2 AND FLAME DETECTORS IN D AND E CELLS	100,000
8.	CONSTRUCT SOURCE PREPARATION AREA FACILITY MISC MODS TO CELL	150,000
9.	PROVIDE LOCALIZED SHIELDING FOR THE BEAM LINE INTO E	20,000
10.	PROVIDE EXPERIMENTAL AREA FLOOR IN E CELL AND UTILITIES	50,000
11.	PROVIDE LOCAL CONTROL STATION OUTSIDE THE HOT CELLS FOR MONITORING SYSTEMS	75,000
	TOTAL MATERIAL AND LABOR	970,000

*INCLUDED IN MODS TO FACILITY LINE ON PAGE 1

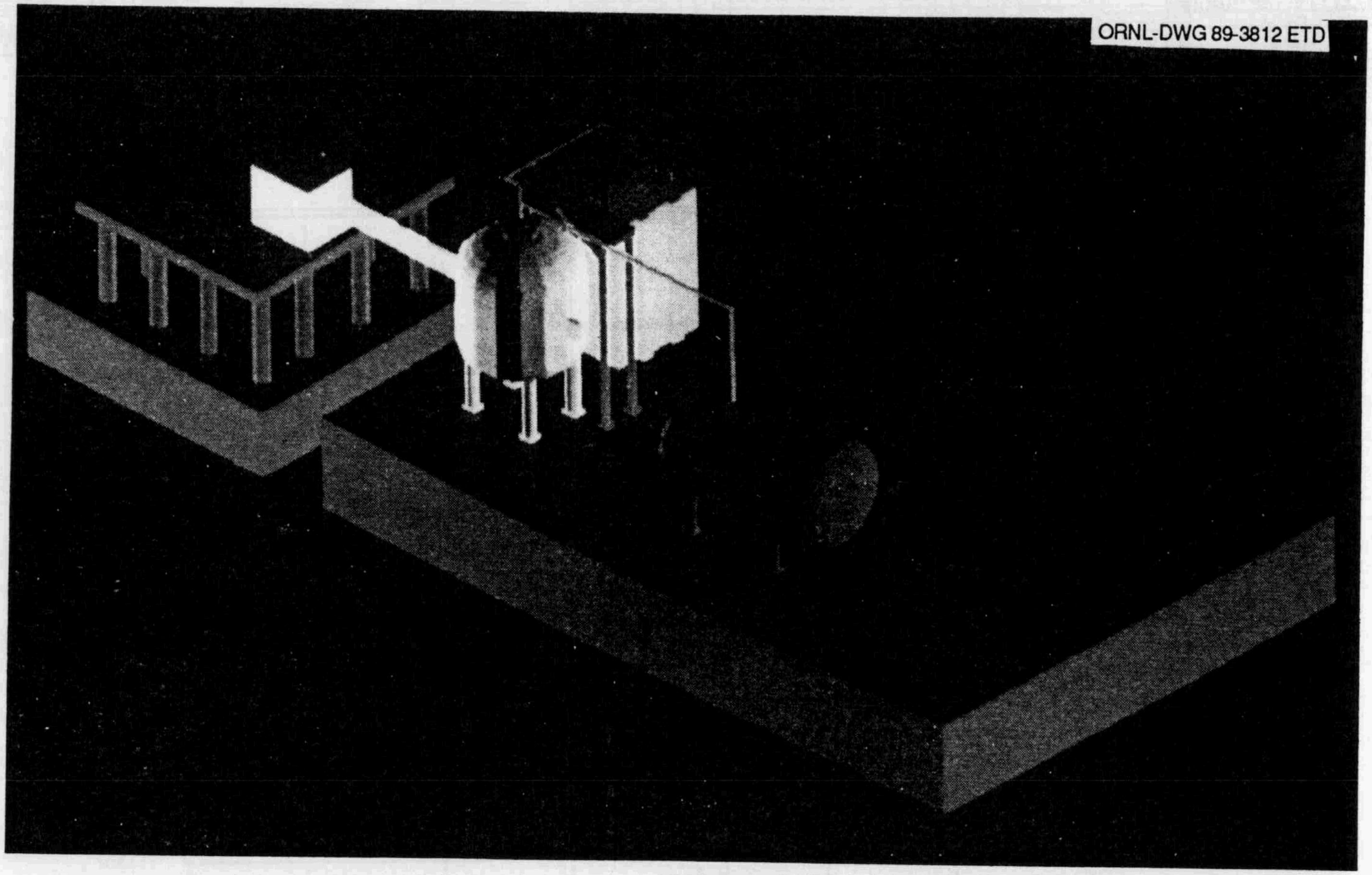
Listing by T. J. McManamy

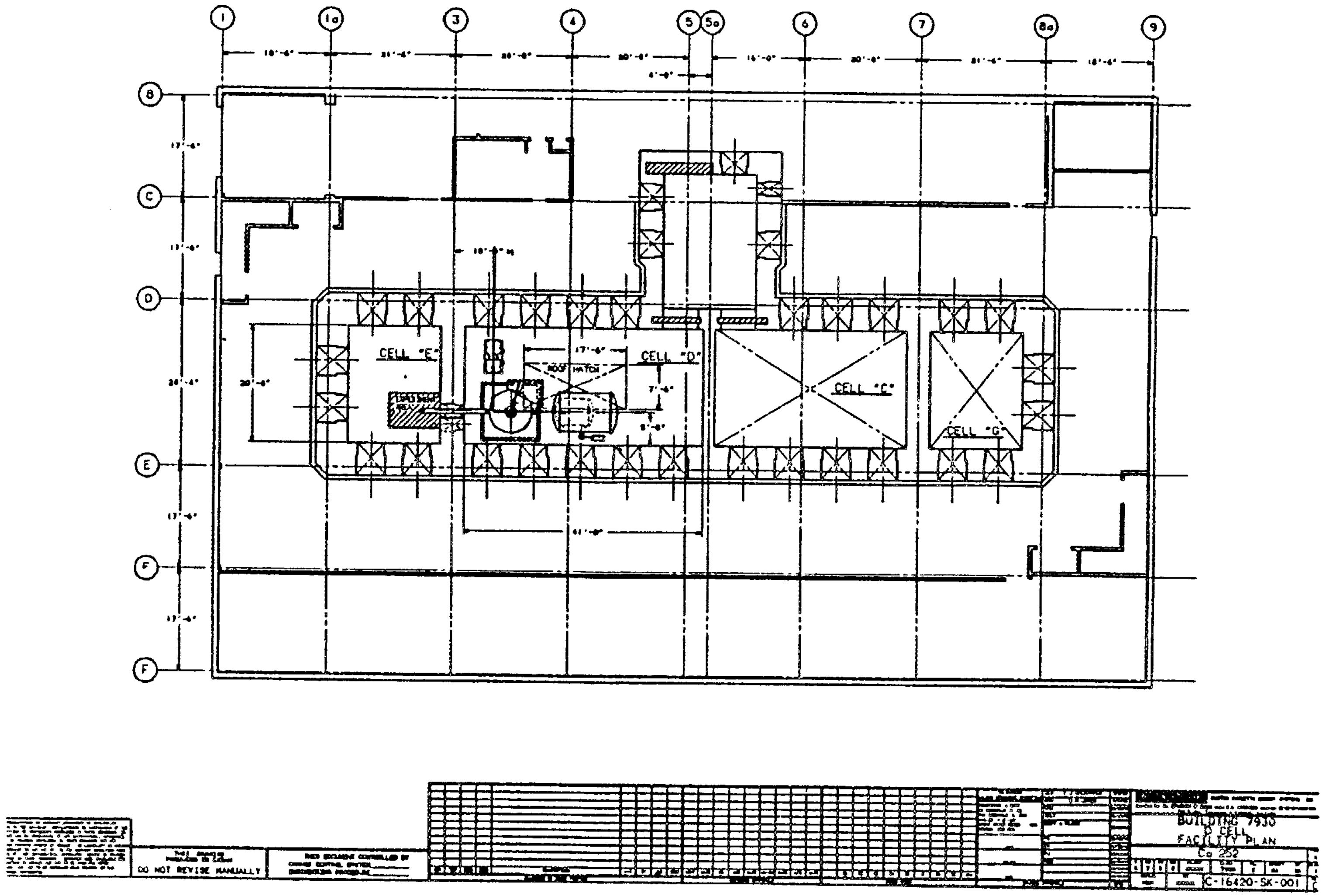
Estimate by D. E. Brashears

APPENDIX C

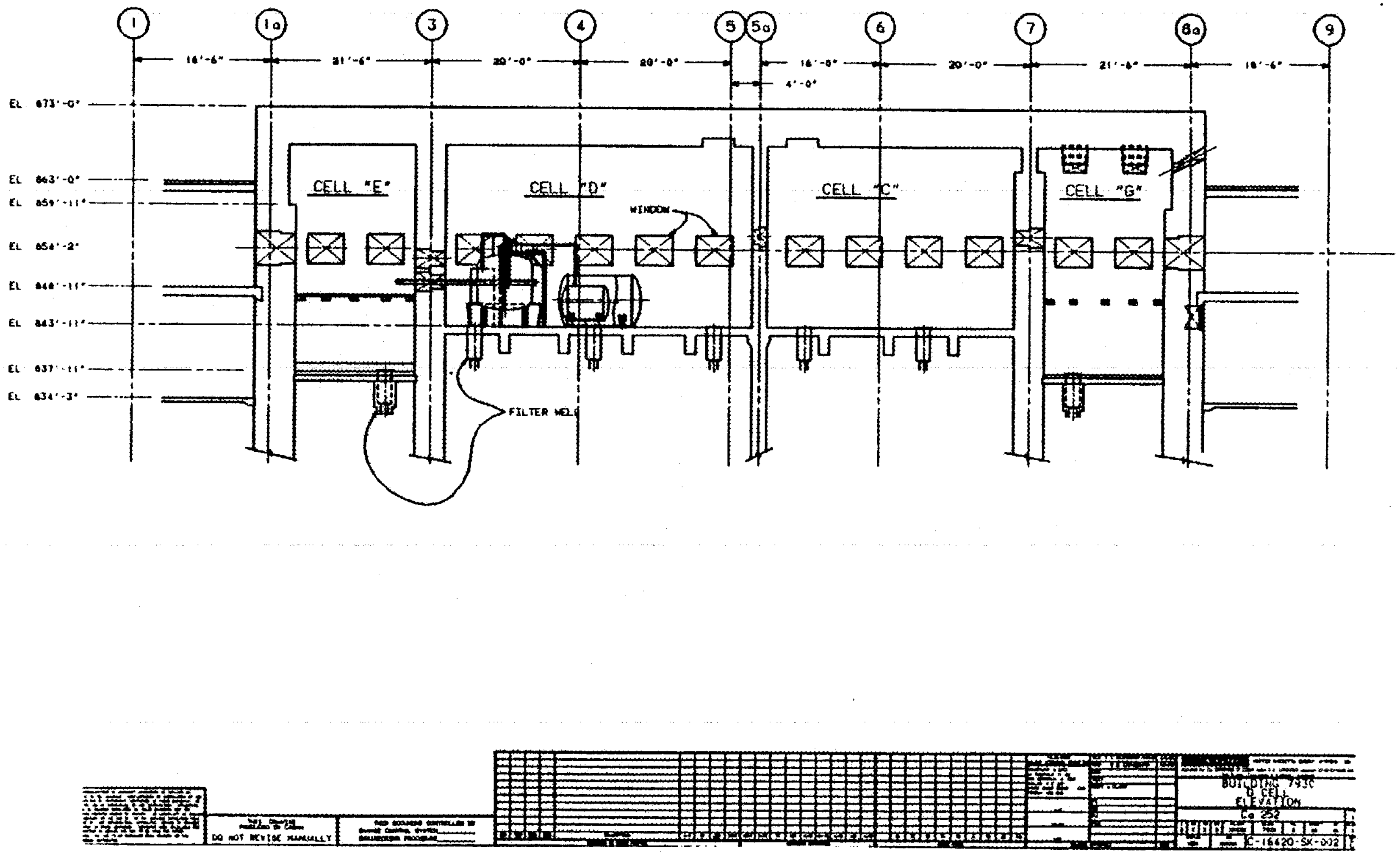
Conceptual Drawings and Photographs for CCNS

ORNL-DWG 89-3812 ETD	Computer Drawing of CCNS
C-16420-SK-001	Building 7930 Cell Facility Plan
C-16420-SK-002	Building 7930 Cell Elevation Plan
C-16420-SK-003	Cold Source Detail
C-16420-SK-004	D2 Secondary Containment
C-16420-SK-005	Cold Source Layout
C-16420-SK-006	Cf-252 Cold Source

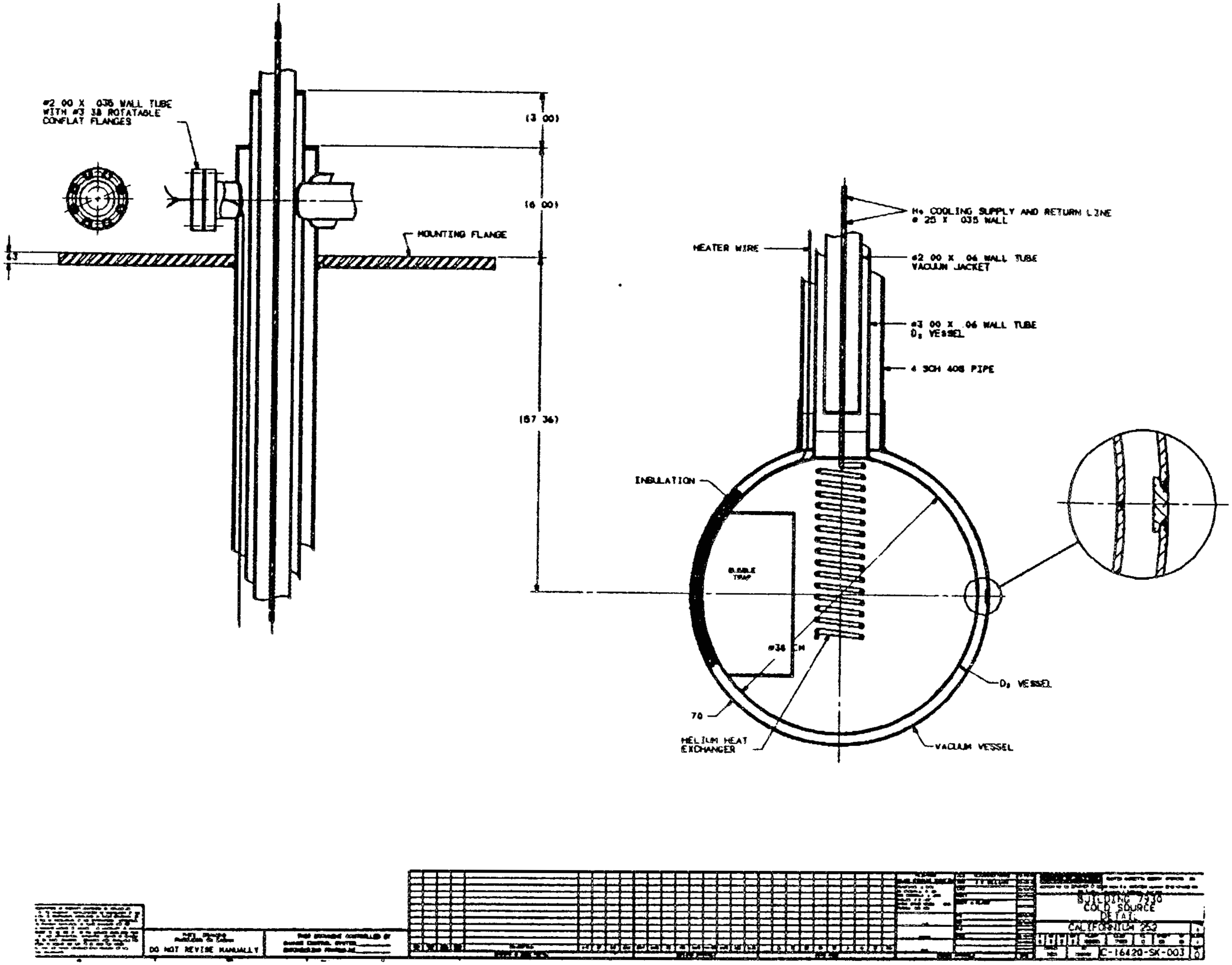

ORNL-DWG 89-3812 ETD

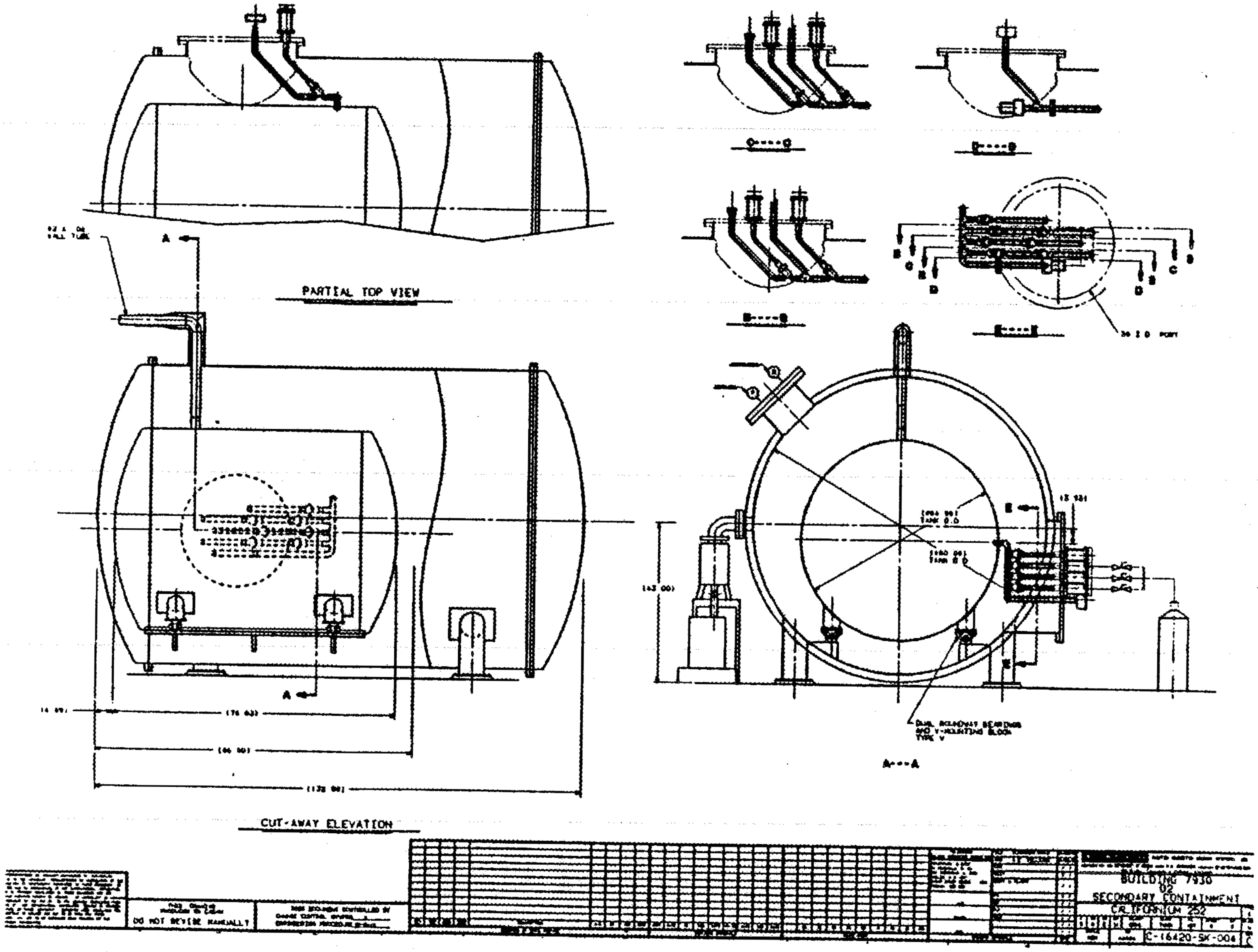


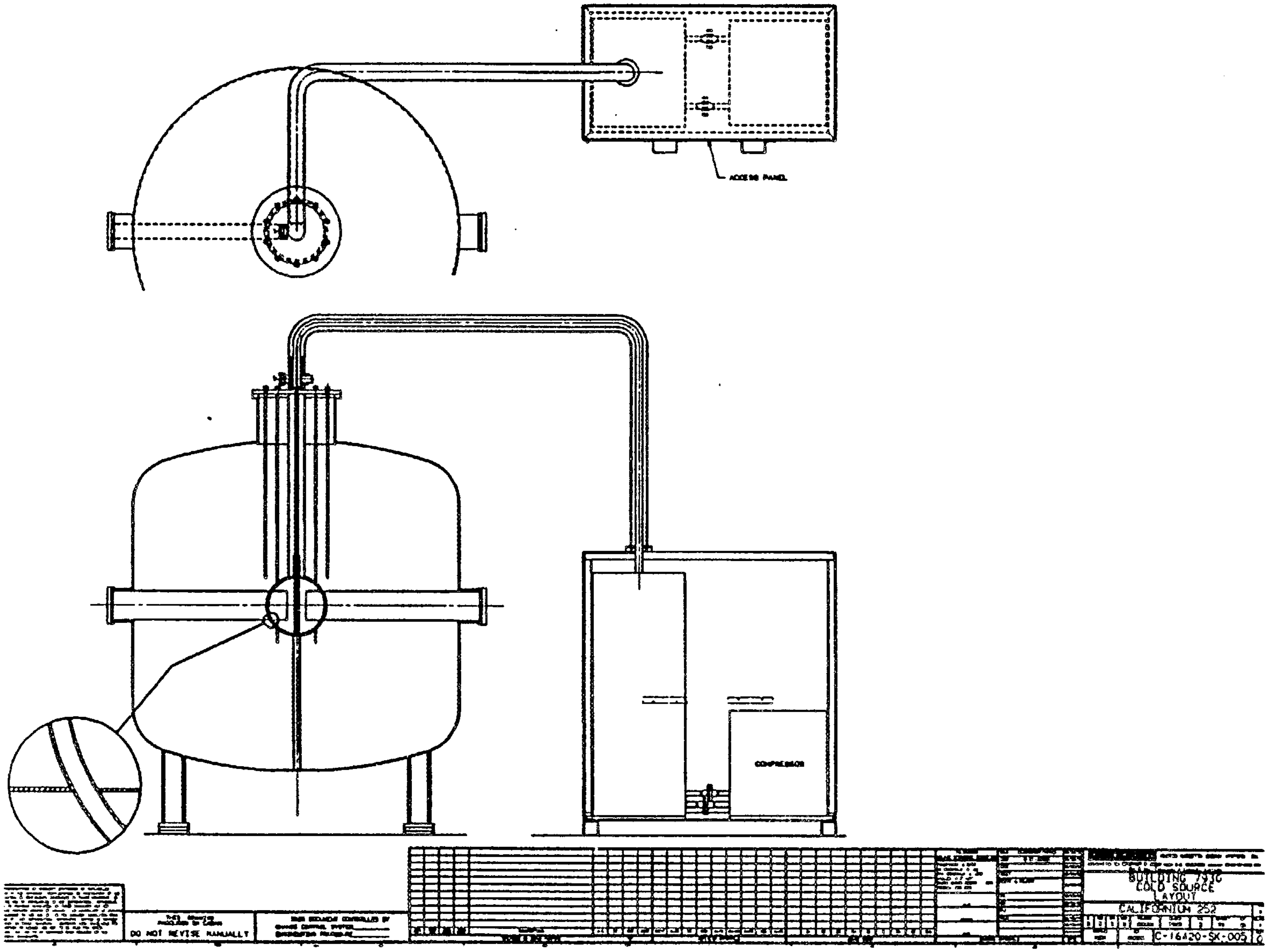
CELL "E"
CELL "D"
CELL "C"
CELL "G"
ROOF HATCH
DO NOT REVISE MANUALLY
BUILDING 7930
D CELL
FACILITY PLAN
Co 252
C-16420-SK-001

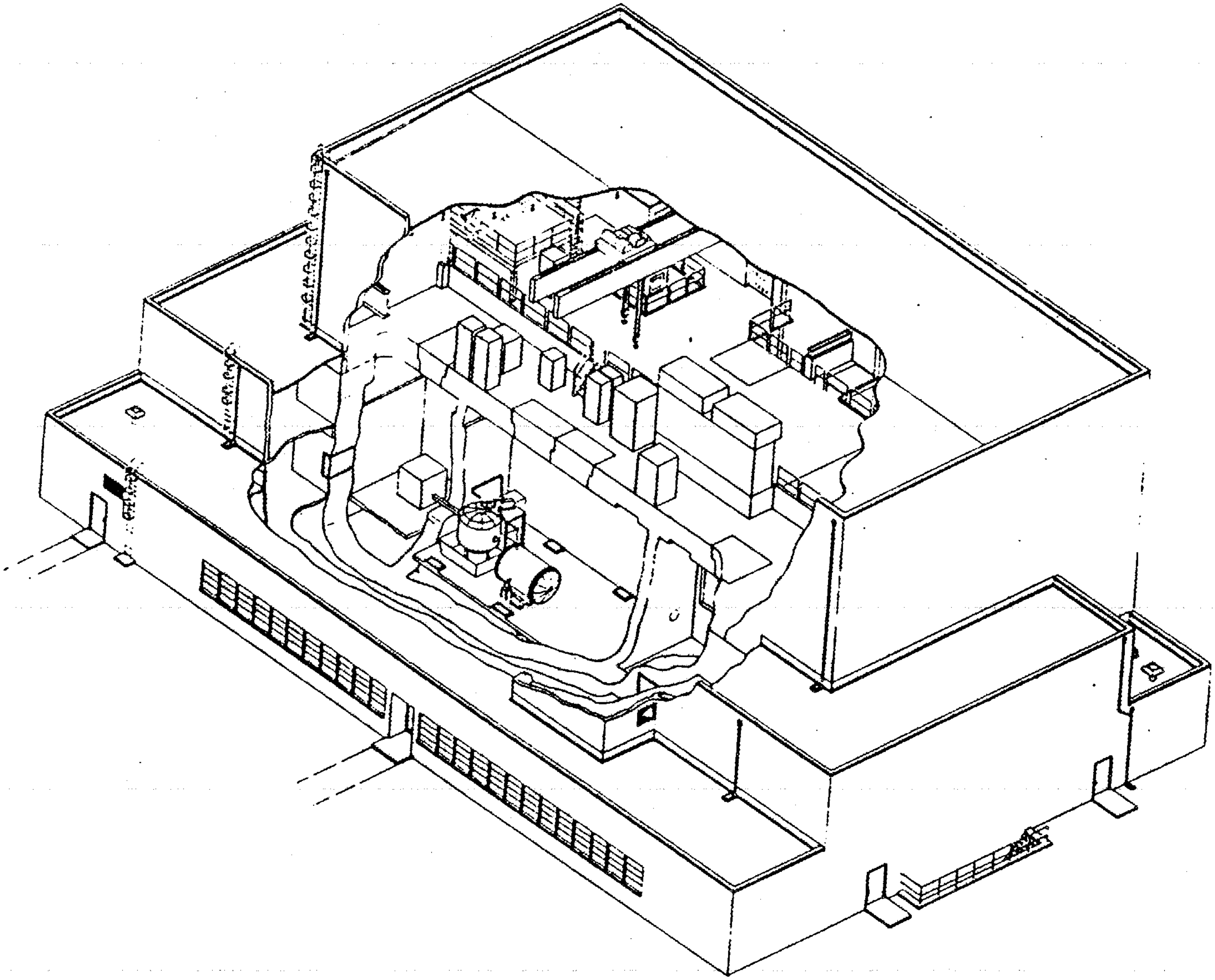


1
1a
3
4
5
5a
6
7
8a
9
16'-6"
21'-6"
20'-0"
20'-0"
4'-0"
16'-6"
20'-0"
21'-6"
16'-6"
EL 673'-0"
EL 663'-0"
EL 659'-11"
EL 654'-2"
EL 648'-11"
EL 643'-11"
EL 637'-11"
EL 634'-3"
CELL "E"
CELL "D"
CELL "C"
CELL "G"
WINDOW
FILTER WELL
DO NOT REVISE MANUALLY
BUILDING 791C
D CELL
ELEVATION
Cа 252
C-16420-SK-002


⌀2.00 X .035 WALL TUBE
WITH ⌀3 3/8 ROTATABLE
CONFLAT FLANGES
(3.00)
(6.00)
MOUNTING FLANGE
.63
(57.36)
He COOLING SUPPLY AND RETURN LINE
⌀ .25 X .035 WALL
HEATER WIRE
⌀2.00 X .06 WALL TUBE
VACUUM JACKET
⌀3.00 X .06 WALL TUBE
D_2 VESSEL
4 SCH 40S PIPE
INSULATION
BUBBLE TRAP
⌀36 CM
70
HELIUM HEAT
EXCHANGER
D_2 VESSEL
VACUUM VESSEL
DO NOT REVISE MANUALLY
BUILDING 7930
COLD SOURCE
DETAIL
CALIFORNIUM 252
C-16420-SK-003


PARTIAL TOP VIEW
CUT-AWAY ELEVATION
A—A
DUAL ROLLOWAY BEARINGS AND V-MOUNTING BLOCK TYPE V
DO NOT REVISE MANUALLY
BUILDING 7930
SECONDARY CONTAINMENT
CALIFORNIUM 252
C-16420-SK-004


ACCESS PANEL
COMPRESSOR
DO NOT REVISE MANUALLY
BUILDING 7930
COLD SOURCE
LAYOUT
CALIFORNIUM 252
C-16420-SK-005



Cf 252 COLD SOURCE

APPENDIX D

Letter to R. M. Moon from C. D. West, *Installation of a Cold Neutron Source at HFIR*, March 25, 1988.

Internal Correspondence

MARTIN MARIETTA

MARTIN MARIETTA ENERGY SYSTEMS, INC.

March 25, 1988

R. M. Moon

Installation of a Cold Neutron Source at HFIR

As you know, John Hayter, Bill Montgomery and Ted Ryan have been preparing a cost estimate for converting the EF-2 facility at HFIR into a neutron source for scattering work; in particular they have been studying the possibility of installing a cold neutron source.

The results of their work are very interesting and, I think, important. An outline design for installing a moderator (for example, polyethylene) in the EF-2, with minimum changes to the reactor and no changes to the reactor pressure boundary has been prepared. This installation could be Phase I of the proposed project and would provide a very useful extra beam line for scattering. Phase II would install equipment to cool the moderator to liquid nitrogen temperature, with a consequential gain in cold neutron flux. Phase III would add a helium refrigerator using the nitrogen system for precooling, allowing the moderator to be operated at approximately 4K with a further gain in cold neutron flux. The cost estimates are shown below: note that these are "unofficial" - that is, they were prepared by Ted Ryan, on the basis of experience and manufacturer's quotes and not by the professional estimators of Martin Marietta Energy Systems Engineering; an official cost estimate would cost ~$4,000 to prepare.

Phase I	Moderator block and access tube design, fabrication and installation (incl. 50% contingency)	$150,000
Phase II	Liquid nitrogen system plus installation (10% contingency)	$178,000
Phase III	Helium system plus installation (12% contingency)	$576,000

Attachment 1 gives a more detailed breakdown. Attachment 2 is Ted Ryan's study. Please let me know if there is anything further I can do to help you pursue this opportunity to provide a cold neutron source at ORNL.

C. D. West, FEDC (4-0370)

CDW:kfr

Attachments
1. Cost Estimates
2. Memo, T. L. Ryan to C. D. West and B. H. Montgomery, dated March 21, 1988

cc/att: B. R. Appleton
J. B. Hayter
B. H. Montgomery ✓
F. R. Mynatt
T. L. Ryan
H. E. Trammell
F. W. Young, Jr.
A. Zucker

Attachment 1 - Cost Estimates

		$
Phase I - room temperature moderator	Engineering - design	37,500
	- title III	15,000
	Vacuum tube & flanges	29,000
	Moderator & heat exchanger	21,000
	Contingency (~50%)	47,500
		150,000
Phase II - liquid nitrogen temperature moderator	Installation drawings	10,000
	Title III	5,000
	Heat exchanger	25,000
	LN_2 system & installation	123,000
	Contingency (~10%)	15,000
		178,000
Phase III - liquid helium temperature moderator	Installation drawings	20,000
	Title III	5,000
	Helium refrigeration system	348,500
	Installation	153,000
	Contingency (~10%)	49,500
		576,000

<u>Summary</u>

Phase I	$150,000
Phase II	$178,000
Phase III	$576,000

MARTIN MARIETTA

Internal Correspondence

MARTIN MARIETTA ENERGY SYSTEMS, INC.

March 21, 1988

C. D. West
B. H. Montgomery

Cost Estimate for HFIR Cold Source

Attached are viewgraphs and a conceptual cost estimate for the HFIR Cold Source. As you will note, most of the cost is associated with the helium refrigerator. The cost shown is for a KOCH Model 1630 unit. A Model 1430 with the maximum number of compressions would work and cost $35,000 less, but I am recommending the larger unit because it provides for uprating its capacity from 133 watts to 218 watts. This provides growth potential at modest cost ($86,000 today) if needed for a future cold source with a higher thermal load.

Ted L. Ryan, Bldg. 9204-1, MS 15, 4-1502

TLR:ldg

cc: K. K. Chipley
M. L. Goins
J. K. Jones

Attachments

For Computer Estimates Only

CODE NO.	JOB TITLE AND BUILDING	SUBTITLE
1	5 HFIR Cold Neutron Source	61

SUBPROJECT 1	WORK ORDER NO. 5	UNION CARBIDE CORPORATION NUCLEAR DIVISION OAK RIDGE, TENNESSEE 37830	BILL OF MATERIAL NO. 61
ACCOUNT NO. 1	CATEGORY (LAND IMP., BLDG. ADD., ETC.) 8		BILL OF MATERIAL SHEET OF
PARTICIPANT 7	CONSTRUCTION BY 9		PROJECT ENGINEER 61
	LEVEL OF ESTIMATE 9	Conceptual COST ESTIMATE	PRINCIPAL ENGINEER 61 T. L. Ryan

DRAWING OR OTHER SOURCE

TYPE		ITEM NO.	MATERIAL AND DESCRIPTION	QUANTITY	UNIT	MATERIAL			LABOR					
							UNIT COST	TOTAL	HOURS UNIT	HOURS TOTAL	RATE	CFT	TOTAL
			Engineering										$ 92,500
		1	Cold Source										50,000
		2	Helium System										526,500
		3	Liquid Nitrogen System										123,000
			Contingency										112,000
			TOTAL										$904,000

UCN-11250 (8-77)	LISTED BY	DATE	ESTIMATED BY	DATE	ESTIMATE SHEET
	T. L. Ryan	3/18/88	T. L. Ryan	3/18/88	OF

JOB TITLE AND BUILDING: HFIR Cold Neutron Source

Conceptual COST ESTIMATE (CONTINUATION SHEET)

WORK ORDER NUMBER:

CATEGORY:

BILL OF MATERIAL NO.:

BILL OF MATERIAL SHEET OF

DRAWING OR OTHER SOURCE:

TYPE		ITEM NO.	MATERIAL AND DESCRIPTION	QUANTITY	UNIT	MATERIAL	MATERIAL UNIT COST	MATERIAL TOTAL	LABOR HOURS UNIT	LABOR HOURS TOTAL	LABOR RATE	CFT	LABOR TOTAL
			Engineering										
			Design Cold Source							750	50 00		$ 37,500
			Title III Engineering							500	50 00		25,000
			LH_e REF Installation Drawings							400	50 00		20,000
			LN_2 Installation Drawings							200	50 00		10,000
			TOTAL										$ 92,500

UCN-8125T (1 10-77)

LISTED BY: T. L. Ryan | DATE: 3/18/88 | ESTIMATED BY: T. L. Ryan | DATE: 3/18/88 | ESTIMATE SHEET OF

JOB TITLE AND BUILDING: HFIR Cold Neutron Source

Conceptual COST ESTIMATE
(CONTINUATION SHEET)

WORK ORDER NUMBER:

CATEGORY:

BILL OF MATERIAL NO.:

BILL OF MATERIAL SHEET OF

DRAWING OR OTHER SOURCE:

TYPE		ITEM NO.	MATERIAL AND DESCRIPTION	QUANTITY	UNIT	MATERIAL			LABOR				
							UNIT COST	TOTAL	HOURS UNIT	HOURS TOTAL	RATE	CFT	TOTAL
		1	Cold Source										
			Vacuum Tube & Flanges	1	lot		$ 10,000	$ 10,000		500	38 00		$ 29,000
			Moderator & Heat Exchanger	1	each		2,000	2,000		500	38 00		21,000
			TOTAL										50,000

UCN-5125T (3 10-77)

LISTED BY	DATE	ESTIMATED BY	DATE	ESTIMATE SHEET OF
T. L. Ryan	3/18/88	T. L. Ryan	3/18/88	

JOB TITLE AND BUILDING	Conceptual COST ESTIMATE (CONTINUATION SHEET)	WORK ORDER NUMBER	BILL OF MATERIAL NO.
HFIR Cold Neutron Source		CATEGORY	BILL OF MATERIAL SHEET OF

DRAWING OR OTHER SOURCE

TYPE		ITEM NO.	MATERIAL AND DESCRIPTION	QUANTITY	UNIT	MATERIAL			LABOR				
							UNIT COST	TOTAL	HOURS UNIT	HOURS TOTAL	RATE	CFT	TOTAL
		2	Helium System										
			Helium Refrigerator	1	each		$288,500.00	$288,500					$288,500
			Model 1630										
			(133 Watts at 4.2K) with										
			High Pressure GH_e Taps										
			Helium Purifier	1	each		20,000.00	20,000					20,000
			LH_e to GH_e 4.2K Heat Exchanger	1	each		25,000.00	25,000					25,000
			500 ℓ LH_e DEM	1	each		10,000.00	10,000					10,000
			LH_e VJ Piping & Valves	200	feet		150.00	30,000					30,000
			LH_e System Installation	1	lot		20,000.00			3,500	38.00		153,000
			TOTAL										526,500

LISTED BY	DATE	ESTIMATED BY	DATE	ESTIMATE SHEET
T. L. Ryan	3/18/88	T. L. Ryan	3/18/88	OF

JOB TITLE AND BUILDING: HFIR Cold Neutron Source

Conceptual COST ESTIMATE (CONTINUATION SHEET)

WORK ORDER NUMBER:

BILL OF MATERIAL NO.:

CATEGORY:

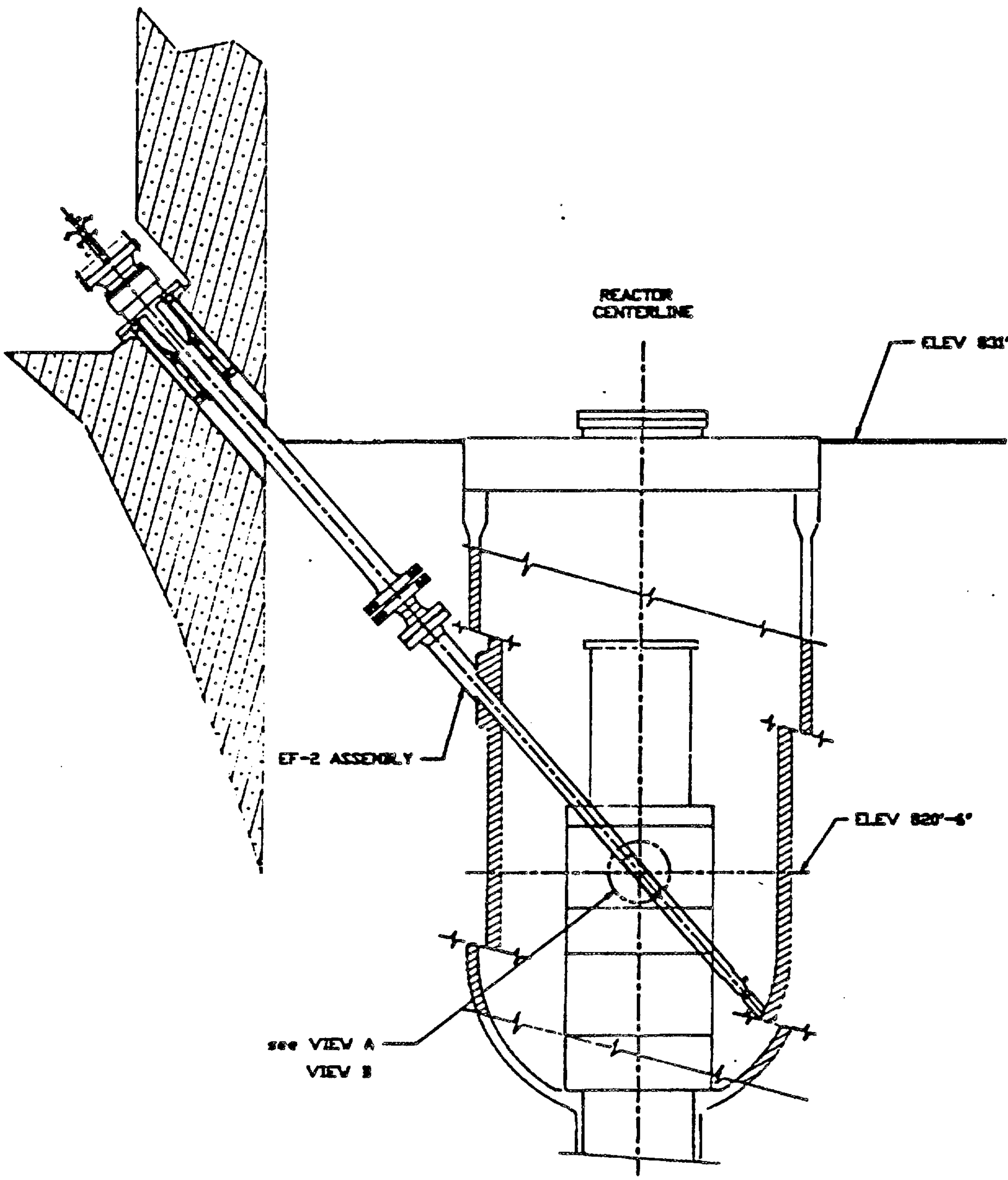
BILL OF MATERIAL SHEET OF

DRAWING OR OTHER SOURCE:

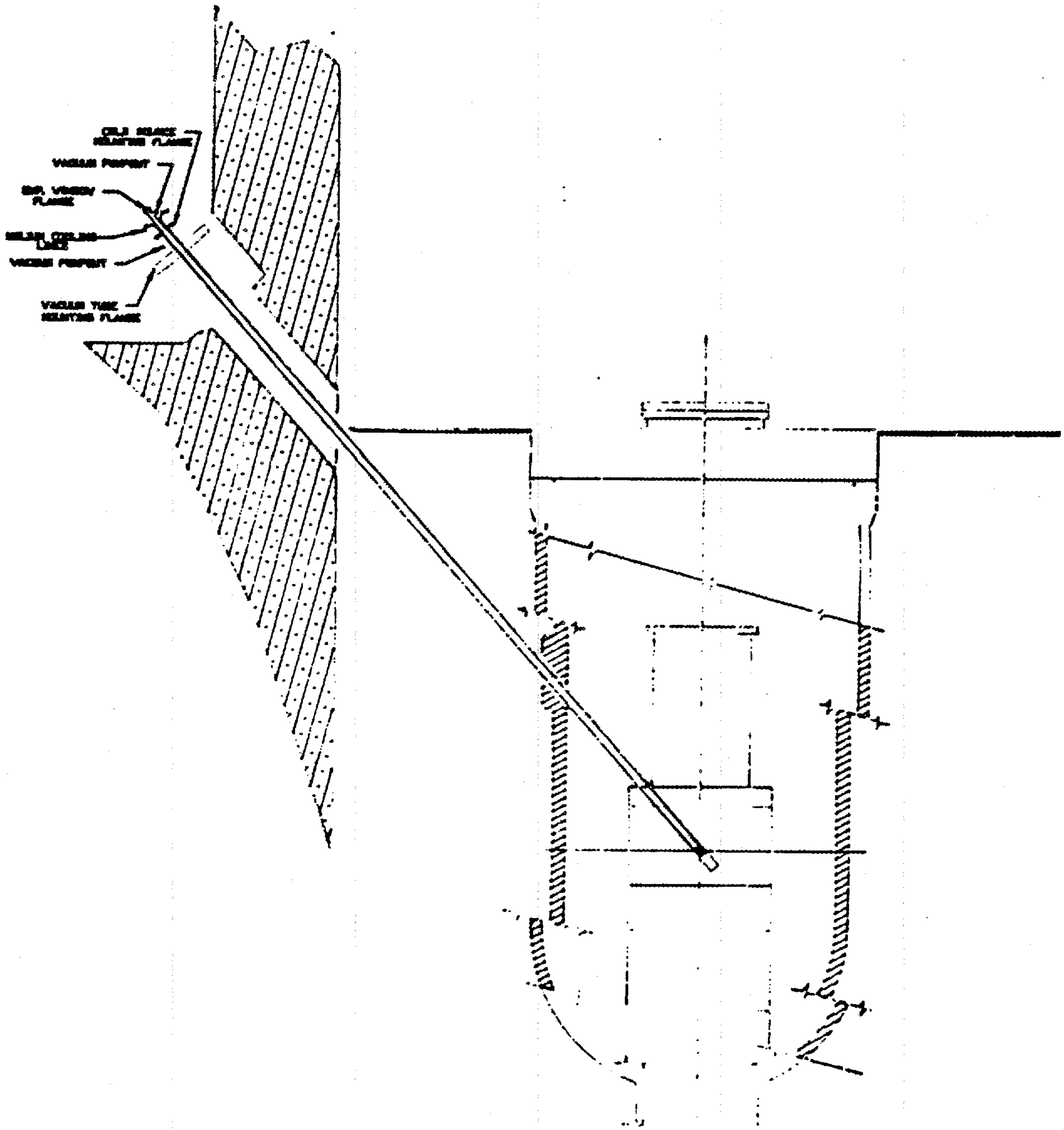
TYPE		ITEM NO.	MATERIAL AND DESCRIPTION	QUANTITY	UNIT	MATERIAL			LABOR				
							UNIT COST	TOTAL	HOURS UNIT	HOURS TOTAL	RATE	CFT	TOTAL
		3	Liquid Nitrogen System										
			LN_2 1000 Gallon Drum	1	each		$ 25,000.00						$ 25,000
			LN_2 VJ Piping & Valves	400	feet		100.00	40,000					40,000
			Installation	1	lot		20,000.00	20,000		1,000	38.00		58,000
			TOTAL										123,000

UCN-51231 (1 10-77)

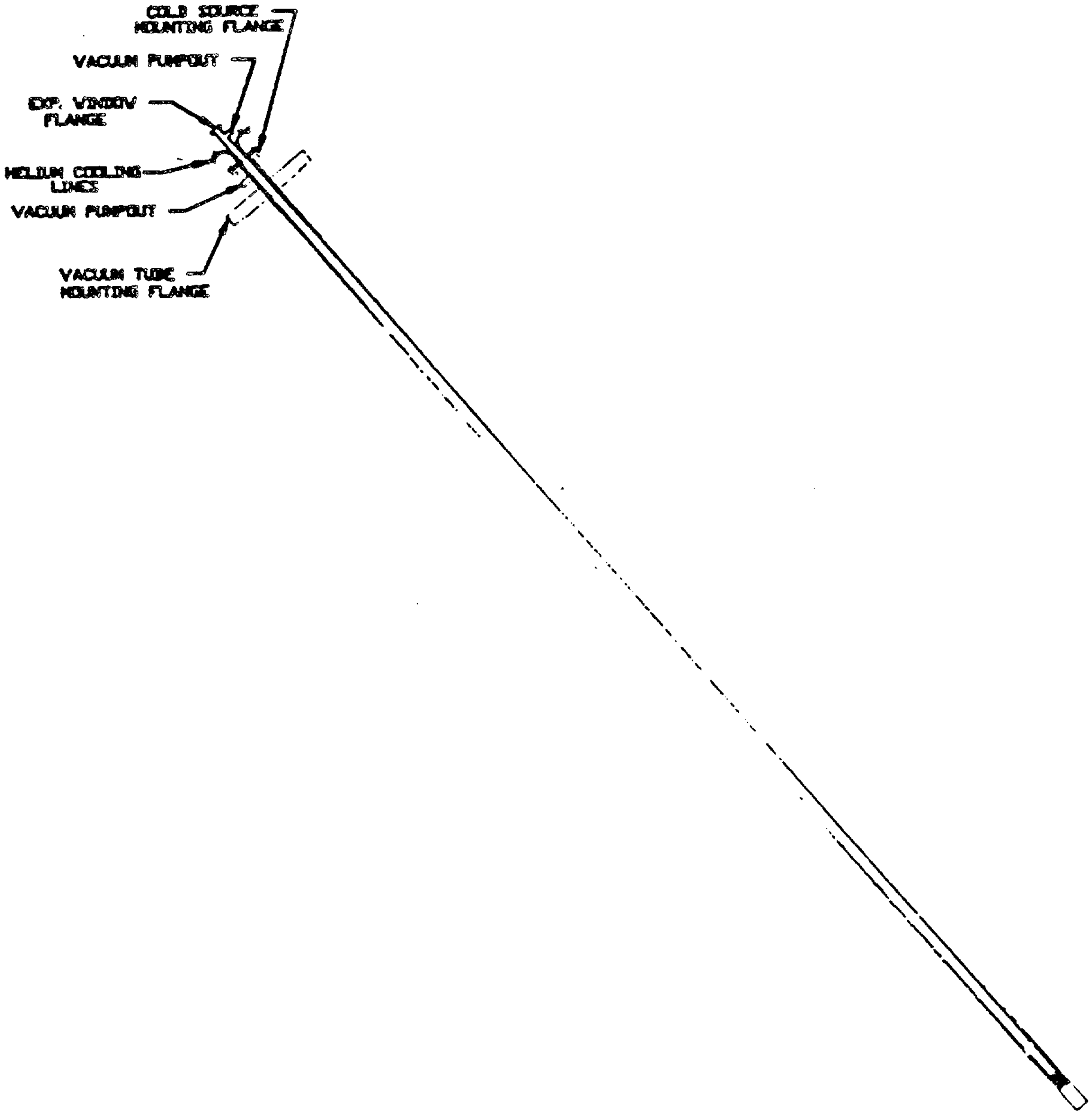
LISTED BY: T. L. Ryan DATE: 3/18/88 ESTIMATED BY: T. L. Ryan DATE: 3/18/88 ESTIMATE SHEET of

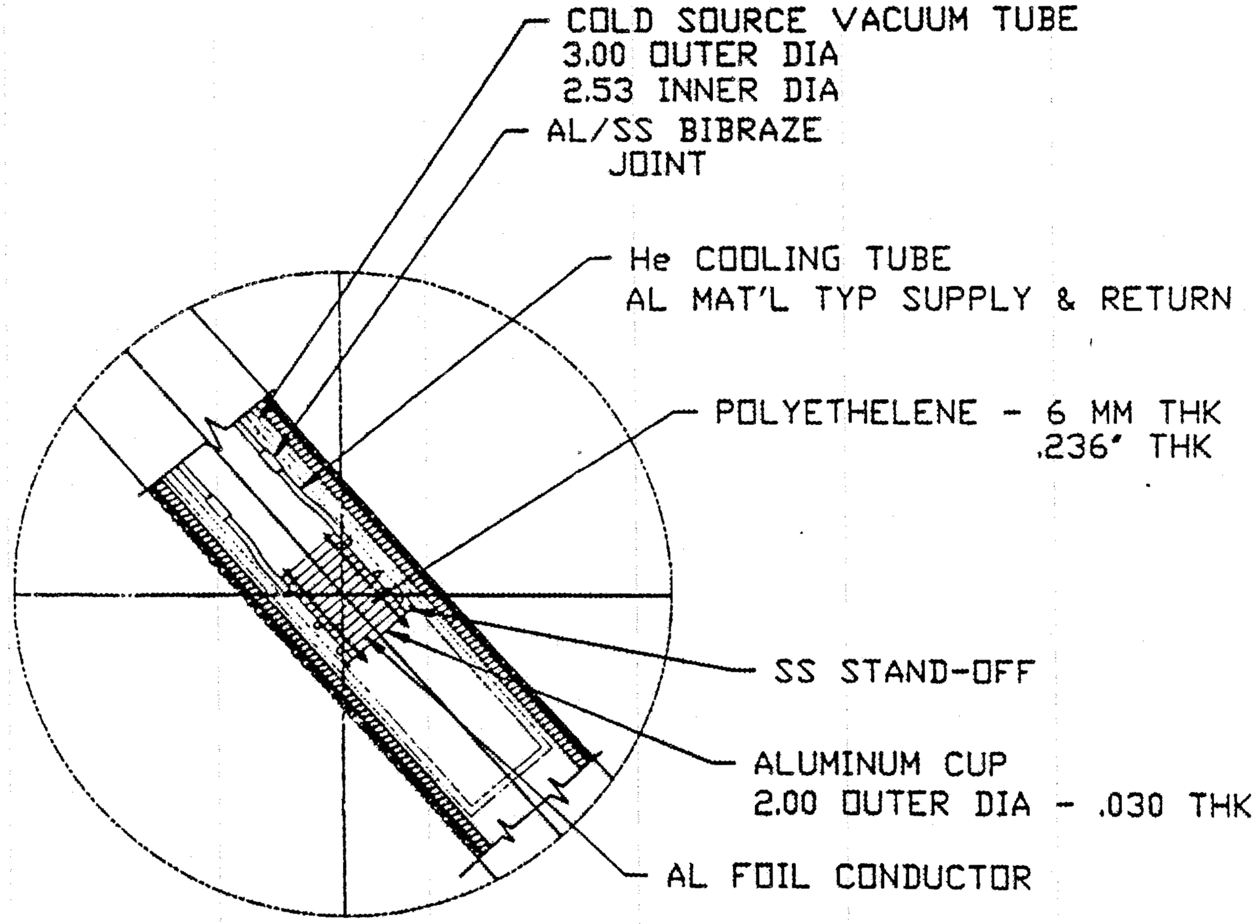


HFIR EF-2 COLD SOURCE
INSTALLATION

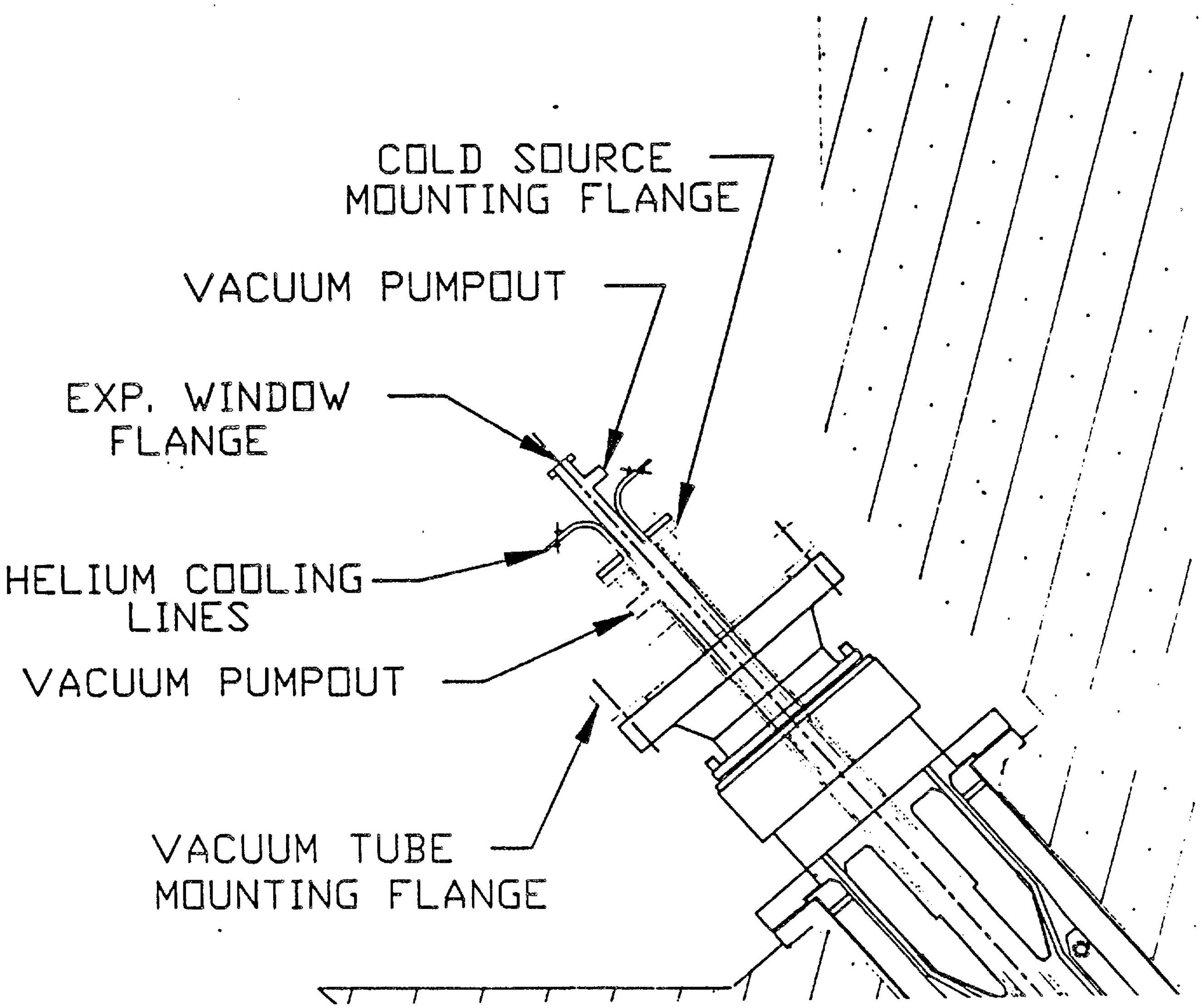


HFIR EF-2 COLD SOURCE
NEW HARDWARE


COLD SOURCE
MOUNTING FLANGE
VACUUM PUMPOUT
EXP. WINDOW
FLANGE
HELIUM COOLING
LINES
VACUUM PUMPOUT
VACUUM TUBE
MOUNTING FLANGE


COLD SOURCE VACUUM TUBE
3.00 OUTER DIA
2.53 INNER DIA
AL/SS BIBRAZE
JOINT
He COOLING TUBE
AL MAT'L TYP SUPPLY & RETURN
POLYETHELENE - 6 MM THK
.236" THK
SS STAND-OFF
ALUMINUM CUP
2.00 OUTER DIA - .030 THK
AL FOIL CONDUCTOR

VIEW A


COLD SOURCE
MOUNTING FLANGE
VACUUM PUMPOUT
EXP. WINDOW
FLANGE
HELIUM COOLING
LINES
VACUUM PUMPOUT
VACUUM TUBE
MOUNTING FLANGE

ORNL/TM-11027
Dist. Category UC-400

Internal Distribution

1. C. W. Alexander
2. R. G. Alsmiller
3. B. R. Appleton
4. J. E. Bigelow
5. K. K. Chipley
6. F. F. Dyer
7. J. A. Getsi
8. M. L. Gildner
9. C. L. Hahs
10. R. M. Harrington
11. J. B. Hayter
12. D. L. Henderson
13. J. A. Johnson
14. J. K. Jones
15. L. M. Jordan
16. B. S. Maxon
17-21. M. R. McBee
22. T. J. McManamy
23-27. B. H. Montgomery
28. R. M. Moon
29. F. R. Mynatt
30. L. C. Oakes
31. R. E. Pawel
32. F. J. Peretz
33. R. T. Primm, III
34. H. Reutler
35. L. Robinson
36. T. L. Ryan
37. D. E. Selby
38. H. B. Shapira
39. W. D. Shults
40. F. J. Sweeney
41. P. B. Thompson
42. K. R. Thoms
43. H. E. Trammell
44. D. E. Welch
45. C. D. West
46. M. K. Wilkinson
47. A. Zucker
48. ORNL Patent Office
49. Central Research Library
50. Document Reference Section
51-52. Laboratory Records
53. Laboratory Record (RC)

External Distribution

54. Office of Assistant Manager for Energy Research and Development, U.S. Department of Energy, Oak Ridge Operations, P.O. Box 2001, Oak Ridge, TN 37831
55. B. Chalmers Frazer, Materials Sciences Division, Office of Energy Research, U.S. Department of Energy, Germantown, ER-132, Washington, D.C. 20545
56. Iran Thomas, Director, Materials Science Division, Office of Energy Research, U.S. Department of Energy, Germantown, ER-13, Washington, D.C. 20545
57. D. K. Wilfert, Energy Programs, U.S. Department of Energy, Oak Ridge Operations, P.O. Box 2001, Oak Ridge, TN 37831
58. R. J. Willard, U.S. Department of Energy, Oak Ridge Operations, P.O. Box 2001, Oak Ridge, TN 37831
59-68. Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831