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INFORMAL

Rebuilding the Brookhaven High Flux Beam Reactor: A Feasibility Study

W.J. Brynda, L. Passell and D.C. Rorer

I Introduction

After nearly thirty years of operation, Brookhaven's High Flux Beam Reactor (HFBR) is still one of the world's premier steady-state neutron sources. A major center for condensed matter studies, it currently supports fifteen separate beamlines conducting research in fields as diverse as crystallography, solid-state, nuclear and surface physics, polymer physics and structural biology and will very likely be able to do so for perhaps another decade. But beyond that point the HFBR will be running on borrowed time. Unless appropriate remedial action is taken, progressive radiation-induced embrittlement problems will eventually shut it down.

Recognizing the HFBR's value as a national scientific resource, members of the Laboratory's scientific and reactor operations staffs began earlier this year to consider what could be done both to extend its useful life and to assure that it continues to provide state-of-the-art research facilities for the scientific community. This report summarizes the findings of that study. It addresses two basic issues: (i) identification and replacement of lifetime-limiting components and (ii) modifications and additions that could expand and enhance the reactor's research capabilities.

II Identification and Replacement of Life-Limiting Components of the HFBR

Generally speaking, replacement of HFBR components in regions where the radiation fields are high is a relatively straightforward operation. There are two important exceptions: replacing either the reactor vessel or thermal shield is, undeniably, a major undertaking. Thus the structural integrity of these two components ultimately determines the operating life of the reactor.

Considering first the (6061 aluminum alloy) reactor vessel, we see in Fig. 1 (a) that the thimbles (of the same 6061 alloy) that define the external beams are welded to its walls and extend inward to the region of peak flux. At their inner ends, the rate of neutron-induced-aluminum-to-silicon transmutation is sufficient to harden the alloy and gradually reduce its ductility. Any leakage of heavy water coolant through a crack in a radiation-embrittled thimble tip would require immediate shutdown of the HFBR.

Fortunately there is evidence from an on-going materials surveillance program that the ductility of the thimbles - after an initial drop - has stabilized at a safe value. But their silicon content rises steadily year after year and if no preventive action is taken it will eventually become high enough to raise questions about further operation.

A different mechanism is responsible for embrittlment of the thermal shield [see Fig. 1 (c)] but the end result is the same. Fast neutron irradiation gradually raises the nil-ductility transition (NDT) temperature of the steel plates of the shield and increases their susceptibility to brittle fracture. It is fortunate that even though the NDT temperature has reached the shield operating temperature there is little likelihood of a crack developing because the stress levels in the regions exposed to the highest fast neutron fluxes are well below those which would induce crack propagation. And even in the unlikely event that a plate did develop a crack, it wouldn't necessarily require immediate shutdown of the reactor. Nonetheless, significant leakage of thermal shield cooling water into the cavity surrounding the reactor vessel [see Fig. 1 (c)] would ultimately lead to shutdown. Hence radiation-induced cracking of the thermal shield also has the potential to limit the operating life of the HFBR.

Although the designers of the reactor assumed that both the reactor vessel and thermal shield would have to be replaced at some future time, no plans have ever been formulated to carry out such an operation. Three separate firms with the appropriate technical background - the Alaron Corporation, PCI Energy Services and Gilbert/Commonwealth - were therefore asked to make preliminary evaluations of the feasibility of (i) remotely dismembering and removing both the reactor vessel and thermal shield, (ii) packaging and transporting the highly radioactive pieces to a place of permanent storage and (iii) designing, fabricating and installing a new vessel and shield. Happily, the replies from all three firms were positive (see the attached Appendix). In fact, one, Gilbert/Commonwealth, even went so far as to include in their reply an outline of a proposed replacement operation.

Our estimate is that it would take roughly 3-1/2 years to select a vendor, plan the details of the replacement process and design and fabricate a new reactor vessel and thermal shield. Removal of the existing vessel and shield could take place during the third year while the replacement vessel and shield were under construction. An additional year would then be needed for installation of the new vessel and shield and for operational testing. Altogether, the replacement process would take the reactor out of service for about two years.

These conclusions are, of course, based on preliminary surveys. Clearly, detailed studies will be needed to determine definitively the feasiblity and cost of the project and the time required for completion. Nonetheless, it is evident from the surveys that appropriate technology for the project is on hand and readily available. The recent successful replacement of the reactor vessel of the Institut Laue-Langevin (ILL) research reactor, a project very similar to the one proposed here and one that was completed with a loss of about two operating years, assures us of the soundness of this conclusion.

Apart from resolving the embrittlement problem for at least three to four decades, replacement of the vessel would permit minor design alterations to be made to improve emergency core cooling and better accommodate equipment added to comply with revised operational and safety standards. (Currently located in ports that were originally intended for in-vessel maintenance during shutdowns, the new equipment blocks access to one of the irradiation thimbles and interferes with routine maintenance operations.) Vessel replacement would also provide an opportunity to employ metal-gasketed flanges (like those used at the ILL reactor) in place of welds to attach the beam thimbles to the vessel walls. Replacement of the thimbles (the components most vulnerable to embrittlement) would then no longer require replacement of the vessel, further extending the useful life of the reactor.

A replacement operation of the type envisioned would also provide an opportunity to enlarge one or more of the apertures in the thermal shield. Larger aperatures through the shield - in combination with larger beam thimbles and larger holes (bored) through the biological shield - would allow bigger neutron beams to be brought out of the reactor and (by taking advantage of modern focussing techniques) would significantly improve instrument performance on the corresponding beamlines. Modifications could also be made to the cavity surrounding the reactor vessel both to reduce leakage of the carbon dioxide blanket gas and to improve monitoring for the presence of tritium, a sensitive indicator of primary coolant leakage.

III Rebuilding of the Liquid Hydrogen Moderator

In the early 1960's when the HFBR was designed, the effectiveness of cryogenic liquids as neutron moderators was more a matter of conjecture than established fact. There were also unanswered questions about whether reactors could operate safely with internal cryogenic moderators. Nevertheless, the prospect of a substantially enhanced low energy neutron flux was so compelling that the H-9 beam thimble was deliberately made large enough to install a cryogenic moderator in the HFBR should it ultimately turn out to be feasible to do so. But since the heat load on such a moderator in the region of peak thermal neutron flux was thought to be unsustainable with the technology then available, it was decided not to extend the H9 beam thimble as far into the vessel as the other thimbles. As a result, the HFBR's liquid hydrogen moderator is currently located in a region where the thermal neutron flux is a third of its peak value.

Since then, however, continuous duty pumps for cryogenic liquids have become commercially available. With their advent it becomes reasonable to consider moving the liquid hydrogen moderator as close to the region of peak thermal flux as possible - in this case 25 cm nearer the reactor core - where the thermal flux is three times higher and it would produce a correspondingly threefold higher flux of subthermal neutrons.

Extending and enlarging the H9 beam thimble and repositioning the liquid hydrogen moderator as shown in Fig. 1(b) would, of course, also increase the moderator heat load threefold. At this higher heating rate the current method of cooling the liquid hydrogen with cold helium gas circulating through tubes brazed to the moderator chamber would be - at best - marginal. Indeed, it is doubtful that the heat transfer rate would even be sufficient to maintain a liquid phase in the chamber. To keep the liquid hydrogen in the moderator at the preferred operating temperature of 15K we therefore propose to pump it around a closed loop containing a high-surface-area external heat exchanger. The loop would be maintained at a pressure of about four atmospheres to prevent boiling. We note that pressurized, pump-driven circulation of liquid hydrogen is also proposed for the cryogenic moderators of the Advanced Neutron Source where the heat loads are estimated to be even higher.

Although the higher heating rates admittedly complicate the design of the proposed new H9 plug, we have nevertheless found we can retain all of the safety features of the present plug, including the most important; i.e. that the hydrogen be everywhere surrounded by helium. In fact as far as safety is concerned, the only significant difference between the new H9 beam plug [shown in Fig. 2(a)] and the existing plug is that the helium, instead of being present as gas, would be dissolved, under pressure, in the heavy water used to cool the plug and vacuum chamber walls [see Fig. 2(b)]. Its function as an ultra-sensitive indicator of an external leak into the moderator vacuum space would, however, be unaffected.

An enlarged and extended H9 beam thimble and beam plug would not only permit a substantial improvement in the performance of the liquid hydrogen moderator but would provide enough extra space to increase the number of neutron guides from three to five, each 2.5 cm wide and 15 cm high. Moreover, it should be possible to enhance the performance of the system still further by taking advantage of present-day Monte Carlo neutron optics computer programs to determine how to position and angle the guides so that they collect and transmit the neutrons produced by the moderator with optimum efficiency. Also the (recent) development of supermirror coatings that more than double the critical angles for total reflection will undoubtedly enhance the efficiency with which neutrons are transported through the guides thus adding further to the over-all performance of the system.

Altogether, the combination of better moderator location, more and bigger guides and better subthermal neutron collection and transmission makes it attractive to consider a major expansion of the HFBR's subthermal neutron instrumentation. In the section to follow we therefore turn to consideration of how such an expansion could be implemented.

IV A Neutron Guide Hall for the HFBR

When the last of the currently funded new beamlines is in place there will be a total of 18 instrument stations on the HFBR experimental floor and nearly all available space will be occupied. Only by drastically constricting the floor space allocation (and thus the performance) of individual instruments would further expansion within the reactor confinement building be possible.

Fortunately, a better alternative was suggested in the original HFBR upgrade proposal of 1984. Even with the then-available neutron guide technolgy, subthermal neutron beams could be transmitted more than 30 meters from the reactor biological shield face before the losses become unacceptable. Now, with the prospect of an optimally-located liquid hydrogen moderator and the possibility of using it to supply subthermal neutrons to an increased number of large-cross-sectional-area, high-efficiency guides, it becomes even more attractive to think in terms of expanding the instrument base beyond the limits imposed by the size of the experimental floor.

What is envisioned is the construction of a four story guide hall building adjacent to the reactor more or less as shown in Fig. 3. While it would be premature to describe the details of such a building on the basis of this preliminary study, we can say that it would have enough room in the basement for a pair of cold helium gas refrigeration plants for the liquid hydrogen moderator and that the two floors above would provide ample space for offices, laboratories and a machine shop, electronics shop and cryogenics facility. On the top floor (at the same grade level as the experimental floor in the confinement building) we visualize five guides - in an as yet incompletely determined arrangement - transporting neutrons to as many as fifteen new subthermal instrument stations. If the experimental facilities of the HFBR were to be so expanded, it would support twice the number of beamlines it supports today and three times the number it served in 1965 when it was originally commissioned.

In such a guide hall, a whole new high-resolution capability based on subthermal beams would be possible. It could support, for example, one or more high-resolution triple-axis spectrometers (either with or without a polarization-analysis capability), a spin-echo spectrometer, a back-scattering spectrometer, a multi-rotor, ultra-high-resolution time-of-flight spectrometer, a time-focussing, time-of-flight spectrometer (either with or without a polarization-analysis capability), both conventional and Laue-type diffractometers for protein crystallography, one or more high-resolution neutron reflectometers for surface and interface studies and several high resolution small-angle-scattering spectrometers for both biological systems investigations and polymer studies.

V Final Comments

The suggested minor alterations in the design of the reactor vessel would neither alter the HFBR's basic internal structure nor require changes in operating procedures. Moreover, enlargement and extension of the H9 beam thimble has been estimated to have little effect on the physics of the reactor core. Hence it may even be possible to enlarge several other beam thimbles and, with focussing optics, improve the performance of the instruments they serve.

Since reactor safety is always a matter of concern, it is important to emphasize that none of the above proposed modifications is outside the original safety envelope of the HFBR. No new unreviewed safety issues would be raised by the project; thus we think it likely that the project safety review would focus primarily on the removal and replacement operations.

An HFBR with 31 instrument stations, a new reactor vessel and thermal shield, an optimally located liquid hydrogen moderator and the expanded experimental capability provided by a guide hall would satisfy a substantial part of the projected U.S. demand for steady-state neutron reseach facilities. Moreover, rebuilding the reactor and upgrading and expanding its research instrumentation would be much less costly and time-consuming than building a completely new facility of comparable size. In an era of extreme budgetary constraints we believe this project to be a realistic and cost-effective way to maintain - for many years to come - a strong, broadly-based position in an important area of basic condensed matter research.

VI Acknowledgements

A number of people provided advice and assistance during the course of this study. A.G. Prodell served as our resident expert on cryogenics safety issues, J.P. Hu made a number of computer-based heat load calculations for us, M.C. Taylor did all of the design studies for the plug and guide hall and P.R. Tichler, apart from giving us guidance on heat transfer questions, also investigated for us the operational effect of expanding and extending the H9 beam thimble. We thank them for their contributions. Work at Brookhaven was carried out under contract no. DE-AC02-76CH00016, Division of Materials Science, US, DOE.

VII Appendix

(i) Letter - ALARON Corporation to C. Scarlett dated 1 August, 1994.

(ii) Letters - PCI Energy Services to C. Scarlett dated 2 and 5 August, 1994.

(iii) Letter - Gilbert/Commonwealth Inc to J.E. Teahan dated 11 August, 1994.

Figure Captions

Fig. 1 (a) Plan view of the HFBR reactor vessel showing the beam thimble layout. In the present design the thimbles are welded to the reactor vessel.

(b) Proposed new beam thimble layout. In the new design the liquid hydrogen moderator thimble is enlarged and extended 25 cm closer to the reactor core. Also flanges are used to attach the thimbles to the reactor vessel.

(c) Side view showing the reactor vessel, thermal shield and cavity.

Fig. 2 (a) Top and side views of the proposed new beam plug for the liquid hydrogen moderator. In addition to locating the moderator chamber in the region of peak thermal flux, the new plug contains five neutron guides 15 cm high and 2.5 cm wide.

(b) Schematic showing the liquid hydrogen and water cooling loops. Heavy water charged with helium gas cools the plug and serves as well as a helium blanket around all spaces containing liquid hydrogen. Light water is used to cool the neutron guides.

Fig. 3 Proposed guide hall. Supplied with neutrons by the liquid hydrogen moderator, it would contain five guides serving a total of 15 new, subthermal instrument stations.

ALARON CORPORATION

August 1, 1994 CL089401

Mr. Clifford Scarlett, PE
Senior Project Engineer
Brookhaven National Laboratory
Building No. 120
Upton, L.I., NY 11973

Subject: Upgrade of the High Flux Beam Reactor (HFBR)

Dear Mr. Scarlett:

During the week of July 10, 1994, ALARON personnel visited Brookhaven to discuss planned activities associated with upgrade of the subject reactor. Specifically, as a decontamination and decommissioning contractor, we wished to evaluate the feasibility of removal of the thermal shield, reactor vessel and other irradiated core components in such a fashion as to allow for reinstallation of a new vessel and components. After visiting the site, discussing planned activities with you, reviewing the drawings and the FSAR, we are confident that the demolition portion of the work can be done in a manner that would allow for installation of the new vessel and components.

We believe the demolition phase of the work could be done in approximately 10-14 months. The key to the job is sufficient pre-planning with the supplier of the new vessel to determine where the cuts are to be made to facilitate the reinstallation. Preplanning of all work activities is also key to the project due to the radiation levels associated with the irradiated components.

In summary, upgrade of the HFBR is feasible. The upgrade would allow the quality of the experiments conducted at Brookhaven to be improved while increasing the operating safety margins. Another potential benefit to the DOE would be the opportunity to demonstrate the application of remote segmentation technology in the course of the demolition.

We appreciate being afforded the opportunity to visit the site and would welcome the chance to work with you in the development of a more definitive engineering cost estimate. Please feel free to call if we can be of further assistance.

Sincerely,

Dean Padgett
Director, Sales and Marketing

cc: Larry Sears
Greg Garlock
File

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PCI Energy Services
FIELD MACHINING, WELDING,
TOOL DESIGN & ENGINEERING

August 2, 1994

Mr. Cliff Scarlett
Brookhaven National Laboratory
P.O. Box 5000
Upton, NY 11973-5000

Dear Mr. Scarlett:

In response to your request I am writing to express our interest in supporting your efforts to change out the BNL reactor. Specifically, we feel confident that the hardware, including the RPV, RPV internals, thermal shield (top and bottom sections) and the steel lines at the bio shield can be successfully removed utilizing techniques which are field proven. Furthermore, installation of replacement components can also be accomplished by combining our newly developed Laser Metrology process and technologies similar to those implemented on Steam Generator Replacement Projects.

As I mentioned, we have worked on many such projects, most notably and recently at Fort St. Vrain and at Shoreham, with our sister company the Scientific Ecology Group (we are both subsidiaries of Westinghouse Electric). In these efforts PCI performs the removal and reinstallation work and SEG packages the removed materials, transports them to their facility in Oak Ridge Tennessee and processes the materials through a variety of steps.

These processes are all oriented towards waste volume minimization and include metal melt, decontamination, incineration and supercompaction.

As an integrated team PCI and SEG can bring unmatched experience to bear on the unique problems associated with this project.

We recommend that a detailed project feasibility study be conducted to include conceptual disassembly/reassembly approaches and rough scheduling as well as disassembly sizing and sequencing. Also included in this study would be waste packaging and processing approaches aimed at volume minimization. It is important to note that PCI is currently performing a contract for BNL in support of the flux thimble beam tube replacement project.

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PCI EnergyServices

Mr. Cliff Scarlett
Brookhaven National Laboratory
August 2, 1994

I have provided as an attachment to this letter a number of technical papers which highlight our relevant experiences. We look forward to further dialogue on this important project.

Sincerely,

Michael S. McGough
Senior Vice President

cc: H. Arrowsmith - SEG
J. Pride - SEG
G. Knetl
J. Polacheck
T. Rennell
G. Parson

Enclosures:

- Internals Segmentation at Shoreham 850 MWe Boiling Water Reactor
- Visual Monitoring of Remote Welding Operations
- The Evolution of Steam Generator Replacement Projects in the United States.
- Under Water Plasma Cutting of the Lower Core Support Assembly and Metallurgical Sample of the Bottom Head at Three Mile Island Unit 2
- Plant Equipment Services with Laser Metrology
- Remote Reactor Repair: GTA Weld Cracking Caused by Entrapped Helium
- The Use of Remote Machining and Welding Techniques for Field Replacement of a Pressurizer Instrumentation Nozzle.

PCI Energy Services

FIELD MACHINING, WELDING.
TOOL DESIGN & ENGINEERING

August 15, 1994

Mr. Cliff Scarlett
Brookhaven
P.O. Box 5000
Upton, NY 11973-5000

Dear Mr. Scarlett:

In my letter of August 2, 1994, I forgot to mention our view of the schedular requirements of your proposed project. It is my hope that the project summaries that were included in that letter provided analogies to your effort and that the periods of performance could be extrapolated. To be clear, we feel that the field implementation phase of this effort would be accomplished in 6 to 12 months.

We look forward to continuing dialogue on this matter and apologize for any inconvenience caused by my omission of this data from my previous letter.

Sincerely,

PCI ENERGY SERVICES, INC.

Michael S. McGough

Michael S. McGough
Senior Vice President

MSM/mck
cc: H. Arrowsmith - SEG
J. Pride - SEG
G. Knetl
J. Polacheck
T. Rennell
G. Parson

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EVALUATION OF THE REMOVAL AND REPLACEMENT OF THE REACTOR VESSEL AND THERMAL SHIELD FOR THE HIGH FLUX BEAM REACTOR AT BROOKHAVEN NATIONAL LABORATORY

BY
GILBERT/COMMONWEALTH, INC.,
ENGINEERS AND CONSULTANTS
READING, PA - OAK RIDGE, TN

AUGUST, 1994

BNL Contract No. 593788
Task Order No. 4, BNL Account No. 05936

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1. THE PROBLEM

The High Flux Beam Reactor (HFBR) at Brookhaven National Laboratory has been in service for almost 30 years, and the neutron damage to the reactor pressure vessel and the thermal shield require that these components be replaced in the future if the HFBR is to continue to operate safely. This report examines the feasibility of replacing these components with new components of an identical or similar design, and estimates the time required to design, analyze, specify, procure, fabricate, and deliver the new components. This examination is a brief review performed using plan and section drawings by Gilbert/Commonwealth engineers familiar with demolition and installation techniques in an activated and contaminated environment. It is not a detailed plan for the safe removal and installation of these components.

2. METHODOLOGY

The feasibility of removing and replacing the HFBR reactor vessel and thermal shield was determined by examination of plan and section drawings of the facility, development of a conceptual plan for access to the components, disassembly or cutting of portions of the assembly and removal into protective packaging or shielded casks, and installation of replacement components. Consideration was given to personnel exposure to radiation, release of contamination, and the feasibility of in situ decontamination of the components. Disposal of the contaminated materials is assumed to be by others.

The estimate of the time required to design, fabricate and deliver the new components was determined by identifying the discreet tasks necessary to accomplish each stage of the activity, and assigning a reasonable duration to these tasks. Estimates of the costs of these components and the time to demolish and install was not in the scope of this task.

3. REMOVAL OF COMPONENTS

3.1 Preparation for Demolition

The preparation phase includes major operations such as defueling the reactor, draining and drying heavy water circuits, removal of all beam tubes and thimbles, removal of control rods, rabbit tubes and experiment tubes. The concept developed herein, and believed to be the most cost effective, is to remove the reactor vessel and the reactor coolant piping in one piece, and to withdraw the assembly into a transport vessel resembling a tank approximately 15' in diameter and 30' high. A hole in the top for the lifting cables and a bottom plate for supporting the reactor and sealing the vessel are features of this vessel. This vessel will provide shielding and containment of any airborne contamination, and will serve as a shipping container for the ultimate disposal of the reactor. To place and remove this vessel, a hole must be cut in the roof of the reactor building, and a heavy-lift crane placed outside. The type of crane (crawler, ring or other) will depend upon the weight and reach required for the heaviest lift.

3.2 Removal and Storage of Reusable Components

The apparatus, piping and wiring located above elevation 135' must be removed above the reactor coolant piping on the piping axes, and at a radius of approximately 6' on the remaining circumference. The corbels at elevation 129'-4" which support the reactor vessel and the shutter drives will not have to be altered using a concept described below. Components removed will be reused, and should be decontaminated and packaged for reinstallation. Inspection and refurbishment of piping, tubing, electrical equipment and instrumentation is recommended prior to re-installation.

3.3 Removal of Reactor and Thermal Shield

The reactor coolant piping flanges located below elevation 107'-3" where the piping transitions from aluminum to steel must be cut off. The pipe does not have to be cut, as the slip-on flange lip on the pipe will clear the pipe chase above. The vessel anchor bolts at elevation 129'-4" are removed, and a lifting fixture attached to the vessel flange at elevation 135'. The receiving vessel described in section 3.1 is positioned on the reactor cavity rim at elevation 149', the lifting cable threaded through the opening in the reactor building roof and the receiving vessel, and the entire reactor with cooling pipe attached is withdrawn into the receiving vessel. When the withdrawing operation is complete, the bottom of the receiving vessel is installed, and the entire assembly lifted out of the reactor building.

The thermal shield, with its lead shielding material is very heavy, and presents a problem in a one-piece lift. In addition, there are no convenient attachment points for lifting apparatus, and structural obstructions above the shield preclude a one-piece removal. This component should be cut into smaller pieces and removed by a competent contractor experienced in the removal of components such as this. It is possible that the lead shot could be drained from the vessel by cutting windows in the lower part of the shell and vacuuming or scooping the shot out. The possibility exists that the shot is partially fused, and draining though windows is not feasible. The existing building crane could be used for placement of small packaging casks for the cut-up shield. The shield cooling supply and return piping can be cut through the access portal below elevation 107'-3", and withdrawn after the lead shot is drained from the pipe chase below elevation 112'-11".

3.4 Precautions During Demolition

Due to the probable activation of materials within the reactor cavity, most of the disassembly and cutting must be done with remote apparatus and long-handle tools. Flooding of the cavity for shielding is not feasible, so suitable precautions must be exercised. Decontamination of walls and floors should be done by conventional means as the disassembly proceeds and surveys are taken. Temporary barriers to airborne contamination must be erected above the reactor cavity, and the beam tube openings should be sealed in the experiment area. Certain components such as beam tube shutters may be so highly activated that reuse is not feasible, and these items must be replaced. A staff of health physics personnel familiar with the hazards of plant demolition must be available during all operations.

4. PROCUREMENT AND MANUFACTURE OF REPLACEMENT COMPONENTS

4.1 Design

The new reactor vessel should be designed using ASME Section III for class 1 reactor vessels. A recent code case pursued by the Advanced Neutron Source has approved 6061 aluminum as a qualified material for class 1 components, so the vessel and the aluminum piping should use this code-approved material. During the design of the replacement vessel, certain enhancements should be included such as the ability to replace beam tube windows from the beam rooms. ASME requires the preparation of a Design Specification for class 1 vessels, certified by a Professional Engineer qualified to design reactors. The Design Specification becomes part of the procurement documents and is the basis for the ASME Class 1 Stress Report produced by the manufacturer. These are necessary for the application of the ASME stamp on the vessel. The design of the vessel and the preparation of the Design Specification is estimated to take six to nine months. The design and specification for the replacement thermal shield will parallel the reactor, and can be accomplished in the same interval.

4.2 Procurement

The procurement cycle includes the preparation of the procurement documents, solicitation of bids from qualified suppliers, evaluation of bids, selection of the successful supplier, and negotiation of a contract. Due to the complex nature of the design and the scarcity of the aluminum material, this phase should be at least six months.

4.3 Fabrication and Shipment

The fabrication, inspection and test of the reactor and shield assemblies are complicated by the necessity to procure ASME N-1 grade 6061 aluminum in the quantities and shapes required. This will require a special mill run by the material supplier to the fabricator, and could take up to nine months to obtain the raw material. The assembly will require special jigs and fixtures to maintain the precision necessary for the beam tube thimbles and other connecting components. Forging the aluminum into the spherical shape, welding and inspecting the assemblies and maintaining the dimensional controls necessary are complex operations, and are expected to take from twelve to eighteen months. The hydrostatic tests and code-required inspections, plus shipment to the site will add approximately two additional months.

5. INSTALLATION OF NEW COMPONENTS

5.1 Installing and Connecting New Reactor and Thermal Shield

The installation of the thermal shield presents a problem with clearances if the shield is installed in a single piece, and the design is the same as the present design. Based on the drawings furnished to Gilbert/Commonwealth, the assembled shield will not clear the corbels that support the reactor vessel, so installation of an identical design in one piece is not possible. The weight of an assembled shield is excessive, and would provide problems with lifting capacity.

A concept developed by G/C envisions a shield composed of an inner and outer shell, installed separately. The shield is not a pressure vessel, does not have to be code-stamped, and its primary function is to contain the lead shielding material. It must be cooled to remove the gamma heating. The G/C concept is an inner and outer shell composed of three or four curved panels with plate heat exchanger channels in each panel. Panels would have openings for beam tubes and experiments. These panels would be connected by hinged joints which could be folded into a diameter less than the final installed diameter, and expanded into a cylinder after lowering into the reactor cavity. A thermal-hydraulic analysis of this concept would determine if the outer shell needed cooling. It is possible that the liner of the cavity could serve this purpose, in which case only the inner shell would be cooled. The bottom of the shield would be a separate disc with heat exchange circuits. The cooling piping would be fed through the existing chase and connected below elevation 107'-3". Lead shot or lead sand would be used to fill the annular spaces and provide the shielding. This concept allows in-place fill with lead shot to 100% of its radiation shielding capacity. G/C estimates that this concept will be more economical than the present design.

The new reactor vessel with cooling piping would be lowered in one piece, the reverse of the removal technique. No shielding or radiation precautions would be required, and the existing crane may be sufficient for this relatively lightweight lift.

The reactor coolant piping is reconnected using segmented slip-on flanges similar to the original, avoiding any in-place welding of aluminum reactor coolant piping. The shield cooling circuits, now consisting of multiple small diameter pipe, can be easily routed and connected in the existing pipe chase. Hydrostatic testing of the shield cooling could be completed prior to adding the lead shot and the reactor vessel installation.

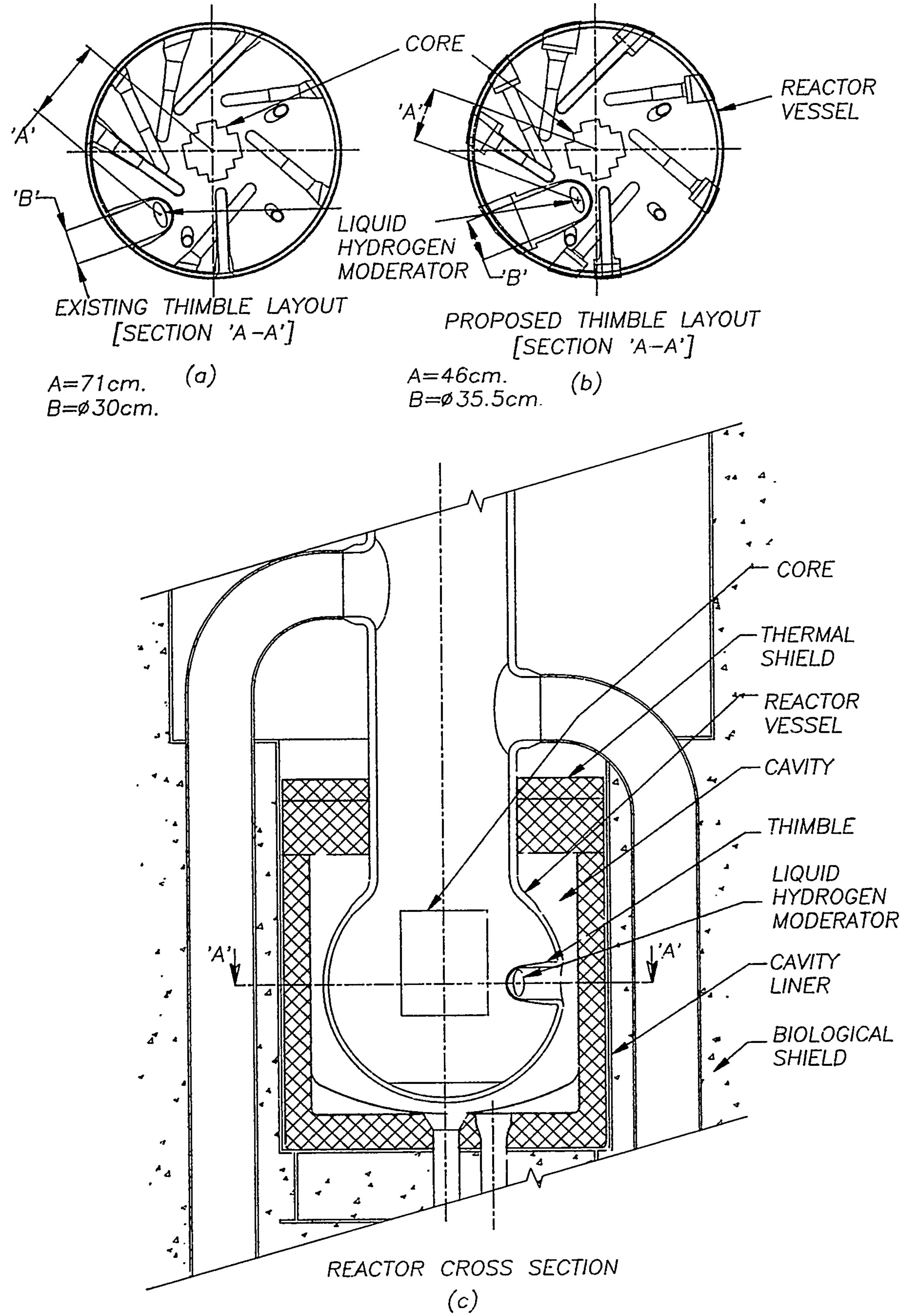
5.2 Reinstalling Supporting Equipment

After installation and alignment of the reactor vessel, the support equipment is reinstalled, aligned, and tested. Background radiation levels at this time should be minimal, so much of the assembly can be done hands-on. Special attention to cleanliness is necessary to assure that no foreign materials enter the cavity or the cooling circuits. Reassembly of the beam tubes and thimbles, control rods and finally fuel complete the installation.

6. CONCLUSIONS

Based on the brief review of the materials provided it is the conclusion of G/C that the replacement of the reactor and thermal shield at the HFBR is feasible, and presents no unsurmountable obstacles. G/C recommends a more thorough examination of the process be conducted, using a 3-D CADD model of all components. This will confirm that the concepts and techniques developed and described herein are valid, and that the clearances and capacities needed for one-piece removal are possible. Use of 3-D CADD models will permit animation of the process and assist in the detail development of the sequence, schedules, estimates and health physics procedures.

The total duration for the design, fabrication and delivery of replacement components is estimated at thirty-five to forty-four months. During the design, fabrication and delivery of the replacement components, demolition and removal of the existing components can proceed. The overall replacement project should be accomplished in approximately four years, pending adequate DOE funding.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(c)

FIGURE 1

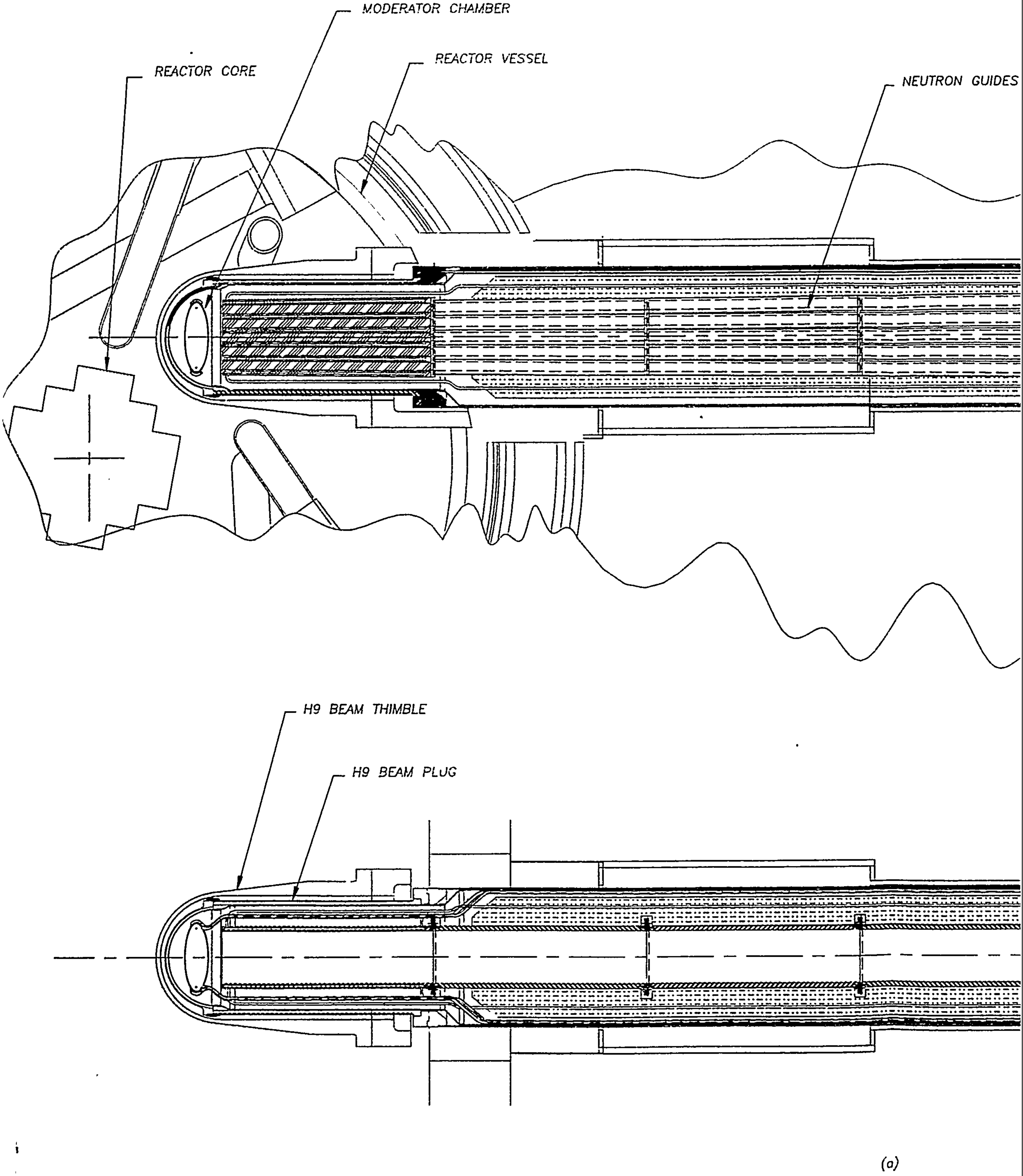
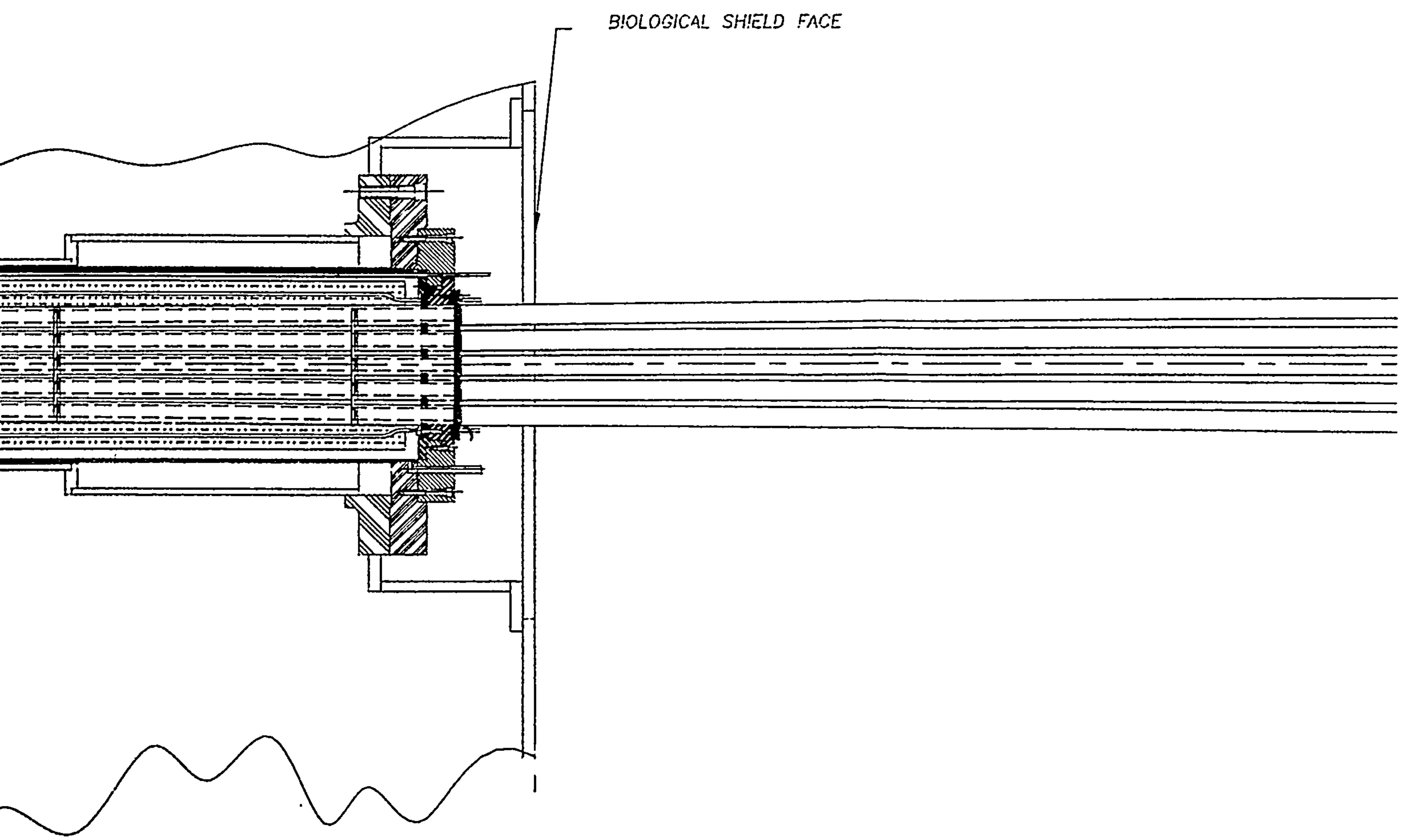
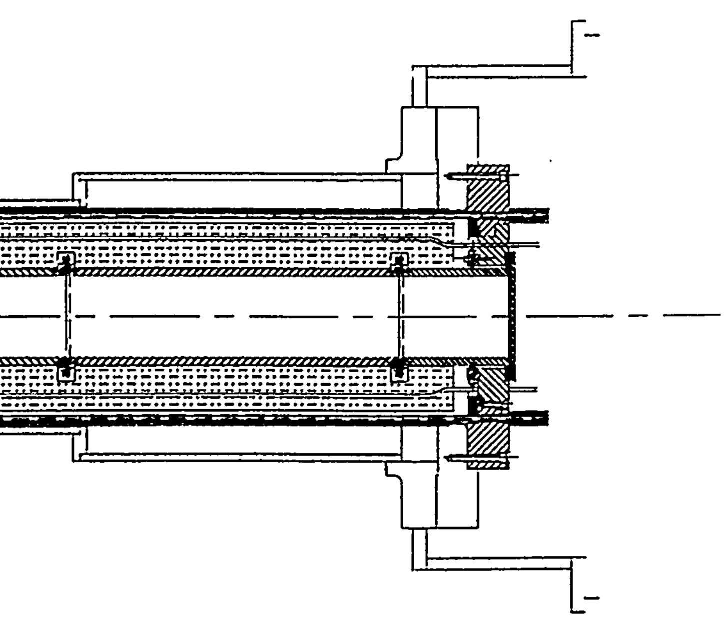
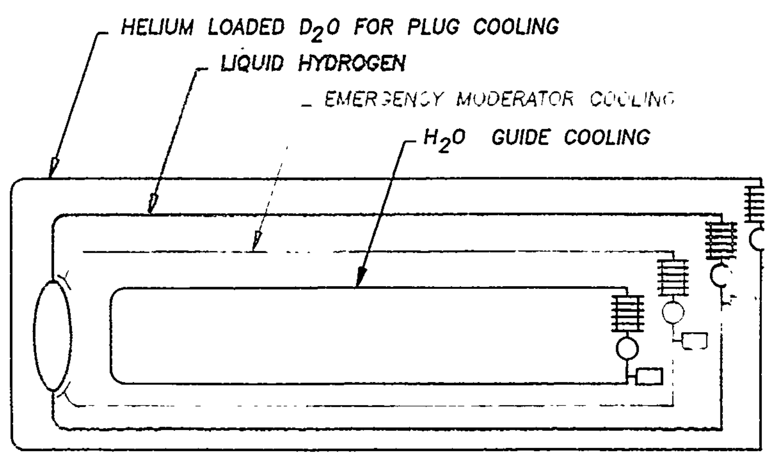

MODERATOR CHAMBER
REACTOR VESSEL
REACTOR CORE
NEUTRON GUIDES
H9 BEAM THIMBLE
H9 BEAM PLUG
(a)

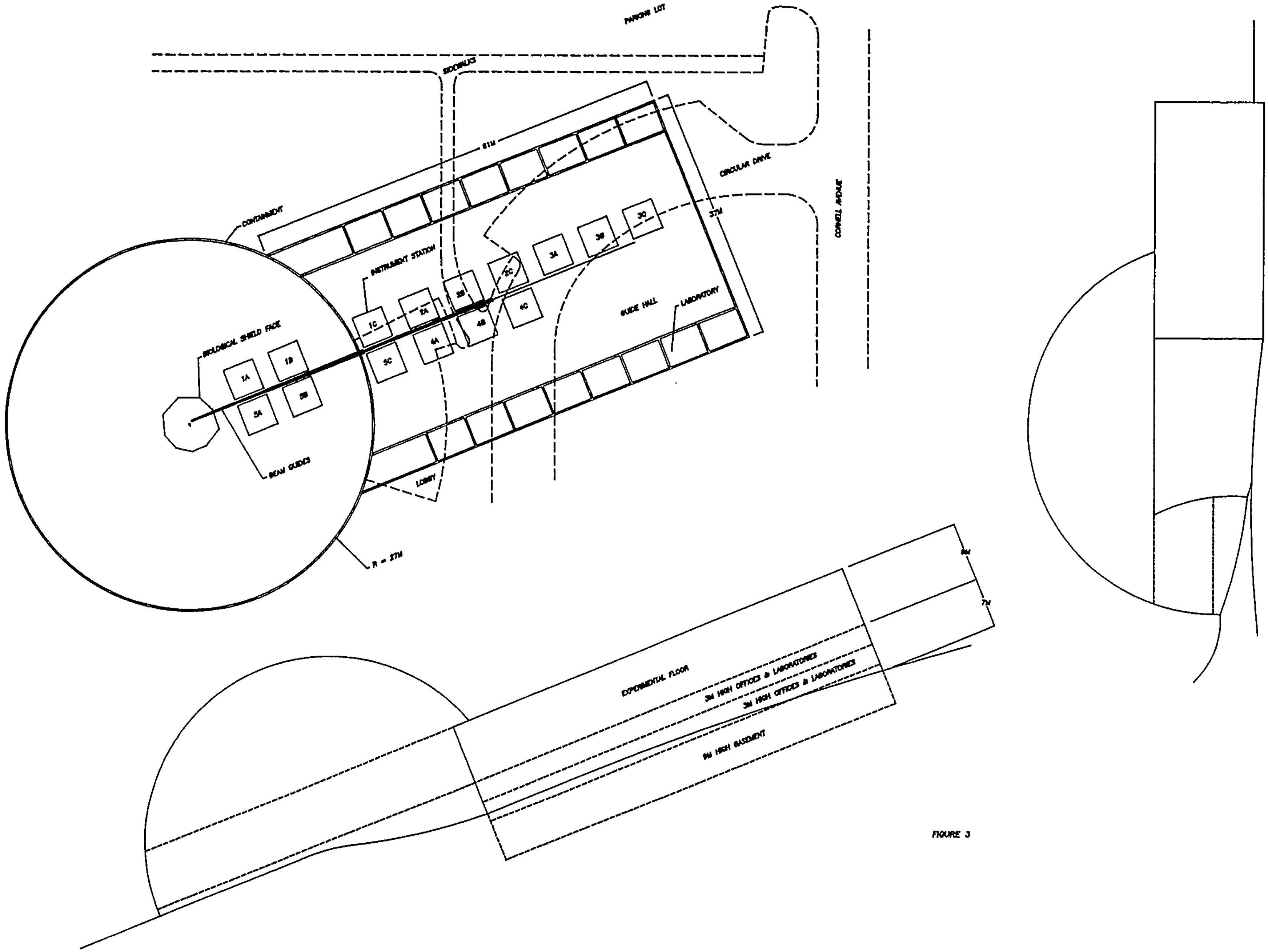
FIGURE 2


BIOLOGICAL SHIELD FACE




HELIUM LOADED D2O FOR PLUG COOLING
LIQUID HYDROGEN
EMERGENCY MODERATOR COOLING
H2O GUIDE COOLING

(b)



PARKING LOT
SIDEWALKS
CIRCULAR DRIVE
CORNELL AVENUE
CONTAINMENT
81M
37M
INSTRUMENT STATION
BIOLOGICAL SHIELD FACE
GUIDE HALL
LABORATORY
BEAM GUIDES
LOBBY
R = 37M
1A
1B
5A
5B
1C
2A
2B
2C
3A
3B
3C
4A
4B
4C
5C
EXPERIMENTAL FLOOR
3M HIGH OFFICES & LABORATORIES
3M HIGH OFFICES & LABORATORIES
9M HIGH BASEMENT
8M
7M

FIGURE 3