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CONCEPTUAL DESIGN OF A LASER-FUSION POWER PLANT

PART I. AN INTEGRATED FACILITY

prepared for

LAWRENCE LIVERMORE NATIONAL LABORATORY

by

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RESEARCH AND ENGINEERING

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PART I

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Section 1

INTRODUCTION AND SUMMARY

1.1 INTRODUCTION

This study is a new preliminary conceptual design and economic analysis of an inertial confinement fusion (ICF) power plant performed by Bechtel under the direction of Lawrence Livermore National Laboratory (LLNL). The purpose of a new conceptual design is to examine alternatives to the LLNL HYLIFE power plant [Bechtel, 1978] [1/] and to incorporate information from the recent liquid metal cooled power plant conceptual design study (CDS) [U.S. DOE, 1981] into the reactor system and balance of plant design. A key issue in the design of a laser fusion power plant is the degree of symmetry in the illumination of the target that will be required for a proper burn. Because this matter is expected to remain unresolved for some time, another purpose of this study is to determine the effect of symmetry requirements on the total plant size, layout, and cost.

In this study we have investigated the impacts on plant design and cost resulting from increasing the number and degree of symmetry of high f/number laser beams. In order to isolate the effect on cost of varying only the illumination geometry, we have assumed that the target gain is the same for both the two- and eight-sided examples; also we have kept the mirror distance and f/number unchanged. Given the present uncertainties in the effects of illumination uniformity on target gain, this is the only prudent assumption. However, it should be understood that the plant layout and cost estimates may be quite different if a larger number of small f/number mirrors, placed closer to the target, are required. We have not examined the latter case.

1/ See Section 5 for references.

The baseline facility design is a twin unit electric generating station. Each unit has an electrical output of 1,000 MW_e. The concept provides for two separate reactor-turbine-generator plants driven by a single 4.4 MJ short wave length laser system operating at a repetition rate of 10 Hz (5 Hz to each reactor). The site also contains all appropriate auxiliary, miscellaneous, and waste handling facilities. The primary design areas that are addressed in this study are the reactor concept, heat transfer system, beam transport architecture, illumination symmetry, balance of plant, and capital cost.

The HYLIFE reactor uses lithium jets to absorb the fusion energy and protect the first structural wall. The high flowrate of Li (~10 times that needed for a typical temperature rise of ~150 K) requires numerous large pumps and, therefore, a large and costly containment building [Bechtel, 1978; Monsler, 1979]. The conceptual design of an integrated ICF facility presented here assumes a low flowrate reactor that allows the typical temperature rise of ~150 K across it. An example of such a low flowrate reactor is LLNL's new JADE concept discussed in Part II of this report.

Alternatives for the primary and secondary heat transport systems are examined. The application of heat pipes to eliminate portions of the primary or secondary coolant loops, thereby reducing the pumping requirements, is considered in Part II. Also evaluated is the use of lithium as opposed to sodium as the secondary coolant.

Two alternative beam transport systems are examined in this study. The first provides two sided illumination of the target as used in the HYLIFE design. The second provides symmetrical eight sided illumination of the target. Note that this does not imply that eight-sided illumination provides adequate implosion symmetry of a target; this is still unknown.

The balance of plant is modeled as much as possible after the current LMFBR design [U.S. DOE, 1981]. The fusion plant design includes unique primary and secondary piping and equipment layouts for the two and eight sided illumination cases. Suggested conceptual designs for containment buildings, optical cells, beam tunnels, and steam generator buildings are given. In addition to these structures and buildings, the turbine-generator building, essential maintenance and operating buildings, and miscellaneous support buildings are described.

1.2 SUMMARY

This study indicates the feasibility of constructing an ICF power plant under reasonable extrapolation of some primary nuclear systems and the balance of plant employed in the LMFBR program.

An order of magnitude cost estimate is that a fifth of a kind, twin 1000 MW_e reactor ICF power plant (excluding laser and target facilities) can at this stage of development be projected to cost ~3 B$ per reactor in 1981 dollars. This figure includes a 33% savings that results in going from a first of a kind plant to a fifth of a kind and an additional 8% savings that multiple reactor siting offers over single unit siting.

Using targets illuminated by high f/number optics, we can increase the number of beams illuminating the target without appreciably affecting the overall plant cost. Although the in-reactor beam transport equipment and architecture increases in cost by a factor of 2.25 in going from two sided to eight sided illumination, the impact on total plant cost is neglible. For two sided illumination, the in-reactor optical system costs ~0.3% of total plant cost, while for the eight sided case it costs ~0.8% of total plant cost.

Conclusions on the JADE reactor concept and the novel use of heat pipes in ICF heat transport systems can be found in Part II of this report.

Section 2

PLANT DESIGN: TWO SIDED ILLUMINATION

2.1 SYSTEMS

2.1.1 OVERVIEW

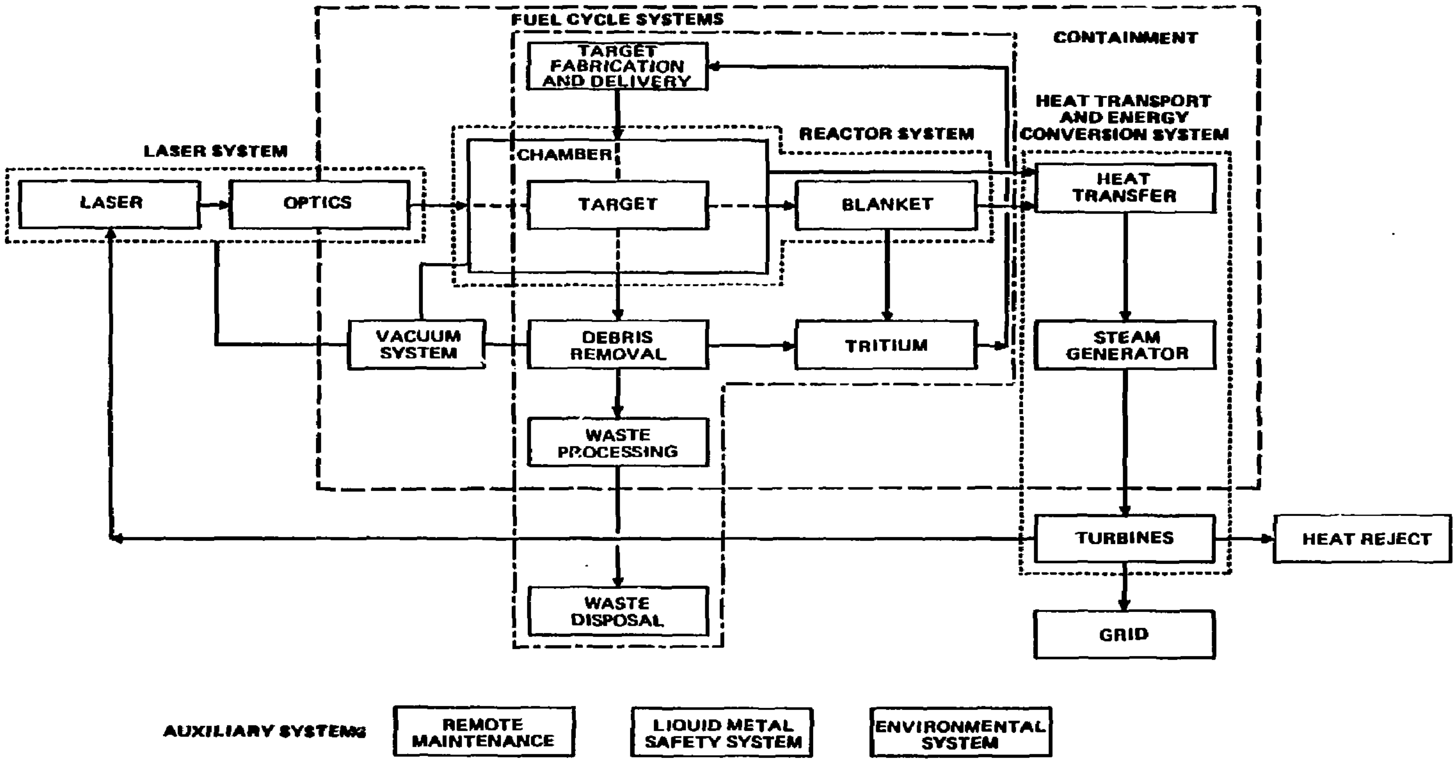
The major systems of a generic laser fusion power plant are shown in Figure 2.1.1.1. It is this complex of devices and processes that determine the structures and buildings required by the plant.

The systems and buildings for a laser fusion plant are comparable in size, number, and function to their counterparts designed for large liquid metal fast breeder reactors (LMFBR). Notable exceptions are the laser, optics, and target systems and their associated buildings. The design of the other systems and buildings however, can benefit significantly from LMFBR design efforts. It is on the latest such LMFBR design [U.S. DOE, 1981] that this study relies when appropriate.

2.1.2 NUCLEAR STEAM SUPPLY SYSTEM

The nuclear steam supply system (NSSS) is comprised of the reactor vessel and internals, primary coolant pumps, intermediate heat exchangers, secondary coolant pumps, steam generators and all other secondary equipment necessary to operate the NSSS in an efficient and safe manner. Design parameters are given in Table 2.1.2.1. A schematic of this system is shown in Drawing 2.1.2.1.

The design assumed in this study calls for the energy developed in the reactor to be removed by two primary lithium loops each of which transports the energy to two intermediate heat exchangers (IHX). Each IHX has a secondary sodium loop which delivers the power to separate steam generator super-heater (SG/SH) pairs. (Thus, the heat transport system contains two primary lithium loops, four IHXs, four secondary sodium loops,



GENERIC LASER FUSION POWER PLANT SYSTEMS

Figure 2.1.1.1

Table 2.1.2.1

DESIGN PARAMETERS FOR THE ICF POWER PLANT NSSS

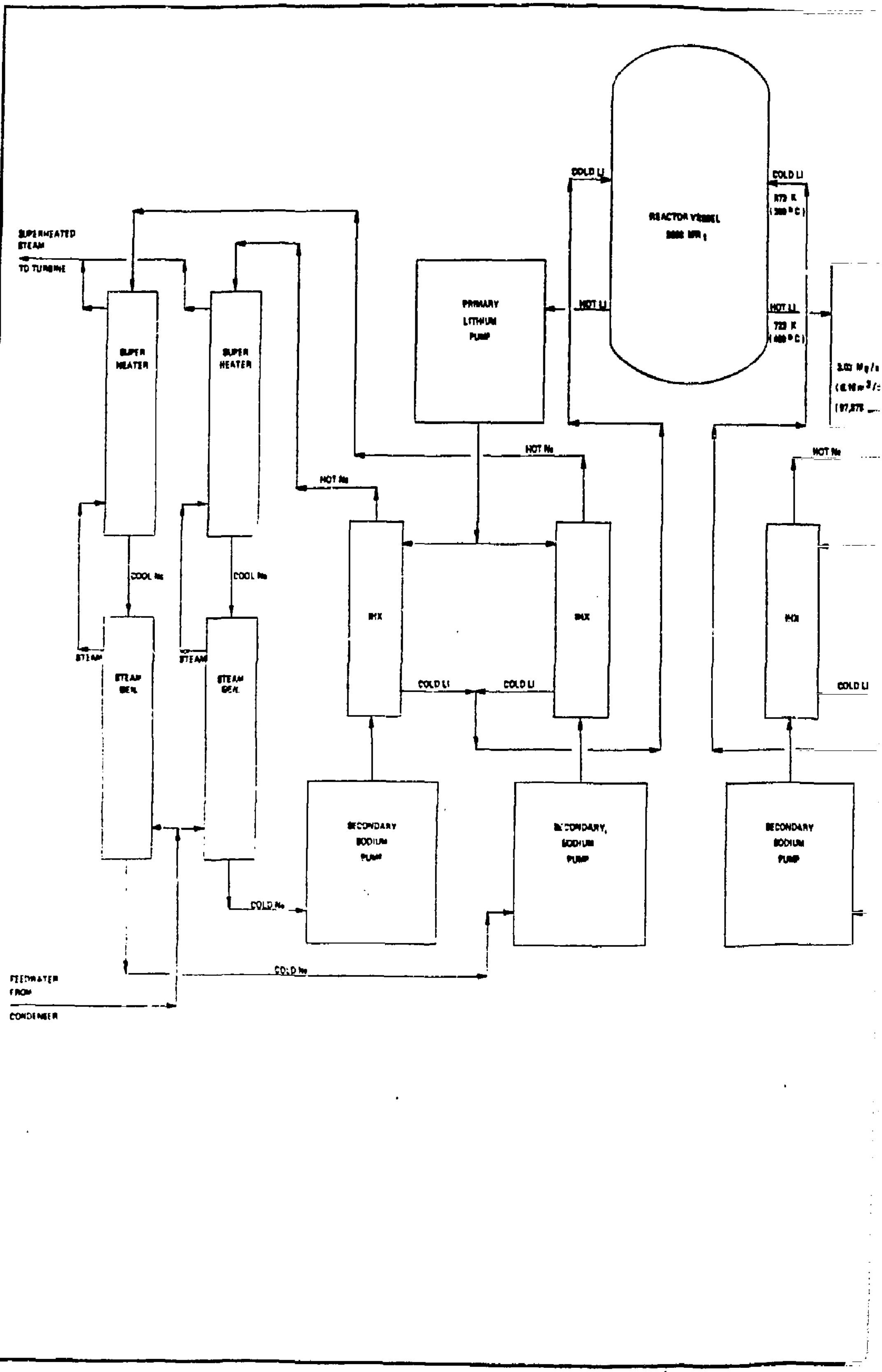
Parameter	Symbol	Value
Power: thermal	P_t	3800 MW_t
net electrical	$P_{e(n)}$	1000 $MW_{e(n)}$
Reactor dimensions: height	H	~15 m
diameter	D	~14 m 1/
Primary coolant loop: coolant	Li	
number of loops		2
load/loop		1900 MW_t
temperature, inlet		573 K (300°C)
outlet		723 K (450°C)
change	$\Delta_1 T$	150 K
flow rate/loop, volume	$\dot{V}_{Li}$	6.18 $\frac{m^3}{s}$ (97,875 gpm)
mass	$\dot{m}_{Li}$	3.03 $\frac{Mg}{s}$
Secondary coolant loop: coolant	Na	
number of loops		4
load/loop		950 MW_t
temperature, inlet		713 K (440°C)
outlet		563 K (290°C)
change	$\Delta_2 T$	150 K
flow rate/loop, volume	$\dot{V}_{Na}$	5.7 $\frac{m^3}{s}$
mass	$\dot{m}_{Na}$	4.93 $\frac{Mg}{s}$

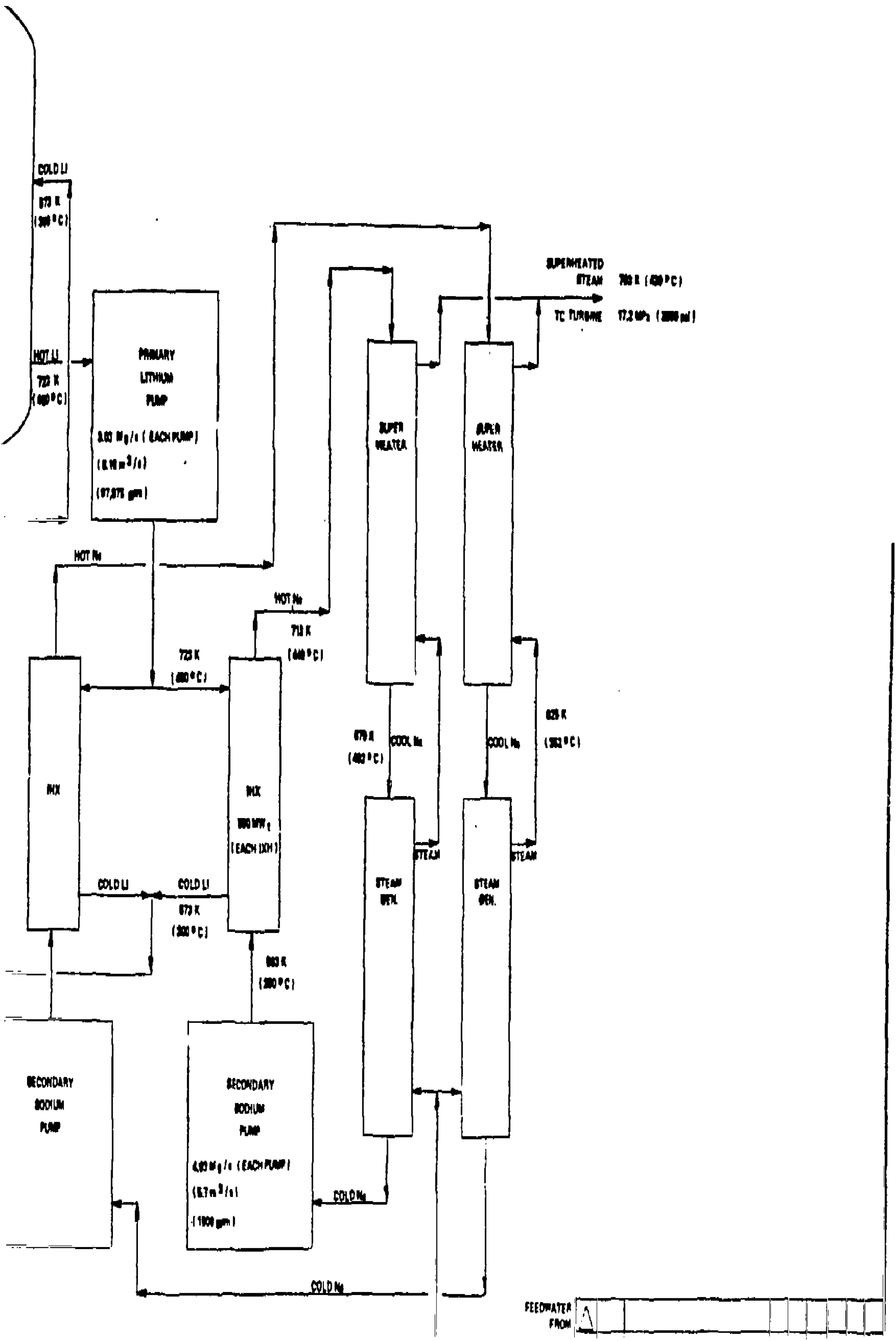
1/ This large a diameter would be used if the reactor were based on a concept similar to the JADE reactor discussed in Part II.

(Cont'd)

Table 2.1.2.1 (Cont'd)

Parameter		Symbol	Value
Water and steam loop:	number of loops		4
	load/loop		950 MW_t
	temperature, inlet		703 K (430°C)
	outlet		503 K (230°C)
	change	$\Delta_3 T$	200 K
	pressure to turbine		17.3 MPa (2500 psi)
	flow rate/loop, volume	$\dot{V}_{H_2O}$	0.57 $\frac{m^3}{s}$
	mass	$\dot{m}_{H_2O}$	479 $\frac{kg}{s}$


SUPERHEATED STEAM TO TURBINE
SUPER HEATER
SUPER HEATER
COOL Na
COOL Na
STEAM
STEAM
STEAM GEN.
STEAM GEN.
FEEDWATER FROM CONDENSER
COLD Na
COLD Na
HOT Na
HOT Na
HOT Na
IHX
IHX
IHX
COLD Li
COLD Li
COLD Li
SECONDARY SODIUM PUMP
SECONDARY SODIUM PUMP
SECONDARY SODIUM PUMP
PRIMARY LITHIUM PUMP
REACTOR VESSEL
HOT Li
HOT Li
COLD Li
COLD Li


COLD Li
HOT Li
PRIMARY LITHIUM PUMP
HOT Na
723 K
IHX
IHX
COLD Li
COLD Li
HOT Na
713 K
SUPERHEATED STEAM
TO TURBINE
SUPER HEATER
SUPER HEATER
COOL Na
COOL Na
STEAM
STEAM
STEAM GEN.
STEAM GEN.
SECONDARY SODIUM PUMP
SECONDARY SODIUM PUMP
COLD Na
COLD Na
FEEDWATER FROM

and four SG/SHs. The superheated steam from the SG/SHs then drives a turbine-generator which produces electricity.

With the exception of the reactor, the ICF NSSS is an extension of current LMFBR technology. The major differences are that the ICF NSSS requires

- lithium as the primary coolant,
- larger primary pumps,
- lithium to sodium instead of sodium to sodium IHXs,
- larger IHXs,
- larger secondary pumps, and
- larger SG/SHs.

Furthermore, there is no emergency core cooling constraint as in the LMFBR where proper elevation differences must exist between the reactor and the IHXs and between the IHXs and steam generators. This lack of requirement is due to having no decay heat to transport after a shut down of a ICF reactor. Upon shutting off the lasers no further power is generated in the reactor.

What follows are descriptions of individual portions of the NSSS, each based as much as possible on projected LMFBR technology.

2.1.2.1 REACTOR

The heart of the NSSS is the reactor. It is a cylindrical vacuum vessel 15 m high and 7 m in radius in which the fusion events occur. The protection of this vessel is a fundamental problem of ICF reactor design. Without protection the vessel is subject to intense neutron loading, high x-ray and target debris fluxes, and large thermal and pressure shocks. In addition the vessel must operate under large temperature gradients (on the order of 150 K), and a liquid lithium primary coolant will expose the reactor to serious corrosion problems. Generally, design lifetimes of these vessels are established by a combination of atomic displacements, internal helium production, and allowable stresses and corrosion.

Previous designs have utilized several different concepts to protect the reactor wall [Blink et al, 1980]. In the second part of this study a preliminary analysis of the JADE reactor is made and the issues peculiar to it are discussed. The JADE concept postulates a porous medium (of some particular geometry) inside the reactor vessel and surrounding a cylindrical void 10 m high and 5 m in radius at the center of which the fuel pellet of DT is imploded. Liquid lithium flows through the medium at a rate slow enough to significantly reduce the pumping requirements over those observed in the HYLIFE design. The lithium acts as a shield to the vessel as well as functioning as the primary coolant. This first part of the study, however, makes no choice of a reactor design other than to assume that it is JADE-like---the walls are protected by the primary coolant which flows internal to the reactor and at a rate slow enough that only two loops are required. Also, the reactor dimensions assumed are those of the JADE. In all other respects, the reactor is treated essentially as a black box---made of 2¼ Cr-1 Mo low alloy ferritic steel to resist lithium corrosion and containing one port for target injection, two for laser beam delivery each of dimensions 2 m x 1.5 m (or eight beam ports of smaller size), and having at least two liquid lithium inlets and at least two outlets for lithium and pellet debris.

2.1.2.2 PRIMARY HEAT TRANSPORT SYSTEM

The lithium blanket employed to breed the tritium consumed by an ICF reactor (ICFR) can also function as the primary coolant and, if flowed through the inside of the reaction chamber, act as a shield for the first wall. One way it may be used as a shield is described in Part II. Its use as a coolant imposes some development constraints on the primary heat transfer loop while offering some advantages in design.

The design of the primary heat transport system in this report differs from the HYLIFE design in that only two primary loops are employed instead of 16 which were required there. As a further comparison, typical LMFBR designs [U.S. DOE, 1981] call for four loops. Only two loops are necessary in this design, first, because it is assumed that the high flow rate found in HYLIFE is significantly reduced by some novel reactor concept such as the JADE concept, and second, because of the higher heat capacity of lithium over that of sodium used in LMFBR design.

Liquid lithium enters the reactor at 573 K (300°C) and resides in the reactor sufficiently long to rise to 723 K (450°C). The residence time depends on the 3.8 GW_t produced and the volume of Li in the reactor. For a volume of 346 m^3 (1 m equivalent thickness of Li), as used in the JADE analysis, the residence time is 28 s.

From the reactor the lithium flows to the primary pumps. At present there is no design for a lithium pump which can handle the required 6.2 m^3/s (97,875 gpm, nominally 100,000 gpm) flow rate of a two loop system. Electromagnetic (EM) pumps have been suggested as a possibility, but a large development program would have to be mounted to bring them into the regime needed here. The mechanical pumps of the breeder program offer an easier extrapolation and so are expected to lead to an adequate ICF pump. The pump is assumed to be a centrifugal, vertical shaft unit equipped with a variable speed drive to provide balanced heat delivery to each loop. Pump outlet pressure is determined by the pressure losses in pipes and the IHX and by the pressure drop developed across the reactor. The drop across the reactor depends on a choice of design for the reactor internals, a choice not made in this report. Although not specified here, the pressure required should be low, and much lower than the ~1 MPa (10 atm) found in an LMFBR.

The piping throughout the loop and the internal surfaces of the pumps and IHXs are specified as 2¼ Cr-1Mo low alloy ferritic steel.

Each pump, located on a hot leg, channels the lithium to two IHXs. After accepting the 723 K hot lithium and removing 950 MW_t each, the

IHXs return the lithium to the cold leg at 573 K. Although this IHX is 50% larger than the 640 MW_t IHXs used in the 2550 MW_t CDS design [U.S. DOE, 1981], the extrapolation in capacity should not present serious problems. Adding several more rows of tubes in the IHX and consequently expanding the radius by 25-30% may be adequate for the task.

2.1.2.3 SECONDARY HEAT TRANSPORT SYSTEM

Each IHX delivers hot sodium at 713 K (440°C) to a superheater where steam from the steam generator is raised to a temperature of 703 K (430°C) and exits the superheater at a pressure of ~17.2 MPa (~2500 psi). After superheating the steam the sodium moves down to the steam generator to develop steam from feed water coming in at ~503 K (230°C). A sodium pump returns the cold sodium at ~563 K (290°C) to the IHX. Sodium flows at 5.7 m^3/s (4930 kg/s) through each loop.

The purpose of the secondary loop is to isolate the primary coolant carrying radioactive target debris from the steam generator and turbine which could become contaminated if there were a rupture in the steam generator. Thus, performance of this function requires that the Na of the secondary loop be kept at a slightly higher pressure than the Li in the primary, so that a break in the IHX will result in sodium flowing into the lithium and not vice versa. The pressure required in the secondary loop is consequently low, as it is in the primary.

Lithium was examined as coolant for the secondary loop. The only significant advantage is the reduction in the number of pumps from four to two. Thus, pump costs are reduced and there is some savings in steam generator building costs.

Disadvantages in using Li include the lack of development of Li steam generators, the greater corrosiveness of Li over Na, and the expected higher background tritium inventory in Li than in Na. Na steam generators have a sizable development program on which the ICF program can build. Although a small Li steam generator was developed for the SNAP/50 (Space

Nuclear Auxiliary Power) space reactor program [Crowley et al, 1978], the system was dropped due to serious corrosion problems. Work with sodium has made some progress on the corrosion problems and so is further advanced than the lithium work.

There have been indications that the liquid metal tubes in the steam generator need not be double walled for Na (although they are conservatively designed so), but the greater corrosiveness of Li would make them necessary, if Li were used.

Of particular importance is the question of tritium inventory in the secondary and its migration throughout the steam generator. Hydrogen isotopes are more easily removed from Na than from Li resulting in higher expected T levels in the coolant and higher risk for contamination of the steam.

It is for these reasons (and the fact that Li is 70 times as expensive as Na) that this report prefers the Na secondary heat transport system.

2.1.3 TURBINE GENERATOR

The turbine-generator is an axial flow, 1800 rpm, tandem-compound, 6-flow unit with 44" final blades. The multicylinder turbine has a double-flow high pressure cylinder, a double-flow intermediate-pressure cylinder, and three double-flow low-pressure cylinders. The turbine is provided with two moisture separator/reheaters, with two stages of reheat in each moisture separator/reheater unit.

The generator is a liquid-cooled stator type with a 1300-1400 MW_e gross capability at rated turbine conditions of inlet steam. (See Table 2.1.3.1)

2.1.4 DRIVER AND OPTICS

The baseline case of this report, two-sided illumination of the

Table 2.1.3.1

TURBINE-GENERATOR SPECIFICATIONS

Turbine Type	TC6F-44
Speed	1800 rpm
Inlet pressure	17.2 MPa (2500 psi)
Inlet temperature	703 K (430°C)
Gross power output	1300-1400 MWe

target, employs by assumption a rare gas halide (RGH) laser system servicing two colocated reactors. The laser drives two amplifiers for each reactor. They are rated as amplifiers of 2.2 MJ output at 5 Hz, thus delivering 4.4 MJ on target five times a second. The laser itself is fired at 10 Hz in order to service both reactors.

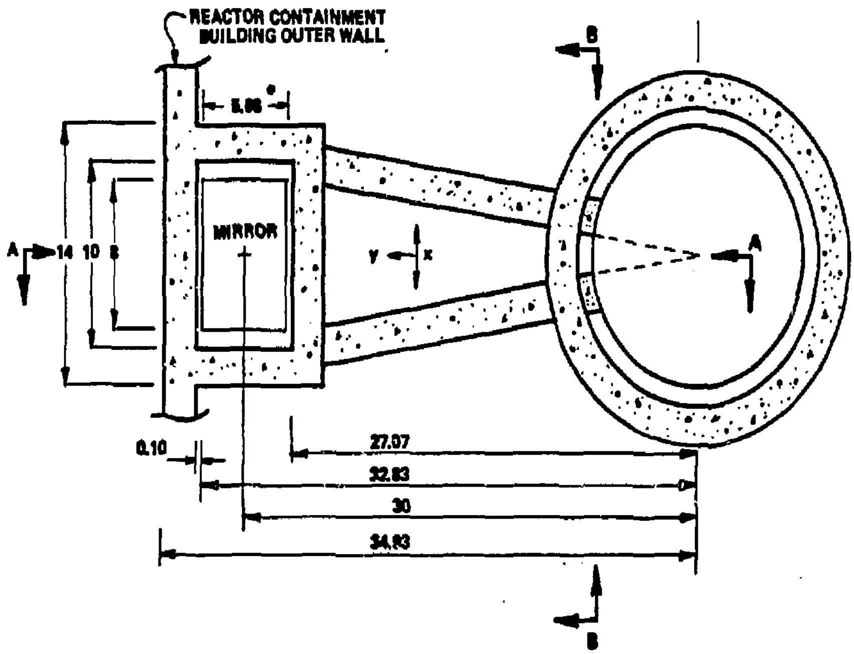
The amplifier output beams are transported through evacuated tunnels to the reactor building where turning mirrors direct the beams to final focusing mirrors 30 m from the target. Figures 2.1.4.1 and 2.1.4.2 display the in-reactor optical cell plan. The turning mirror is an 8 m x 8 m array of planar 1 m x 1 m mirror segments. The final focusing mirror is a parabolic array of 1 m x 1 m segments. Thus, two-sided illumination requires 256 1 m x 1 m mirror segments in the reactor containment building. Several (three or four) times this many mirror segments will be needed to transport the beams from the amplifier to the reactor.

In-reactor mirrors are actively cooled with flowing sodium.

Figure 2.1.4.3 shows a view from the reactor of the optical cell used in the two-sided case.

2.1.5 FUEL CYCLE SYSTEMS

A fusion power plant site requires extensive fuel cycle capabilities. The equipment and buildings for mass fabricating the 3×10^8 targets per year consumed by a twin reactor plant is one such fuel cycle system. Target delivery and debris removal systems must be attached to the reactor. Systems to remove the debris from the lithium coolant and others to recover unburned tritium are also required. Processes to recondition the debris for recycle as target material and to purify the tritium for reuse must similarly be housed in the plant. Finally, radioactive waste material must be separated and processed to some degree on site before shipment to a final waste repository.

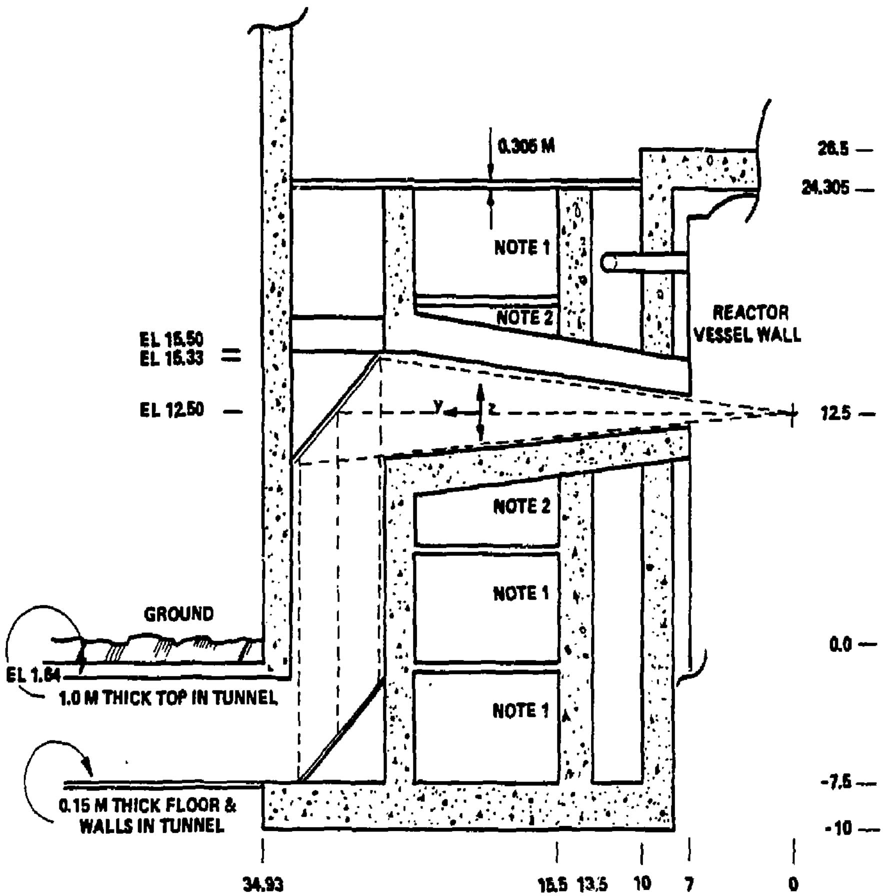


* TRUE MIRROR LENGTH IS 8 M

ALL DIMENSIONS IN METERS

OPTICAL CELL PLAN VIEW
TWO-SIDED ILLUMINATION

Figure 2.1.4.1



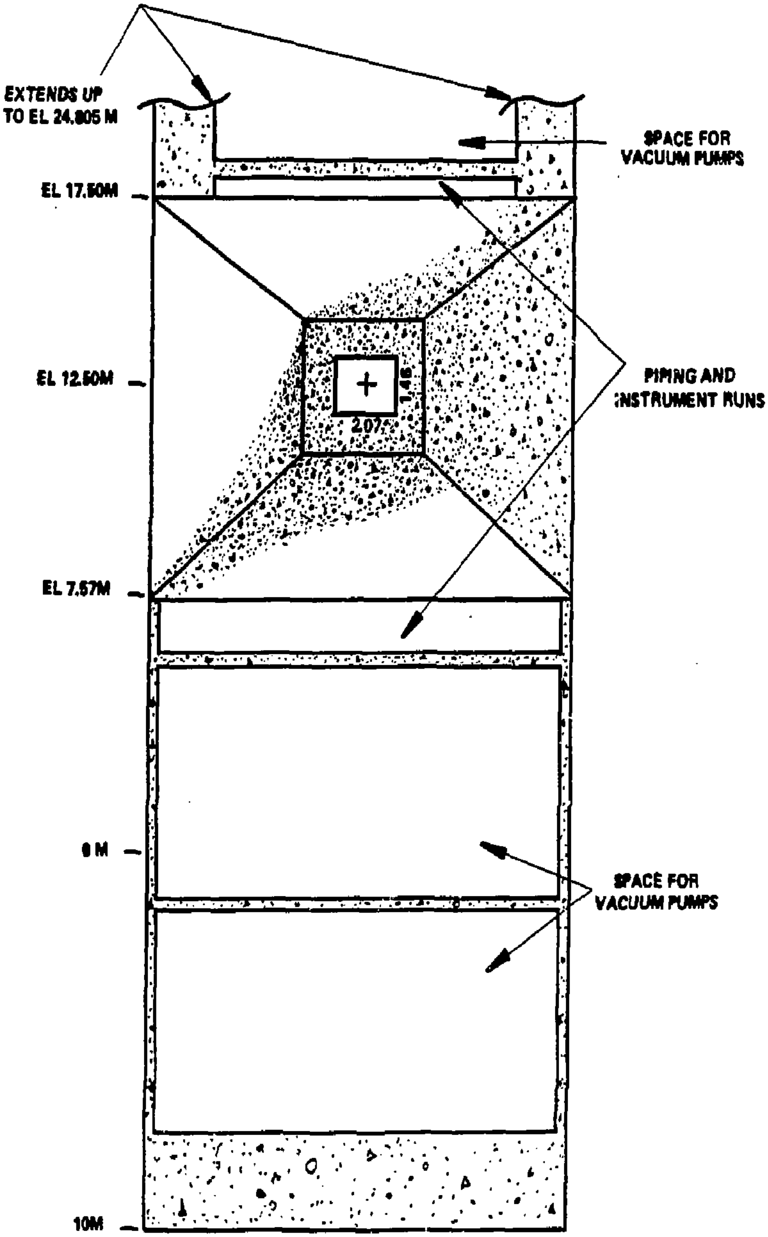
NOTES

1. SPACE FOR VACUUM PUMPS

2. SPACE FOR PIPING AND INSTRUMENT RUNS

OPTICAL CELL SECTION A-A
TWO-SIDED ILLUMINATION

Figure 2.1.4.2



OPTICAL CELL SECTION B-B
TWO-SIDED ILLUMINATION

Figure 2.1.4.3

2.1.6 AUXILIARY SYSTEMS

Auxiliary systems that an ICF power plant requires include such things as safety systems against fires and especially liquid metal fires, radiation monitoring systems, service systems (some remote) for the reactor, IHXs, pumps, SG/SHs, and other major equipment, security systems, emergency power systems, receiving and storage facilities for liquid metals, cover gas storage systems, and water treatment facilities. Systems such as these and others must be included in an overall plant design and cost estimate.

2.2 BUILDINGS

2.2.1 INTRODUCTION

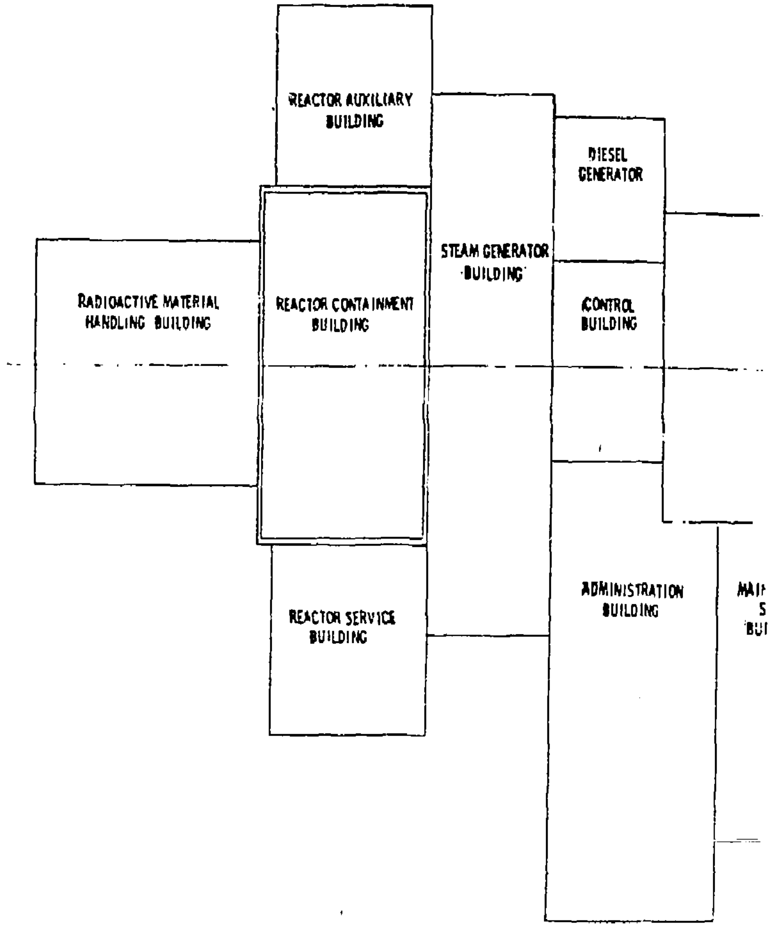
All the major and auxiliary systems described above require buildings and structures of various specifications to support and house them. Drawing 2.2.1.1 shows the building arrangements for a typical ICF power plant. A list of the structures is given in Table 2.2.1.1 where they are categorized as belonging to the Primary Nuclear System (PNS) or the Balance of Plant (BOP).

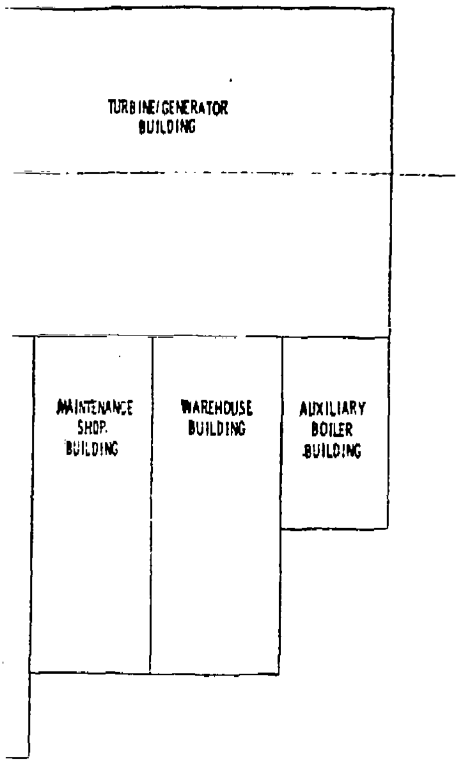
2.2.2 PRIMARY NUCLEAR SYSTEM (PNS) BUILDINGS

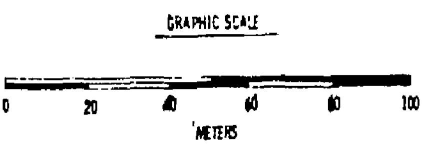
REACTOR CONTAINMENT BUILDING

The reactor containment building (RCB) is a 70 m x 42 m tornado-hardened, seismic category I structure. Thus, the building is designed to withstand the largest possible earthquake or tornado that is credible for the site and to withstand the impact of tornado generated missiles. The building extends 10 m below ground and rises another 78 m above the surface.

The major systems housed in the RCB are the fusion reactor, the laser transport tunnels, the final turning and focusing mirrors, the target injection system, the primary Li heat transport system, the IHXs, and portions of the secondary Na heat transport system. Also included are portions of the recirculating gas cooling system. Typically a well


REACTOR AUXILIARY BUILDING
DIESEL GENERATOR
STEAM GENERATOR BUILDING
RADIOACTIVE MATERIAL HANDLING BUILDING
REACTOR CONTAINMENT BUILDING
CONTROL BUILDING
ADMINISTRATION BUILDING
REACTOR SERVICE BUILDING





BECHTEL
SAN FRANCISCO

LLNL INERTIAL CONFINEMENT FUSION
REACTOR CONCEPTUAL DESIGN

POWER PLANT BUILDING ARRANGEMENT
TWO SIDED ILLUMINATION

JOB No.	DRAWING No.	REV
13740	2.2.1.1.	

Table 2.2.1.1

BUILDINGS AND STRUCTURES

Primary Nuclear System (PNS)

Reactor Containment Building (RCB)

Steam Generator Building (SGB)

Reactor Service Building (RSB)

Reactor Auxiliary Building (RAB)

Radioactive Material Handling Building (RMHB)

Control Building (CB)

Balance of Plant (BOP)

Turbine-Generator Building (TBG)

Diesel Generator Building (DGB)

Administration Building (AB)

Maintenance Shop Building (MSB)

Warehouse Building (WB)

Auxiliary Boiler Building (ABB)

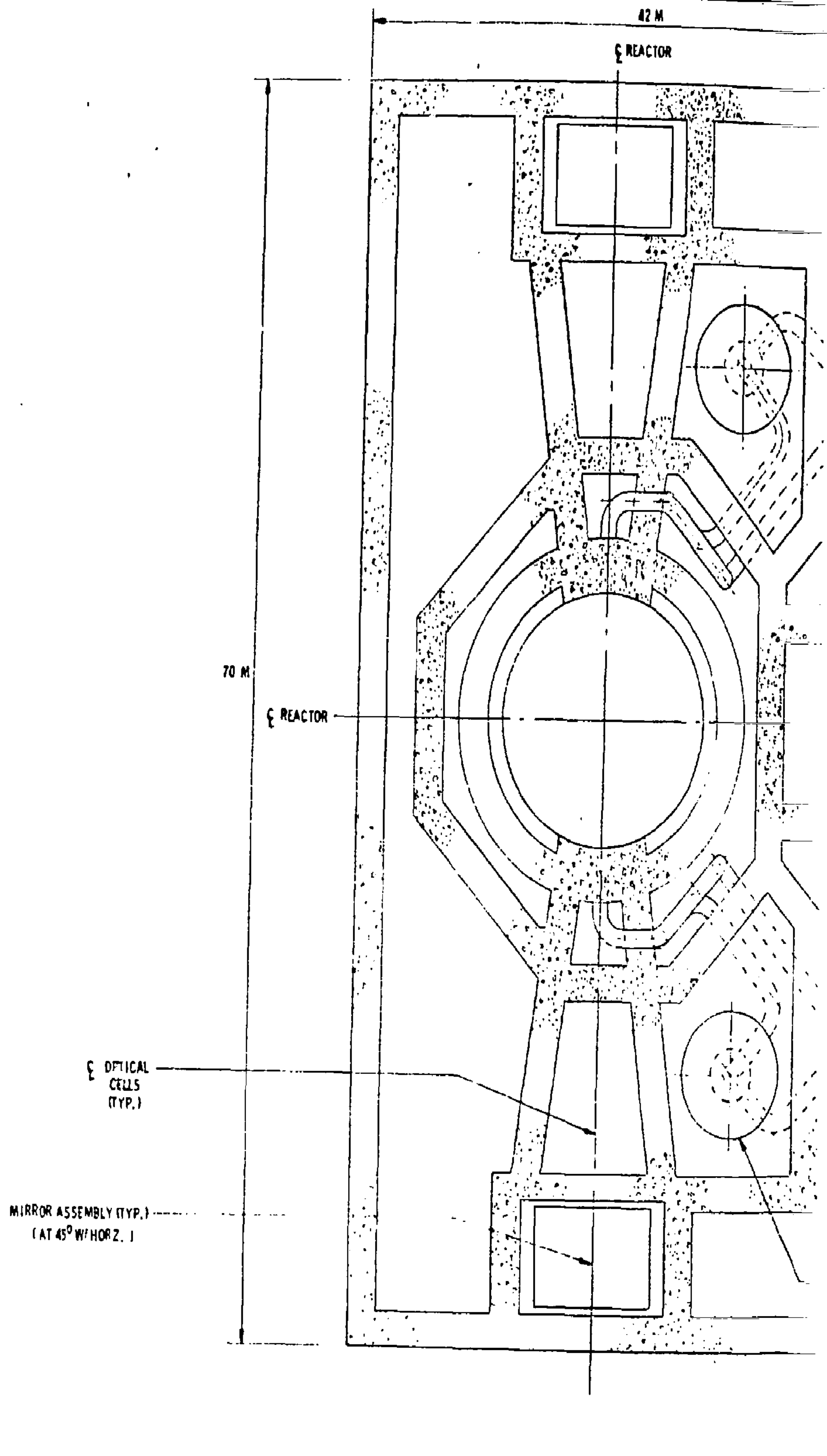
insulated 3800 MW_t reactor and heat transport system will leak 10-15 MW_t. Since the temperature of the concrete everywhere in the RCB must be maintained below 339 K (150°F) to prevent the evaporation of its water and so maintain structural integrity, the cover gas in the RCM must be actively cooled.

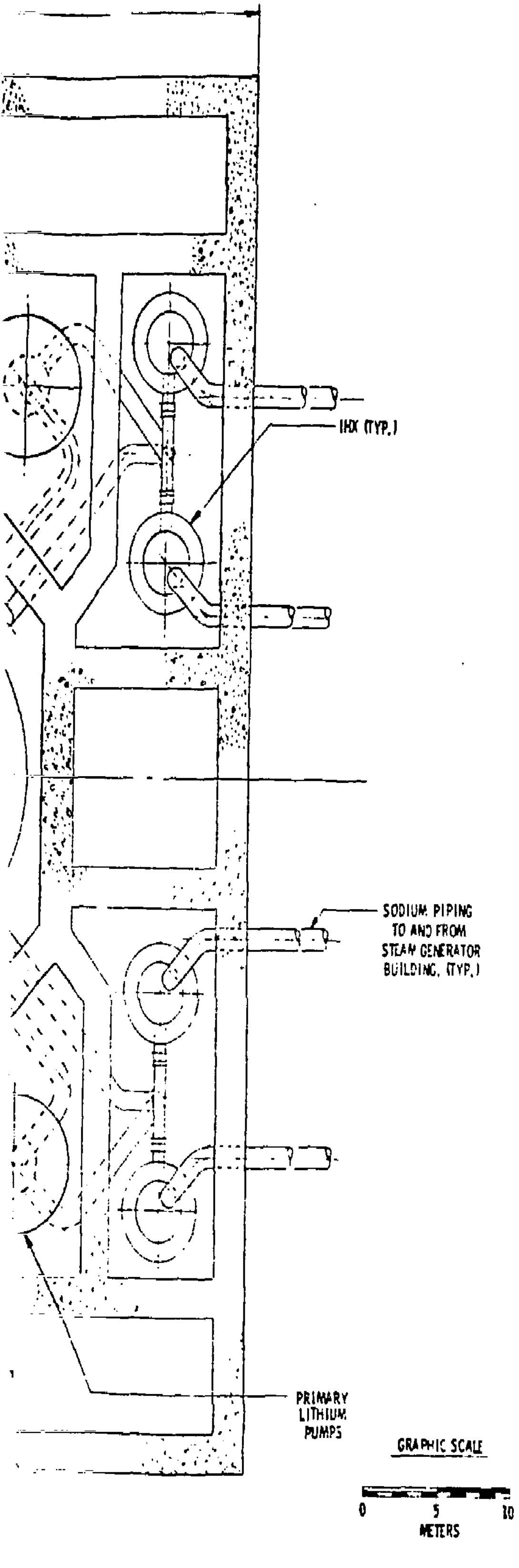
The RCB serves to structurally support its internal systems, protect them from the environment, and to contain them and their working fluids and materials in the case of an accident. The building also provides radiation shielding for protection of equipment and personnel during operation and maintenance, provides space for maintenance and removal of equipment which it houses, and provides separation and fire protection for the systems. The walls and floors internal to the containment are seismic category I and, among other things, serve as equipment supports and radiation shields. Although the internal structures are designed to withstand all design loads, including those from design basis accidents, vibrations of operating equipment, and earthquakes, their thickness is generally dictated by shielding requirements. Typically they are 2 m thick, normal density reinforced concrete. The RCB sits on a reinforced concrete mat required for all seismic category I nuclear island buildings.

Drawing 2.2.2.1 displays the layout of the RCB. The reactor vessel is completely wrapped in insulation except for instrumentation, inspection access areas, and support structures. Beyond the insulating area is a 2 m thick shielding wall. A second wall 3-4 m further out surrounds the reactor allowing the intramural area to be broken into cells for isolation purposes. The cells contain the liquid Li metal piping runs and ancillary equipment necessary for the operation of the reactor.

Two laser beam tunnels also of 2 m thick walls converge on the reactor from opposite sides. They provide an evacuated pathway from the final focusing and antecedent turning mirrors to the target.

The pipes immediately surrounding the reactor exit their cells


42 M
℄ REACTOR
70 M
℄ REACTOR
℄ OPTICAL CELLS (TYP.)
MIRROR ASSEMBLY (TYP.) (AT 45° W/HORZ.)



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LLNL INERTIAL CONFINEMENT FUSION
REACTOR CONCEPTUAL DESIGN

REACTOR CONTAINMENT BUILDING LAYOUT
TWO SIDED ILLUMINATION

JOB No.	DRAWING No.	REV
1540	2.2.2.1.	

and enter two separate cells containing and isolating the primary lithium pumps. From each pump room the Li lines proceed into separate heat exchange chambers in each of which are located two IHXs. These cells not only provide liquid metal spills confinement but also separate the radioactively hot primary coolant loop from the non-radioactive secondary loop. Four Na lines exit the RCB from these chambers.

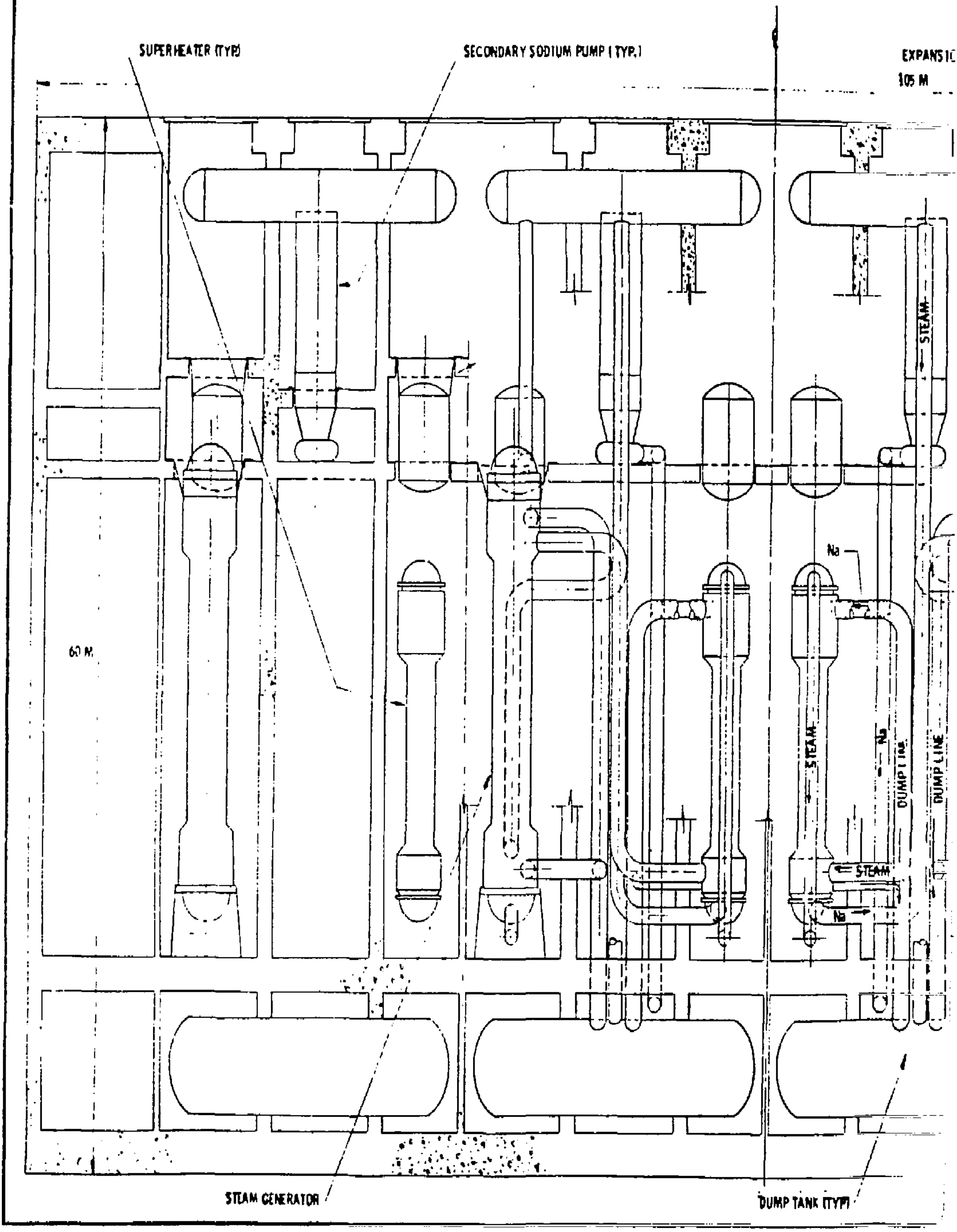
All RCB compartments containing liquid metals are steel lines to allow a spilled metal to collect in a catch pan covering the cell floor.

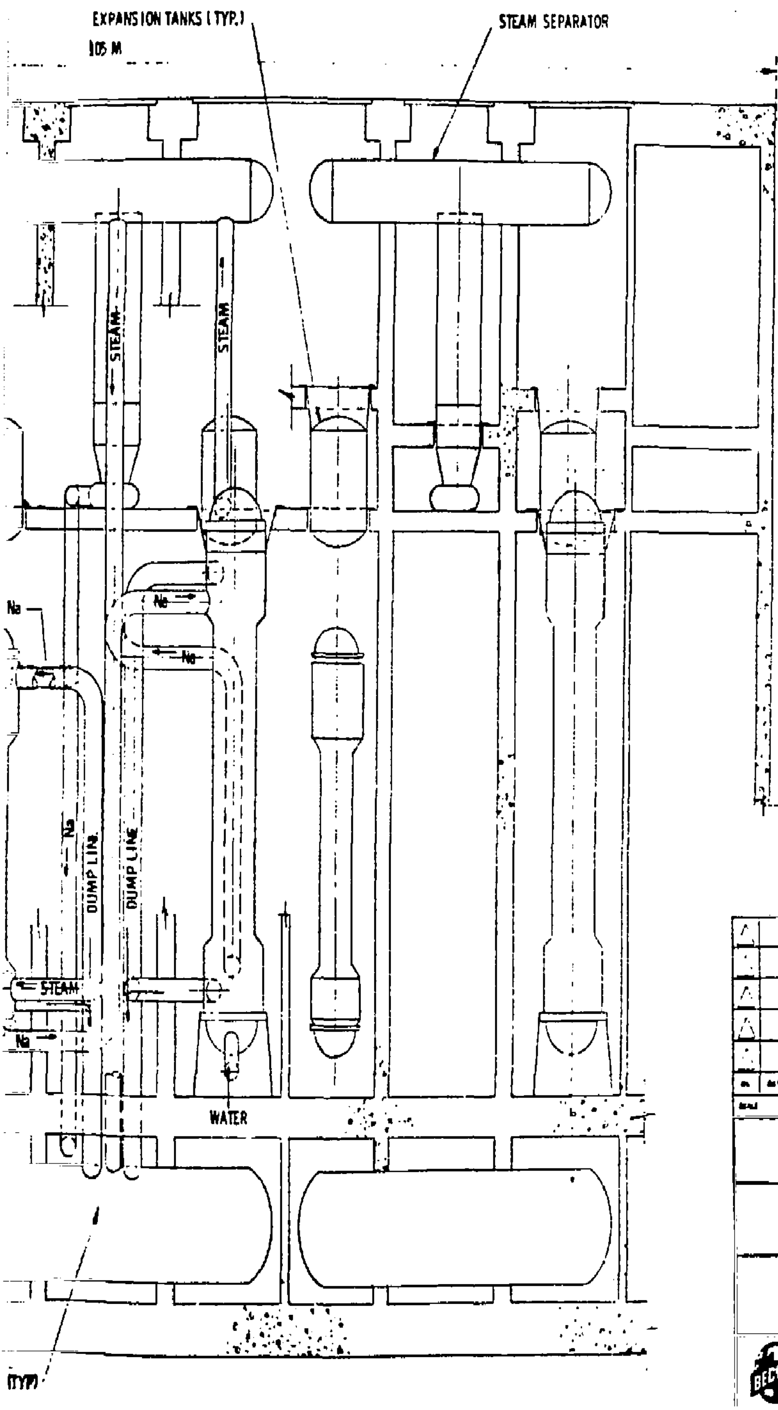
The RCB must also provide compartments for electrical cable, piping, and gas duct runs, space for equipment transfer, elevators, stairwells, and redundant control panels (not shown in the drawings at this level of design). Piping runs must loop the liquid lithium to the reactor service building where processing equipment removes the target debris in order to prevent fouling of the primary heat transport pumps and the IHXs and for recovery of usable target shell material and tritium. Portions of the RCB are also set aside for reactor and beam tunnel vacuum systems. Cells must be dedicated to liquid metal spills clean up and fire control equipment such as pumps and some fire extinguishing stores.

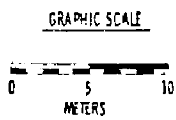
STEAM GENERATOR BUILDING

Adjacent to the RCB is the steam generator building (SGB), a 30 M x 105 m reinforced concrete structure of height 60 m. It too is a seismic category I, tornado-hardened structure. In addition to equipment support requirements the SGB must also have the integrity to withstand internally and externally generated missiles. The buildings outer walls, roof and floors are 1.5 m thick reinforced concrete. See Drawings 2.2.2.2 and 2.2.2.3.

The building is partitioned so as to include four steam generator cells each containing a steam generator, steam separator, superheater, sodium pump, sodium dump tanks for use during a sodium water reaction, and sodium expansion tanks. Each such compartment has two


SUPERHEATER (TYP)
SECONDARY SODIUM PUMP (TYP.)
EXPANSIC
105 M
60 M.
STEAM
Na
DUMP LINE
STEAM
Na
STEAM GENERATOR
DUMP TANK (TYP)



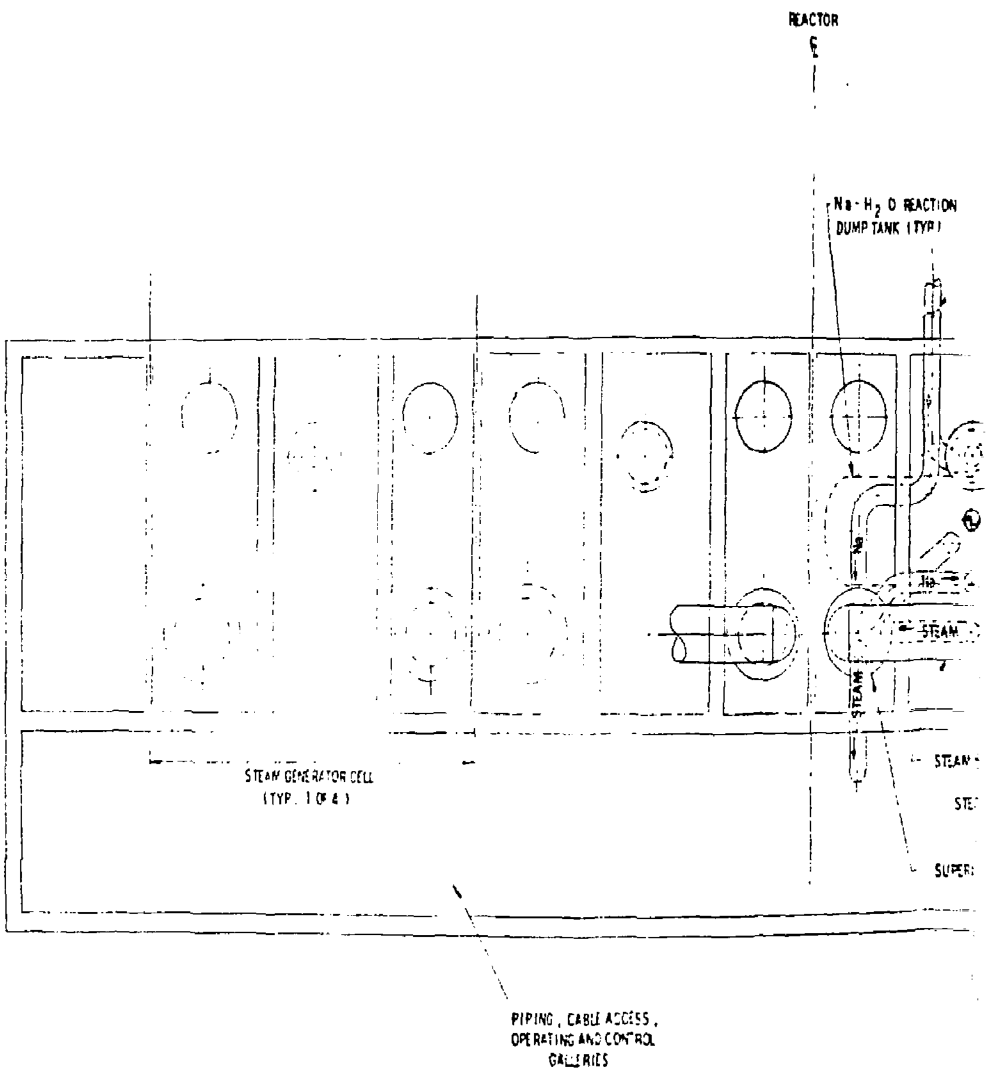


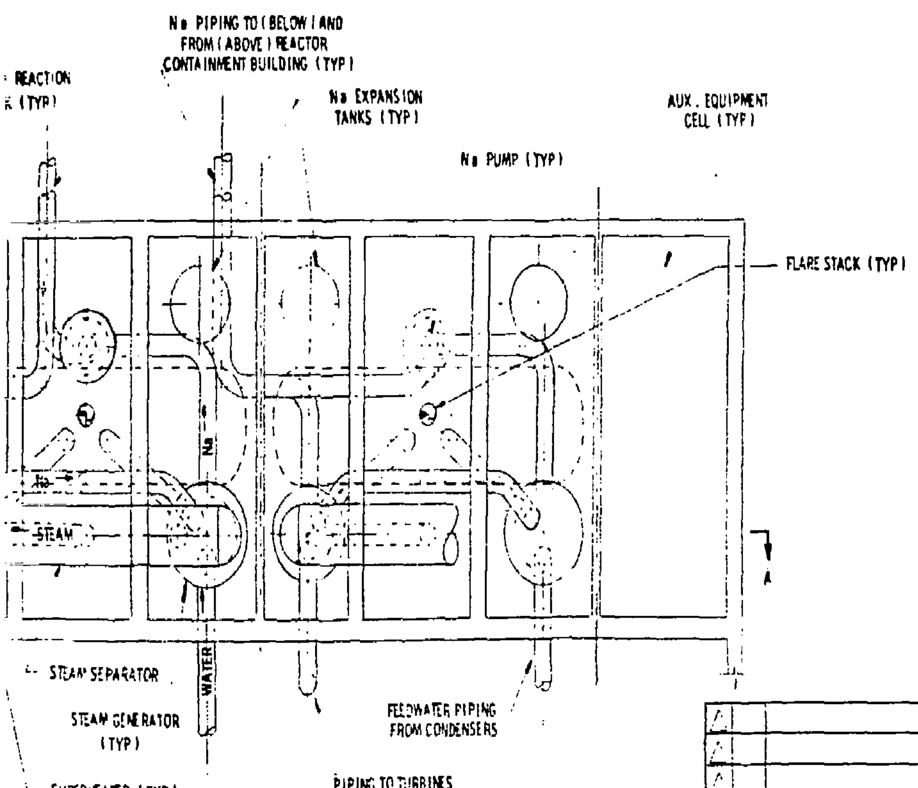
BECHTEL
SAN FRANCISCO

LLNL INERTIAL CONFINEMENT FUSION
REACTOR CONCEPTUAL DESIGN

STEAM GENERATOR BUILDING SIDE VIEW
(EIGHT OR TWO SIDED ILLUMINATION)

JOB No.	DRAWING No.	REV
13740	2.2.2.2	


REACTOR ℄
Na - H_2 O REACTION DUMP TANK (TYP)
Na
STEAM
STEAM
STEAM GENERATOR CELL (TYP. 1 OF 4)
A
PIPING, CABLE ACCESS, OPERATING AND CONTROL GALLERIES



GRAPHIC SCALE

0 5 10

METERS

BECHTEL

SAN FRANCISCO

LLNL INERTIAL CONFINEMENT FUSION
REACTOR CONCEPTUAL DESIGN

STEAM GENERATOR BUILDING PLAN
EIGHT OR TWO SIDED ILLUMINATION

internal walls separating each of the three main pieces of equipment (steam generator, superheater, and sodium pump) to isolate sodium from water systems as much as possible. Walls of the cells are steel lined and have a catch pan covering the floor for sodium containment in case of a spill. The atmosphere of the SGB is inert and maintained at 339 K (150°F).

The foundation mat for the SGB is part of the common reinforced concrete mat required for seismic category I nuclear island buildings.

REACTOR SERVICE BUILDING

The reactor service building (RSB) attached to the RCB is a 38 m by 38 m by 50 m high, seismic category I, tornado-hardened structure. It is tied to the nuclear island base mat.

The RSB provides housing for major portions of the cover gas processing system (gas coolers, water chillers, gas storage) and the debris removal and tritium recovery process equipment. It provides storage, transfer and lay down space for new RCB equipment and components. It also houses environmental control systems needed for the safety of personnel on the nuclear island. Portions of the RSB are set aside for liquid metal storage.

The tritium is piped from the RSB to an on-site target fabrication building (not shown in Drawing 2.?.1.1), as is the recovered target material, where they are recycled into new targets.

REACTOR AUXILIARY BUILDING

The reactor auxiliary building (RAB) shares the nuclear island, base mat and is of similar size to the RSB. It also is a seismic category I and tornado-hardened structure.

The RAB houses a variety of ancillary systems such as low level waste handling systems, HVAC, and Li pump and Na pump motor controls.

RADIOACTIVE MATERIAL HANDLING BUILDING

The radioactive material handling building (RMHB) is a 48 m x 53 m structure 88 m high. The RMHB is the remote maintenance and radwaste handling facility servicing the RCB and the RSB. It provides space and equipment to retrieve radioactively hot reactor internals (such as the porous metal liner discussed in Part II), canyons in which to cut up, package and store such component, and packaging and storage areas for materials received from the RSB, materials such as process fluids and solids used in the debris and tritium recovery systems.

The RMHB is a seismic category I, tornado-hardened structure located on the nuclear island base mat.

CONTROL BUILDING

The control building (CB) is located between the SGB and the turbine-generator building to minimize cable runs. It is a seismic category I, tornado-hardened, 40 m by 28 m by 40 m high structure located on the same base mat as the other PNS buildings.

On the main operational floor the CB houses the main control room, technical support center, and auxiliary control and computer systems not in the main room. The floor above and below are dedicated to the main cable spreads. The floor above the upper cable spread accommodates the CB maintenance systems (HVAC, power). The floor below the lower cable spread contains the on-site operational support center. This along with the technical support center assists in the administration and control of the plant during accidents as well as during routine operation.

2.2.3 BALANCE OF PLANT (BOP) BUILDINGS

TURBINE-GENERATOR BUILDING

The turbine-generator building (TGB) supports and environmentally protects the turbine-generator and the support equipment needed for the power conversion (steam condensers, condensate pumps, feed water pumps). It is located adjacent to the CB and is 102 m by 62 m by 50 m high. The TGB is supported by its own concrete base mat.

DIESEL GENERATOR BUILDING

The diesel generator building (DGB) houses and protects two redundant diesel generators used to provide emergency power in the event that the off-site source of auxiliary power fails as well as the reactor power recycle system. The building provides separate cells for the generators to preserve their redundancy. The diesels are designed to reach rated speeds in 10 seconds and carry full loads within 30 seconds. Each generator has a fuel oil day tank and a fuel storage tank. A seven day supply of fuel is maintained on site.

The DGB is a 28 m x 28 m, seismic category I, tornado-hardened structure located next to the CB. It is structurally independent of the nuclear island base mat.

ADMINISTRATION BUILDING

The administration building (AB) is a 90 m x 42 m two story structure housing the many support services required by the plant. It provides offices for administrative, engineering, and plant operation personnel. There are laboratories for chemical and radiological analysis and a shop for calibration and storage of plant instrumentation. Also included are health physics facilities, a whole body counter room, protective clothing stores, personnel locker rooms, showers, and personnel decontamination facilities. A plant cafeteria and other personnel related services are located in the AB. The AB also provides controlled access to the nuclear island.

MAINTENANCE SHOP BUILDING

Adjacent to the TGB is a maintenance shop building (MSB). It is a two-story, steel-frame building that is 30 m wide and 64 m long. It houses the shops necessary to maintain the noncontaminated equipment and instrumentation. The MSB is furnished with overhead cranes, monorails, hoists, tool room, electric, welding, machine, paint, and carpentry shops.

WAREHOUSE BUILDING

The warehouse building (WB) lies next to the MSB and is of similar size and construction. A fire wall separates the two structures.

AUXILIARY BOILER BUILDING

An auxiliary boiler building (ABB) is a 25 m x 35 m building attached to the end of the TGB and houses auxiliary boilers and associated equipment.

OTHER BOB BUILDINGS

In addition to the buildings described above the plant requires other structures not shown in Drawing 2.2.1.1. These include a small switchyard relay house behind the TBG. A large power switchyard to interface with the utility power grid lies beyond the relay house. A small pump house extracts cooling water from a lake or river and transfers it to another pump house servicing large mechanical draft cooling towers. A fire protection pump house is centrally located on the site. A sizable water treatment facility is also required. Finally, guard houses appropriately positioned are also present.

Section 3

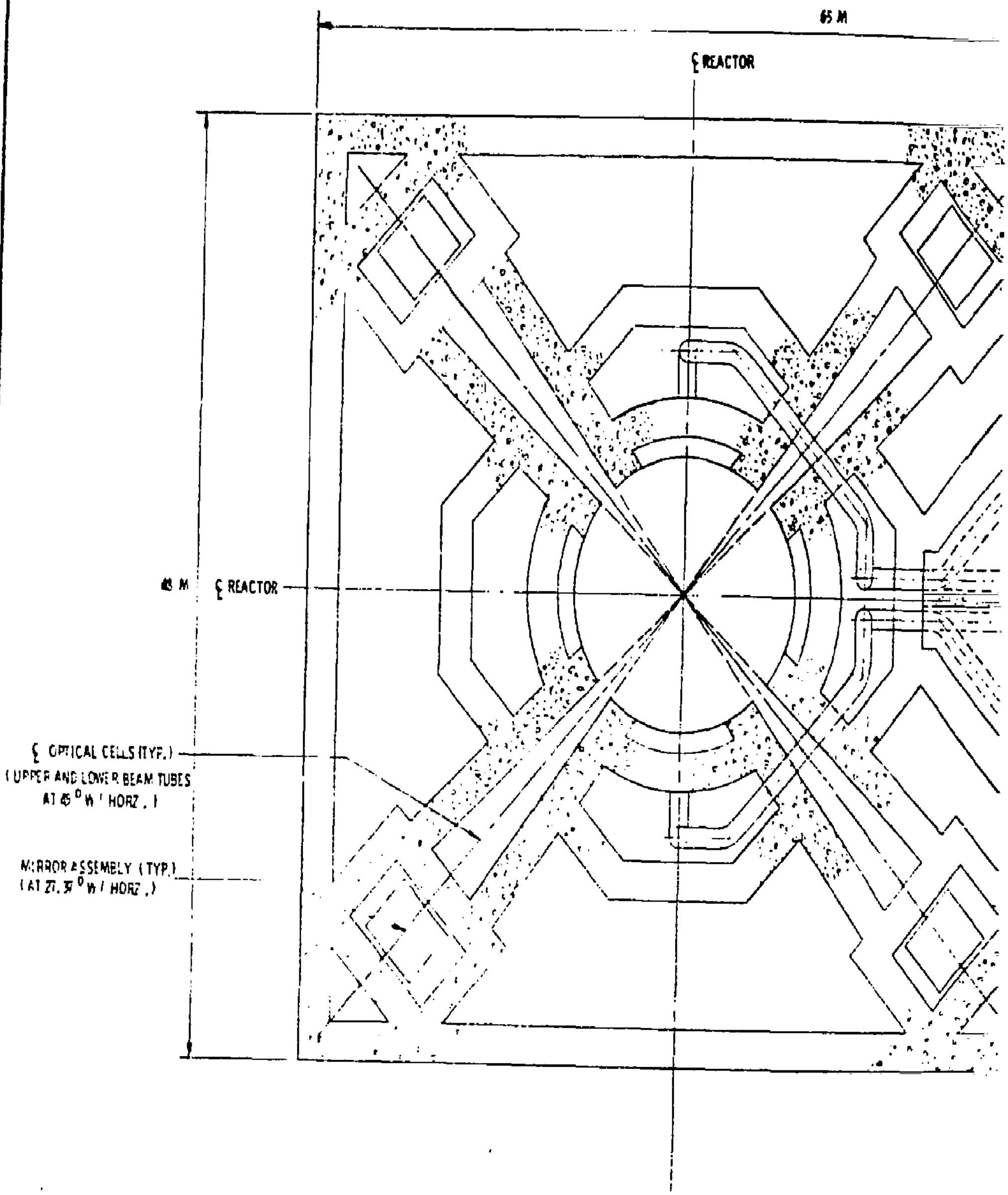
PLANT DESIGN: EIGHT SIDED ILLUMINATION

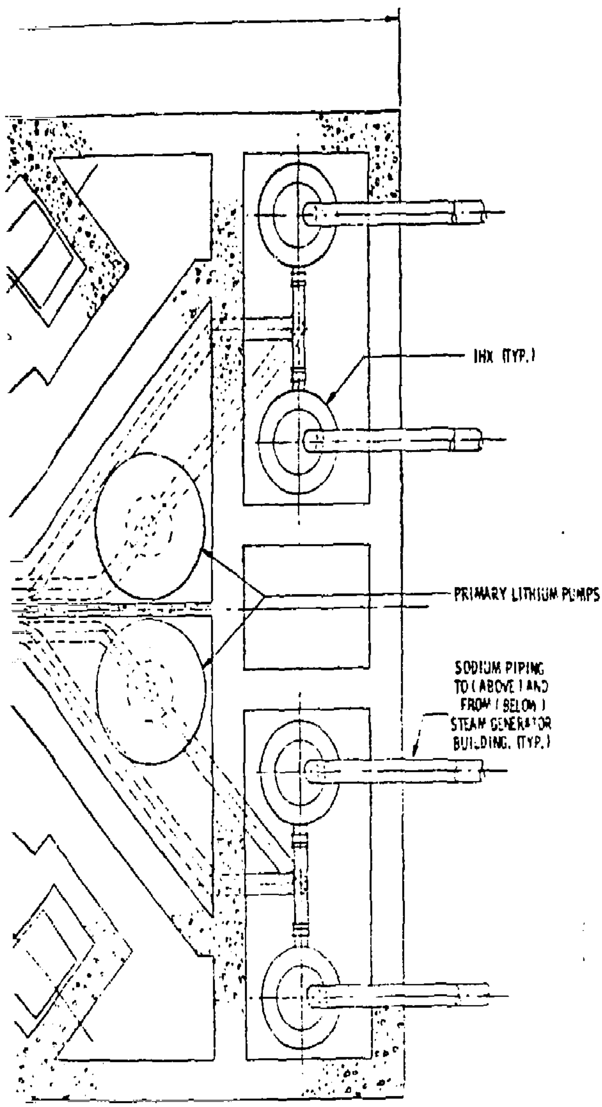
The dependence of total plant design and cost on the number of beams required in the illumination of the target was studied. Only the reactor containment building, its contents, and the laser beam tunnels layout are affected by this change from the two-sided case.

Drawing 3.1 displays the RCB layout for the eight sided case. Light is symmetrically brought to the target through the eight corners of a cube containing the reactor at its center. Area dimensions of the building are 65 m x 48 m. The height is the same as in the base case, 88 m. Thus, the requirements of eight-sided target illumination have little affect on RCB size, as long as high f/number beams can be used.

Figures 3.1 and 3.2 show details of the in-containment optical cells required in this case. The final focusing mirrors are retained at 30 m from the target resulting in taller (51.5 m) optical cells than in the base case (25.5 m). The final mirrors are 4 m x 4 m parabolic reflectors composed of 1 m x 1 m segments. This requires 128 mirror pieces to accomplish the final focusing. There are two 4 m x 4 m planar turning mirrors in each of the four cells. These, too, are segmented into 1 m x 1 m pieces. Thus, 128 units are required for turning. As before, there are 256 mirror segments in the RCB.

The increase in overall plant cost required for eight-sided illumination is discussed in the next section.


65 M
℄ REACTOR
65 M
℄ REACTOR
℄ OPTICAL CELLS (TYP.)
(UPPER AND LOWER BEAM TUBES
AT 45° W / HORZ.)
MIRROR ASSEMBLY (TYP.)
(AT 27.5° W / HORZ.)



GRAPHIC SCALE

0 5 10

METERS

BECHTEL

SAN FRANCISCO

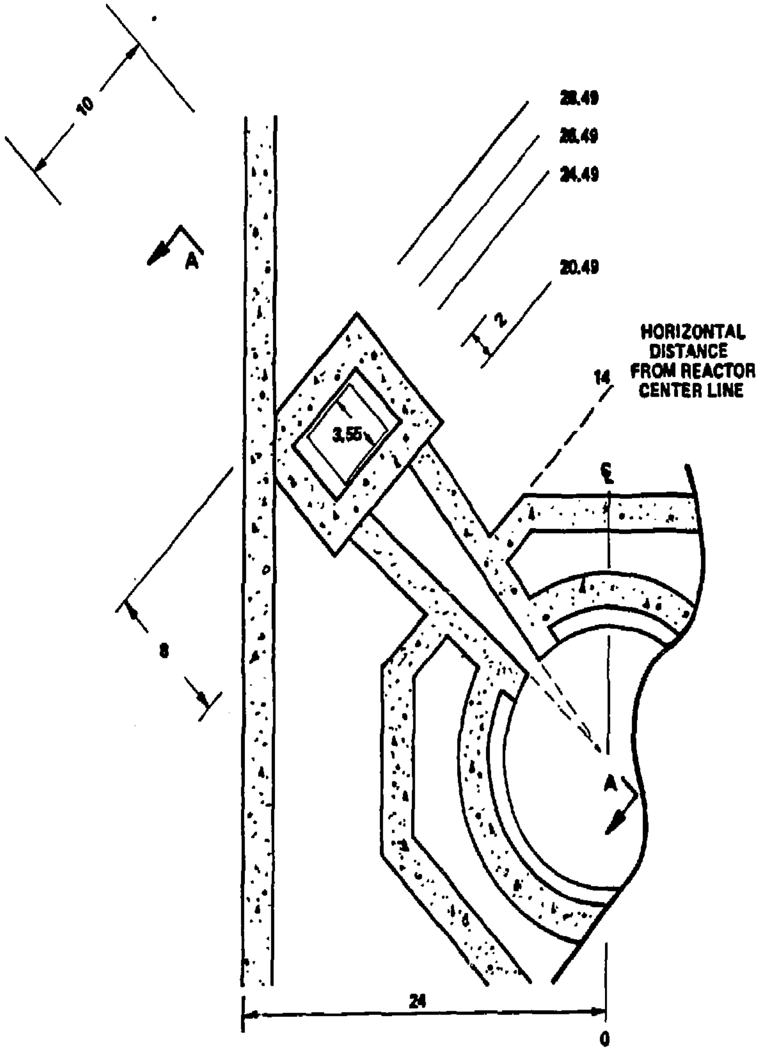
LLNL INERTIAL CONFINEMENT FUSION

REACTOR CONCEPTUAL DESIGN

REACTOR CONTAINMENT BUILDING LAYOUT

EIGHT SIDED ILLUMINATION

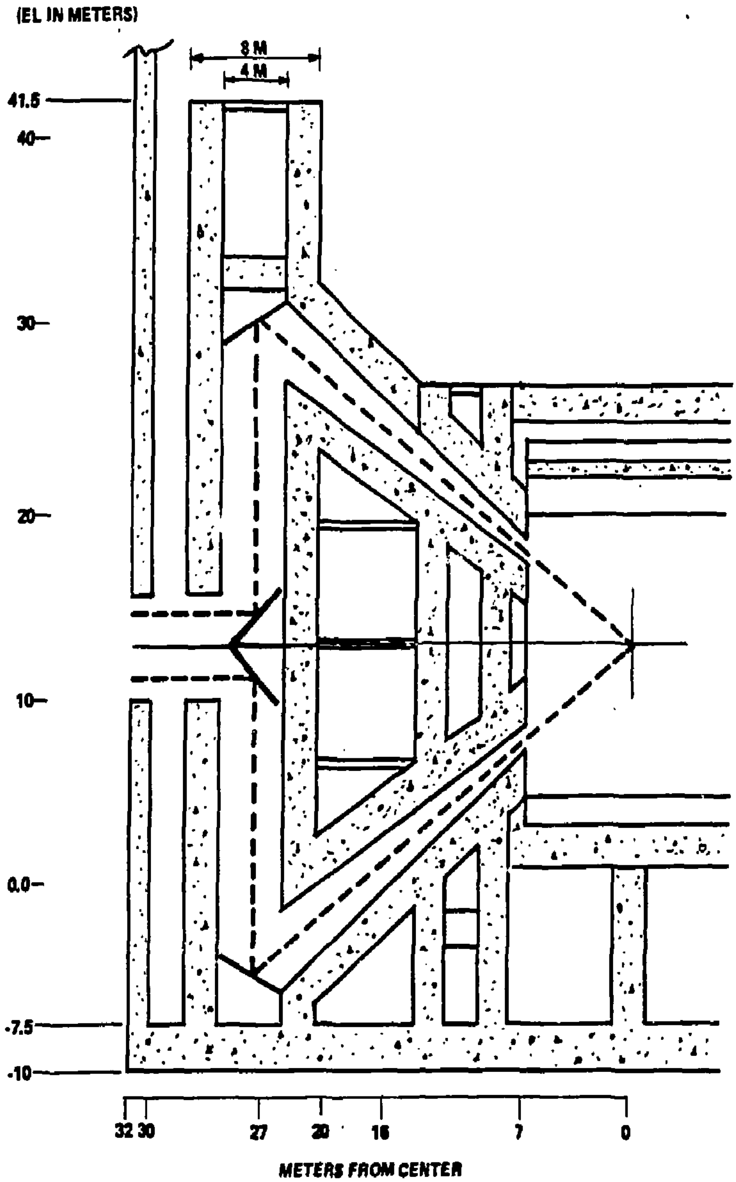
JOB No.	DRAWING No.	REV.
13740	3.1	



NOTES: ALL WALLS ARE 2M THICK
ALL DIMENSIONS ARE IN METERS
TRUE MIRROR SIZE IS 4M x 4M

OPTICAL CELL PLAN VIEW
EIGHT-SIDED ILLUMINATION

Figure 3.1



OPTICAL CELL SECTION A-A
EIGHT-SIDED ILLUMINATION

Figure 3.2

Section 4

COST ANALYSIS

CAPITAL COST SUMMARY

Order of magnitude capital cost estimates for an ICF power plant were based on the conceptual designs of this report. A large portion of the total plant, including most of the heat transfer systems, auxiliary systems, and balance of plant, represents conventional liquid metal fast breeder reactor technology, so cost estimates were based largely on previous experience [Bechtel, 1978; U.S. DOE, 1981; Bechtel and General Electric, 1977].

Two plant variations were costed---the base case two sided illumination design and an eight sided illumination design. Capital costs for both systems were estimated by unit and component cost methods. Table 4.1 presents the two sided case. Estimates are made for a first of a kind and a fifth of a kind, single unit plant and a fifth of a kind twin unit plant. Table 4.2 displays the same information for the eight sided case.

Exclusions from both these cost summaries are costs for the

- laser
- laser building
- optics fabrication and maintenance facilities
- target fabrication and delivery systems and buildings
- power switchyards
- roads, railroads, or barge facilities on site
- process royalties and licenses, and
- start-up and operating costs.

Table 4.3 compares the in-reactor optical systems costs.

Table 4.1

COST SUMMARY FOR AN ICF POWER PLANT, TWO SIDED ILLUMINATION

Item	One Unit		Two Units
	First of a kind M$	Fifth of a kind M$	Fifth of a kind M$
Land and Land Rights	Included in owner's cost		
Structures and Site Facilities			
Site Improvements	29.5	29.5	43.1
Reactor Building	202.6	152.0	304.0
Turbine Building	50.5	50.5	76.7
Cooling System Structures	14.0	14.0	28.0
Steam Generator Building	67.4	50.6	101.2
Miscellaneous Buildings	195.3	195.3	259.3
Sub Total	559.3	491.9	812.3
Reactor Plant Equipment			
Reactor Equipment	196.8	86.6	164.4
Main Heat Transfer System	98.7	55.3	105.0
Secondary Heat Transfer System	403.2	221.8	421.9
In-Containment Optical System	11.2	6.7	13.4
Radioactive Waste Systems	125.0	62.5	100.0
Other Reactor Plant Equipment	323.7	142.4	227.8
Instrumentation, Plant Control and Protection	66.6	29.3	46.9
Miscellaneous Reactor Equipment	8.1	3.6	5.8
Sub Total	1,233.3	608.2	1,085.2

(Cont'd)

Table 4.1 (Cont'd)

Item	One Unit First of a kind M$	One Unit Fifth of a kind M$	Two Units Fifth of a kind M$
Turbine Plant Equipment			
Turbine-Generator	85.0	85.0	166.0
Heat Rejection System	7.1	7.1	13.3
Heating and Condensing System	51.1	51.1	98.3
Other Turbine Plant Equipment	51.2	51.2	92.2
Sub Total	194.4	194.4	369.8
Electric Plant Equipment	100.0	100.0	180.2
Miscellaneous Plant Equipment	63.5	42.3	61.5
Total Direct Cost	2,150.5	1,436.8	2,509.0
Direct Cost	2,150.5	1,436.8	2,509.0
Field Distributable Costs	430.1	287.4	501.8
Engineering and Home Office Costs	516.1	344.8	602.2
Owner's Cost	216.8	144.8	252.9
Contingency	662.7	442.8	773.2
Interest and Escalation During 10 Year Construction	1,110.0	741.6	1,295.0
Total Capital Cost (mid 1981)	5,086.2	3,398.2	5,934.1
			2,967.0/unit

Table 4.2

COST SUMMARY FOR AN ICF POWER PLANT, EIGHT SIDED ILLUMINATION

Item	One Unit		Two Units
	First of a kind M$	Fifth of a kind M$	Fifth of a kind M$
Land and Land Rights	Included in owner's cost		
Structures and Site Facilities			
Site Improvements	29.5	29.5	43.1
Reactor Building	212.7	159.6	319.2
Turbine Building	50.5	50.5	76.7
Cooling System Structures	14.0	14.0	28.0
Steam Generator Buildings	67.4	50.6	101.2
Miscellaneous Buildings	195.3	195.3	259.3
Sub Total	569.4	499.5	827.5
Reactor Plant Equipment			
Reactor Equipment	196.8	86.6	164.4
Main Heat Transfer System	98.7	55.3	105.0
Secondary Heat Transfer System	403.2	221.8	421.9
In-Containment Optical System	23.2	13.9	27.8
Radioactive Waste Systems	125.0	62.5	100.0
Other Realtor Plant Equipment	323.7	142.4	227.8
Instrumentation	66.6	29.3	46.9
Plant Control and Protection	8.1	3.6	5.8
Sub Total	1,245.3	615.4	1,099.6

(Cont'd)

Table 4.2 (Cont'd)

Item	One Unit First of a kind M$	One Unit Fifth of a kind M$	Two Units Fifth of a kind M$
Turbine Plant Equipment			
Turbine-Generator	85.0	85.0	166.0
Heat Rejection System	7.1	7.1	13.3
Heating and Condensing System	51.1	51.1	98.3
Other Turbine Plant Equipment	51.2	51.2	92.2
Sub Total	194.4	194.4	369.8
Electric Plant Equipment	100.0	100.0	180.2
Miscellaneous Plant Equipment	63.5	42.3	61.5
Total Direct Cost	2,172.6	1,451.6	2,538.6
Direct Cost	2,172.6	1,451.6	2,538.6
Field Distributable Costs	434.5	290.3	507.7
Engineering and Home Office Costs	521.4	348.4	609.3
Owner's Costs	219.0	146.3	255.9
Contingency	669.5	447.3	782.3
Interest and Escalation During 10 Year Construction	1,121.4	749.2	1,310.3
Total Capital Cost (mid 1981)	5,138.4	3,433.1	6,004.1 3,002.0/unit

Table 4.3

COST COMPARISON

FOR IN-REACTOR OPTICAL SYSTEMS

(ONE UNIT, FIFTH OF A KIND)

	Cost	
Item	Two Sided Illumination k$	Eight Sided Illumination k$
Structures	5,120.4	12,691.2
Mirror Assemblies	4,104.4	7,356.4
Support Equipment (sodium coolant, pumps, vacuum pumps, piping, etc.)	2,607.9	6,558.0
Direct Cost Total	11,832.7	26,605.6

PRICING LEVELS

The cost estimates reflect mid-1981 price and wage levels.

DIRECT COST

Direct costs include costs of mechanical equipment, materials, and construction labor. These costs for all systems other than the optical system were developed from Bechtel experience and previous, similar studies. Direct costs for the optical system are based on sketches, specifications, and equipment lists and estimated using methods consistent with the conceptual nature of the design.

MECHANICAL EQUIPMENT

Mechanical equipment costs are based on recent Bechtel experience, current pricing data, and vendor quotes.

MATERIALS

Material quantities were computed from specifications, and prices are similarly based on recent Bechtel experience, current pricing data, and vendor quotes.

CONSTRUCTION LABOR

Labor costs required for installation of the mechanical equipment and materials are estimated using a typical manhour rate of $20.00 per manhour. This wage rate includes applicable premiums, fringe benefits, taxes, insurance, and allowances for casual overtime.

FIELD DISTRIBUTABLE COSTS

Field distributable costs are indirect material and labor costs which cannot be directly identified with permanent facilities, systems or equipment. These costs include those for temporary construction facilities, miscellaneous construction services, construction equipment and supplies, field office operations, preliminary checkout and acceptance testing, project insurance, taxes and permits.

ENGINEERING AND HOME OFFICE COSTS

Engineering and home office costs include costs for design engineering, cost estimating and control, planning and scheduling, procurement and expediting, quality assurance, home office start-up assistance, project and construction management, overhead and fee.

OWNER'S COSTS

Owner's costs were estimated at 7% of the total field and home office cost and include project administration and engineering, site acquisition, environmental reports, operator training, start-up, pre-operation taxes and insurance.

CONTINGENCY

Contingency is an allowance for the uncertainty that exists within the conceptual design in quantity, pricing, or productivity and which is under the control of the engineer/constructor and within the defined scope of the project.

INTEREST AND ESCALATION DURING 10-YEAR CONSTRUCTION

Interest and escalation during the ten year construction period were estimated assuming a real escalation rate of 2% per year and an interest rate of 3.5% per year.

ECONOMIC EVALUATION

The costs estimates presented above show that about a 33% savings can be realized in total plant costs in a fifth of a kind plant over a first of a kind due to a significant decrease in the cost of engineering and assembly of plant equipment before installation. This resultant 33% cost reduction is seen in both illumination cases studied. The reduction in cost results from a gain in technical expertise over time and the formation of capital specific to ICF plant construction.

In Table 4.3 one sees that the total direct construction cost for the eight sided in-reactor optical system is 2.25 times as expensive as the two sided case. Although the difference in costs of the two optical systems is significant in and of itself, when considered as part of the total plant cost this difference is neglibible. In either case the in-reactor optical system cost is less than 1% of total plant costs.

In summary, there is an appreciable financial advantage to multiple unit siting, a significant savings in a fifth of a kind plant over a first, and little difference between a two sided illumination design and eight-sided illumination of a target of the same gain.

Section 5

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