4.0 TARGET SYSTEMS

4.1 TARGET PRODUCTION

4.1.1 Objectives and Requirements

In this portion of the study, we identify a viable set of elements of an IFE reactor target production facility and develop a plan for the combination of the elements into an operable factory design. The objects were to

- Identify primary production steps and options for each step
- Identify features with significant impact on cost, reliability, and safety
- Attempt to minimize cost and enhance reliability and safety in facility design

The baseline design of the production facility contains a deuterium-tritium (DT) handling and storage facility, a fuel container (capsule) production facility, a system for filling the capsules with DT fuel, a measurement system for quality assurance (QA) purposes, and a target storage and delivery section. The characteristics, such as size, production rates, etc., have been estimated and interfaces included where necessary and appropriate. A helium liquefaction and cryogenic plant and production control systems have been included as necessary parts of the complete production facility. Figure 4.1 is a block diagram of the IFE reactor target production facility showing the major production steps. Other peripheral facilities such as receiving, chemical preparation room, materials storage, etc., are not shown and should not add significantly to the cost of the facility other than a per-square-foot building cost, which should be, at most, 5-10% of the overall facility foot-print.

The facility has several important features worth pointing out. The production equipment and overall building area are quite compact. This is largely the result of using production techniques that minimize the production time per target and thus the inventory of targets being handled at any one time. The compact design also helps minimize target production costs. While cost reduction or minimization has not been an overriding part of this study, determination of a plausible cost estimate for the target production facility is addressed later in Chapter 8. Operational safety and the minimization of total tritium inventory have been considered to be critical aspects of the facility design. The tritium inventory is minimized by 1) using rapid production techniques and 2) reducing the inventory of filled targets in storage. The inventory of filled targets can be small because the system is very reliable. As indicated in Fig. 4.1, the proposed production facility is 100% redundant in order to give high reliability. Under normal conditions, each production line operates at half of its possible production rate. If a component on one line fails or requires repair, the other line is brought to full production capacity. To further enhance the safety characteristics of

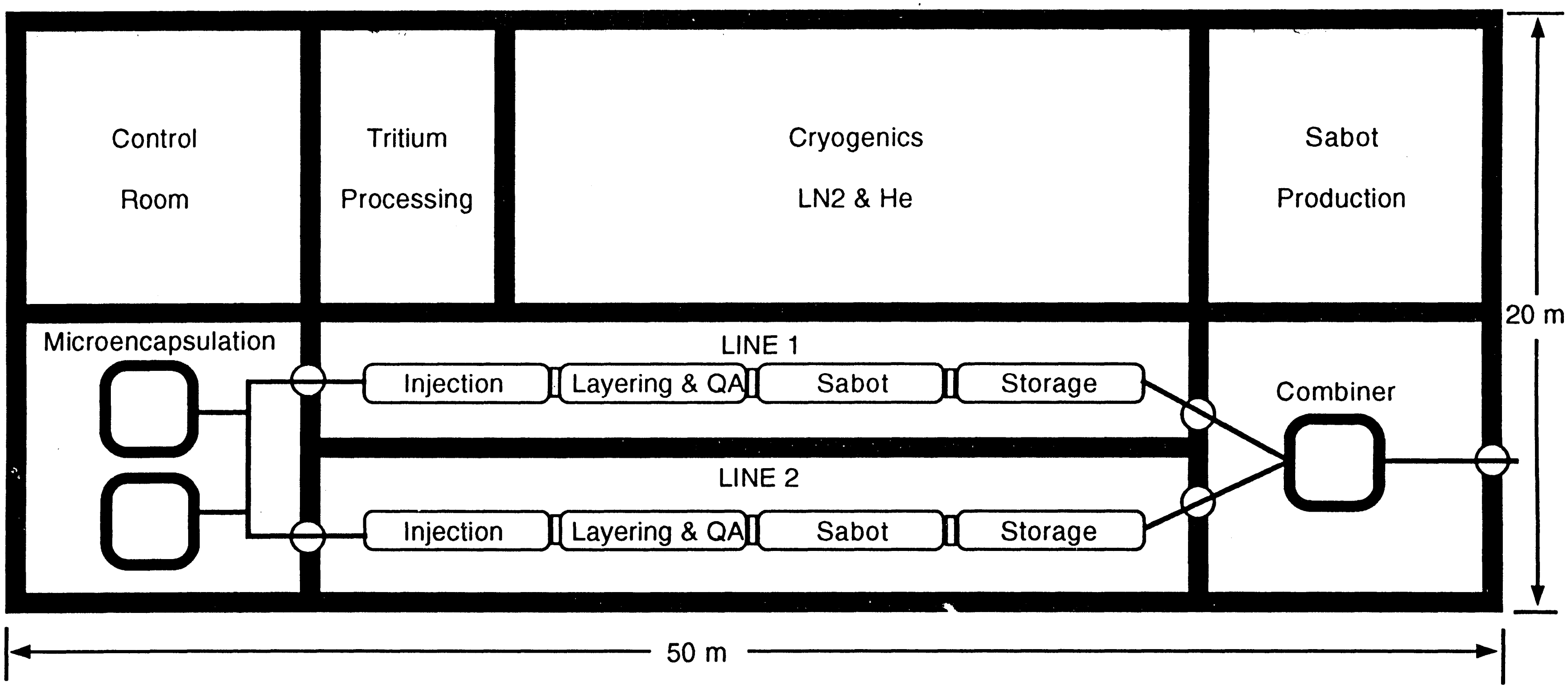

Fig. 4.1. Layout of baseline target production facility.

the production facility, the production stages and components are compartmentalized to reduce the consequences of a tritium leak in any one part of the system.

In order to produce targets economically, the production facility must be operated as a completely automated factory, not as a research facility. We assume that all processes to be employed in producing the capsules, filling the capsules with fuel, adding sabots as target carriers, and handling and manipulating targets will have been developed, tried, tested, integrated and demonstrated in a pilot plant, and perfected before use in an IFE power plant. One of the major implications of this assumption is that complete characterization of the individual targets is not required. Only an occasional measurement will be made to ensure the several fabrication processes are operating as they should. While it may be sufficient to monitor the target yield per pulse as a check on target production processes, other factors could reduce the yield (e.g., a degradation of driver output or alignment accuracy). Thus, it will be necessary to statistically monitor target quality in each of the production steps to assure of the continued correct operation of the factory.

The major production steps are

1) Capsule Production
2) Fuel Fill
3) Fuel Layering
4) Capsule Insertion into Sabots
5) Storage of Complete Targets

Several sub-steps are associated with these major production categories. For example, capsule material must be acquired and loaded into the capsule production apparatus, DT must be stored, transported to the fill system, set to the correct temperature, and flowed into the capsules in a metered and controlled manner.

4.1.2 Overview of the Reference Design

The design is based on the production of direct drive targets as used in the SOMBRERO reactor. Production steps for indirect drive targets would be the same, except for the final step of loading the capsule into a hohlraum. Depending on its characteristics, the hohlraum could possibly serve as the sabot for the indirect drive target, thus eliminating the sabot loading step. From the various options for each of the production steps, we have chosen a reference design approach listed in Table 4.1. These choices and the sizing of production facility components were based on the target parameters given in Table 4.2. Note the fuel mass is calculated assuming a yield of 400 MJ (i.e., the SOMBRERO yield) and a burn fraction of ~ 30%, which is a typically cited value for future reactor-class targets. The choices were made after considerations of several options for each of the elements of the target production facility. The options and the reasons for

Table 4.1. Baseline Target Production Techniques

Production Step	Chosen Technique
Capsule Production	Drop Generator / Microencapsulation
Fuel Fill	Injection Fill Techniques
DT Layer Formation	Freeze - Laser Pulse Vaporization - Refreeze

Table 4.2. Reference Case Target Design

Target Type	CH shell with solid DT fuel layer
Nominal Yield	400 MJ
Nominal Dimensions	5 - 6 mm outer diameter
	0.03 - 0.05 mm thick shell
Production Rate	~ 6.7 Hz (~ 400/min or ~ 580,000/day)
Fuel Mass per Target	~ 4 mg DT (~ 2.4 mg T)
Tritium Throughput	~ 1.4 kg/day

the choices are discussed in the next several sections. The advantages and disadvantages of each option are compared.

4.1.3 Capsule Production

4.1.3.1 Capsule Production Options

Several techniques can be used to produce the hollow, spherical, thin wall capsules necessary for the IFE targets. Table 4.3 lists a number of the techniques and briefly notes some of the advantages and disadvantages of each of the primary techniques. It should be noted here at the outset that no claim is made that the list of techniques presented here is exhaustive, nor is it claimed that there will not be other techniques developed which may be better, cheaper, or easier than those which have been considered. This is certainly true for the other production steps as well as for capsule production.

Drop tower generation refers to the technique whereby uniform drops of a liquid precursor solution of the capsule material are formed by means of a drop generator at the top of a heated vertical column. As the drops fall freely through the hot column, the solvent in the drops evaporates and leaves a shell of the solute material. If the shell is to be a hollow polymer shell, the

Table 4.3. Capsule Production Options

Technique		Advantages (+) and Disadvantages (-)
Drop Tower Generation	+	Consistent constant shell mass and dimensions
	+	High production rate (up to 1000's per second)
	-	Shell uniformity may decrease as size increases
Microencapsulation	+	Low vacuole density in shell walls
	+	Uniform shell wall thickness
	-	Process inherently produces a wide range of diameters and wall thicknesses
Drop Generator / Microencapsulation	+	Combines the advantages of both techniques (i.e., uniform shell mass, diameter, and wall thicknesses)
Hollow DT Shells from Drop Generator	+	Shells formed directly from liquid DT drops:
	+	Uniform mass
	+	Ablative layers formed by condensation of CH_4 gas
	+	Shells formed as needed (i.e., no storage required)
	+	On-demand delivery

solvent is probably an organic liquid that can be evaporated at a relatively low temperature leaving a shell of the polymer material. Shells of polystyrene have been formed by this technique using mixtures of ethyl chloride, methyl chloride, and methylethyl ketone as solvents and high molecular weight polystyrene as the solute.[4-1] The column temperatures have been less than 200 ^{o}C and column heights as small as two meters. If the shells were to be formed of some type of inorganic glass, then the column temperatures would range from 1000^{o}C to 1600^{o}C, depending on the glass shell composition being used.

With the drop generator and heated column technique, the rate of production of shells can be as high as several thousand per second. Techniques have been employed to reduce the production rate to several hundred per second by removing, for example, all but every 100th or 200th drop.[4-2] This leaves large spaces between successive drops preventing collisions between drops as they fall through the hot column. It also reduces the rate at which solvent must be removed from the column.

A concern about the drop technique is that the shells might become less uniform as the size of the shell is increased. This, however, has not been proved and indeed, has been shown not to be the case with production of shells up to several millimeters diameter. Further work may show that the drop generator / hot column technique is the most satisfactory means of producing fuel capsules in large quantities.

Capsules have also been produced by a technique known as microencapsulation.[4-3] This is a proven technology with high reliability and no major development issues. In the micro-encapsulation technique, as shown schematically in Fig. 4.2, mixtures of water, solvent, and solutions of polystyrene in a solvent are physically shaken to form minute droplets of immiscible components in a complex emulsion. The polymer shells form around the droplets and the liquid inside the shells is subsequently diffused out in alcohol to leave hardened, hollow shells of polystyrene. Careful control of the solvents, mixtures, and polymer molecular weight allow the production of uniform shells without vacuoles in the walls of the shells. However, the shaking process inherently produces a wide range of particle sizes and, hence, a wide range of shell diameters and wall thicknesses.

A method to make DT shells directly has been demonstrated[4.4] and is shown in the diagram in Fig. 4.3. The DT shells can be formed by initiating bubble growth in a liquid droplet of DT which is maintained at a temperature above the triple point. If a bubble is nucleated ultrasonically, the bubble will grow and result in a hollow liquid shell of DT. By passing the liquid shell through an orifice into a region at lower pressure, the evaporation of a very small amount of the DT will cause the shell to freeze and thus produce a solid hollow shell of DT. If the frozen shell of DT is introduced into a region containing a small partial pressure of a gas such as methane (CH_4) some methane can be condensed onto the DT shell to produce an ablative shell of CH around the DT. The composite CH-DT shells can be produced at high rates or one at a time at the chamber rep-rate (i.e., on demand). Thus, no storage of targets would be necessary and the tritium inventory would be reduced to a minimal amount. There are large advantages to this totally cryogenic technique for target production. However, even though the technique has been experimentally demonstrated using normal hydrogen and other gases, it is not considered to be a proven target production technique and is not being chosen as the base case option.

4.1.3.2 Selected Approach for Capsule Production

The option selected for capsule production in the base case is the combination of drop generators to produce uniform liquid drops of water layered with a solution of an appropriate polymer. This has been called the controlled microencapsulation technique. It combines the advantages of the drop generator technique, which produces droplets with a fractional standard deviation in diameter of better than 10^{-5}, and the microencapsulation technique which delivers

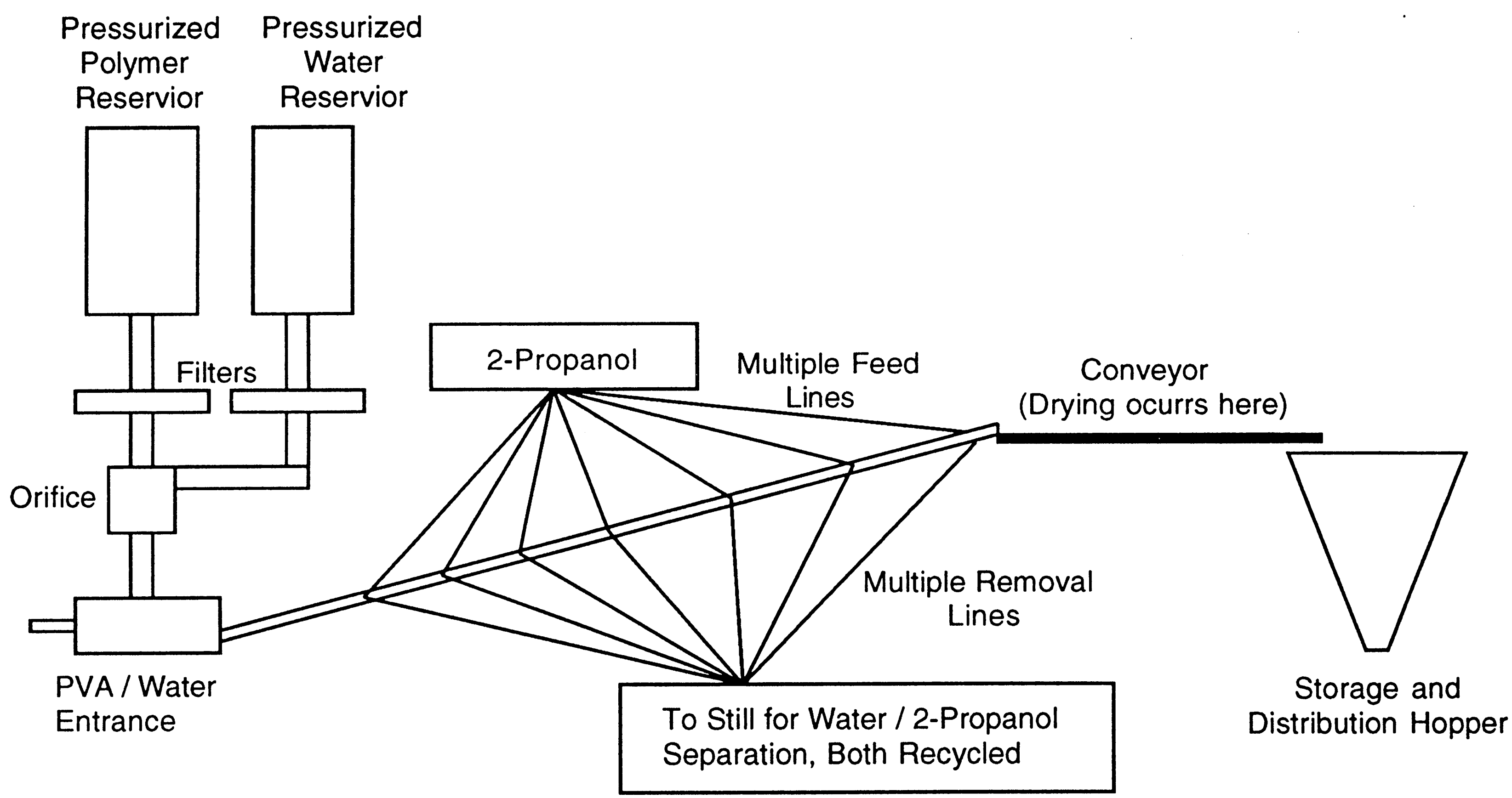

Fig. 4.2. Schematic representation of microencapsulation equipment.

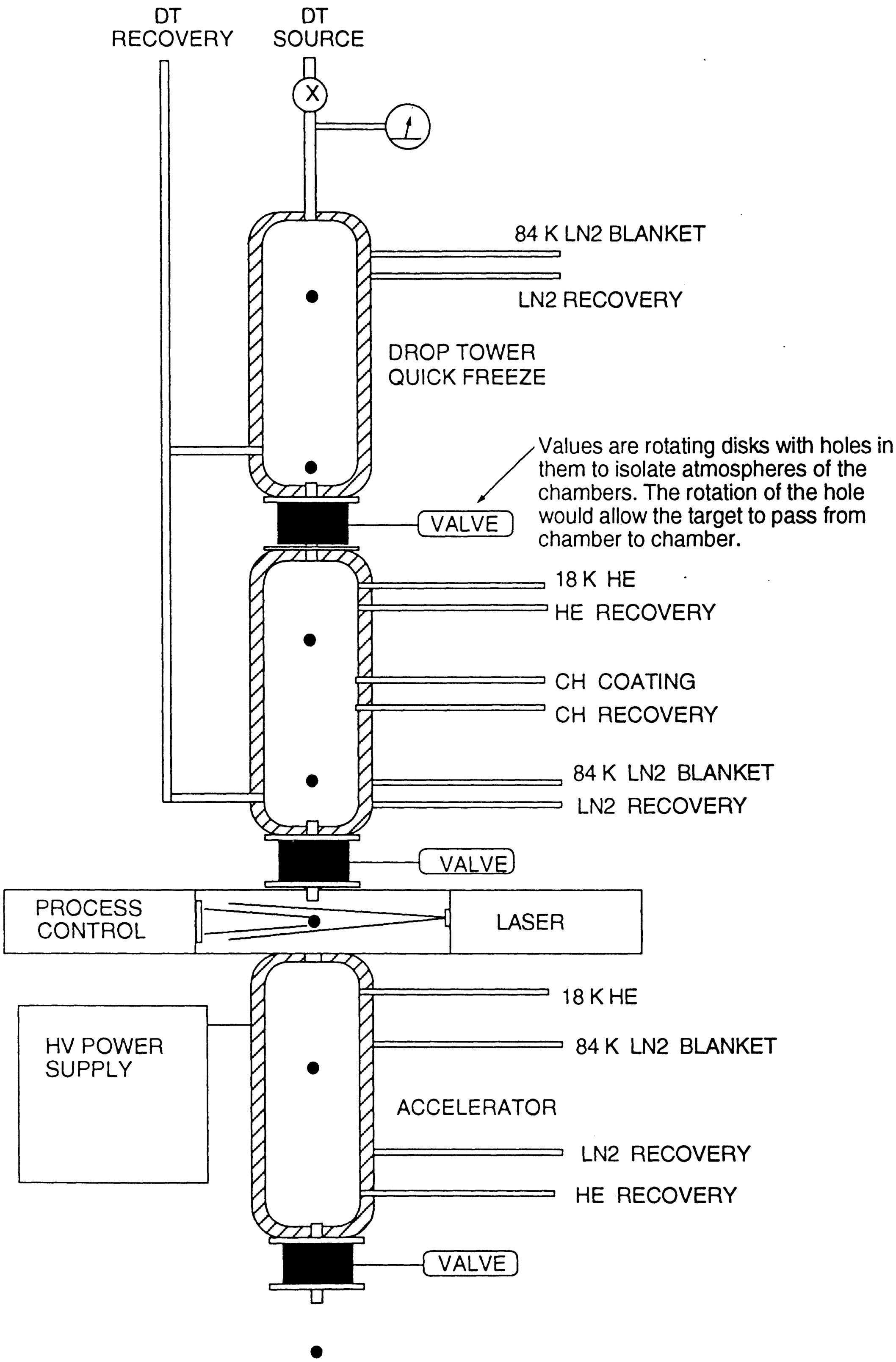

Fig. 4.3. Schematic of system for producing frozen DT targets.

shells which are round and have uniform wall thicknesses. A drop generator is used to produce uniform drops of polystyrene or other suitable polymer. The drops are injected directly into a liquid where they are treated to form shells as in the microencapsulation technique. Thus, shells will have uniform mass, diameter, wall thickness, and shape like those produced by the shake-type microencapsulation technique.

The multilayer drop is either generated directly in water where the solvent in the polymer solution diffuses out to leave a shell which can be subsequently recovered, or the multilayer drops are formed in air and injected into an appropriate liquid such as water in which the drops can be processed to produce the desired capsules. An important advantage of the combination technique is the control which can be exercised over the various aspects of the process. It is not necessary to depend on selection of the shells from a randomly-produced melange of shells with varying diameter and wall thickness. The shells as produced are the correct diameter and wall thickness and have the quality necessary to serve as the fuel capsules for IFE reactor targets. Using this method, the capsules can be produced in large numbers and stored in preparation for the fuel fill step in the target production process.

4.1.4 DT Fuel Filling

4.1.4.1 DT Fuel Fill Options

Several techniques were considered for the fuel fill step in target production. Because of the use of radioactive tritium, two major considerations were tritium inventory and safety for operating personnel. Table 4.4 presents the options which were considered and the advantages and disadvantages of each.

Because of the importance and difficulty of filling the capsules with the DT fuel, it is clear that much more research and development are required before a final fuel fill technique can be established. However, during this study, it became apparent that the presently used standard method of fuel filling, diffusion of DT gas through the capsule wall, is quite unattractive for reactor targets. It is, therefore, important that a development program be initiated to generate better methods for fuel filling.

Figure 4.4 is a schematic diagram of a typical permeation fuel fill system. Filling the capsules by permeating the DT through the capsule walls from a gaseous environment requires very long times (estimated at approximately 60 hours) and also requires a large tritium inventory. The process requires high pressure DT handling systems and fast cool-down after the fuel fill operation to minimize fuel loss through outward permeation.

The technique of making hollow frozen spherical shells of DT directly with condensation coating of CH layers is very attractive (Fig. 4.3). However, even though the technique has been demonstrated experimentally,[4.5] the study guidelines specified that the DT filled, polymer capsules

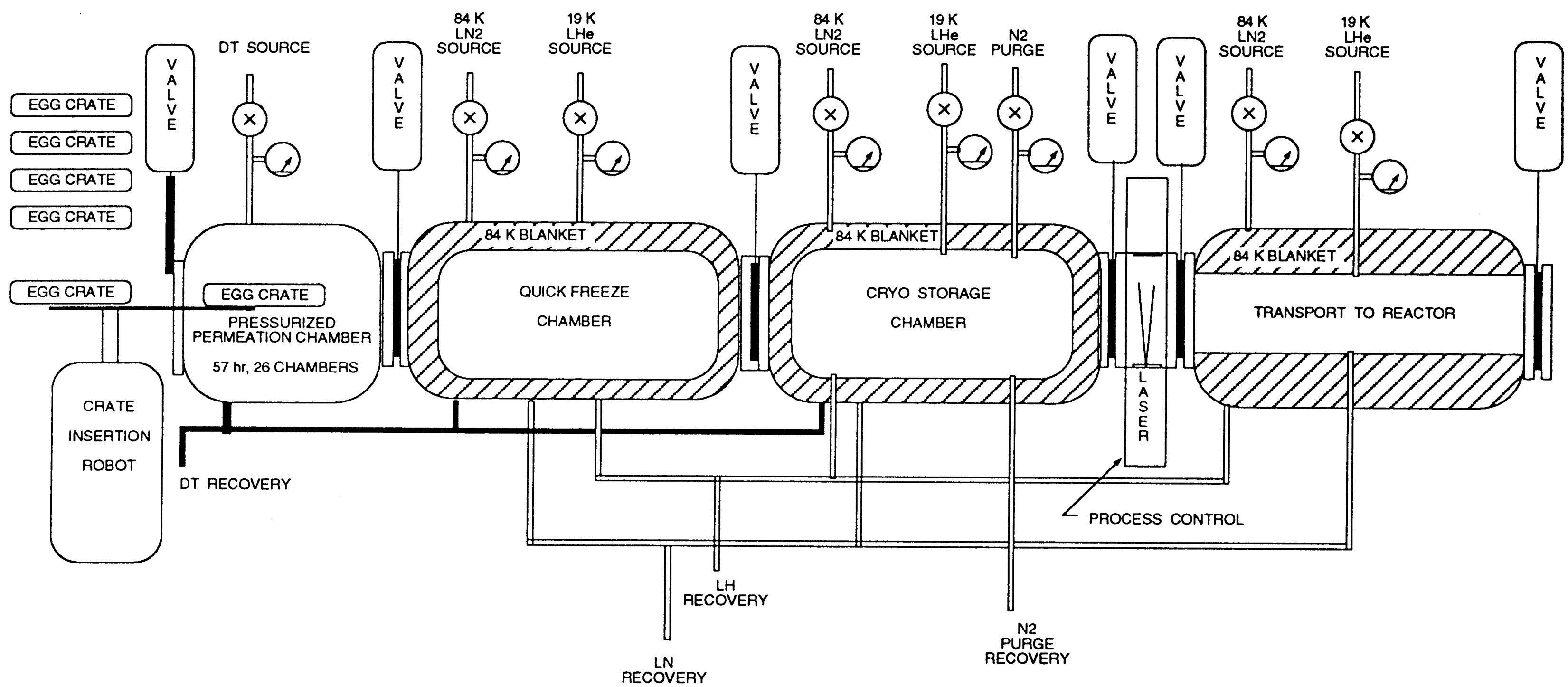

Fig. 4.4. Target prodution line for permeation fill approach.

Table 4.4. **DT Fuel Filling Options**

Technique		Advantages (+) and Disadvantages (-)
Permeation Fill	+	Proven technique
	-	Excess DT handling required
	-	Long fill times
	-	High pressures required in the DT handling system
	-	Fast post-fill cool-down required to reduce permeation
Frozen DT Shells	+	No "handling" of targets (make-one, burn-one)
	+	No storage required
Injection Fill of Liquid Fuel	+	Precise delivery of DT
	+	Rapid fill (times ~1 shell / min / injector)
	+	High fill pressures not required
	-	Development of technique is required

be used as the based case for the target factory design. At some future time, generating frozen shells of fuel may be the least expensive, require the lowest tritium inventory, provide high quality targets directly with no storage requirements (make one, burn one capability) and require only a low cost building and maintenance facility. However, at present , the decision was made to use the injection fill option for putting fuel into the IFE target capsules.

4.1.4.2 Selected Approach for Fuel Filling

A new and undeveloped method, called injection fill, has been selected for the DT fuel filling process because the presently available method of diffusion fill was judged to be unattractive. The basic approach to the injection fill technique is as follows:

1) A very small hollow fiber or needle is inserted through the wall of a capsule,
2) Liquid DT flows through the needle into the capsule,
3) The needle is removed from the capsule wall, and
4) The wall smoothed to a quality sufficiently high for use as an IFE target.

A hollow optical fiber could be used as the transport tube for the liquid DT fuel. The wall of the fiber forms an optical waveguide for a laser pulse that softens the wall of the capsule allowing the tip of the hollow fiber to easily penetrate the capsule. The outside surface of the fiber can be coated with a material which does not "wet" the capsule wall material. Thus, when the fiber is inserted through the wall, the wall material does not become attached to the fiber, and the wall is not severely damaged. When the fiber is removed, none of the wall material is removed by the fiber. As the end of the fiber leaves the wall, a pulse of laser light can be used via the fiber wall to heat the material around the hole. This will allow the material around the hole to flow back into the hole to repair any irregularities left by the fiber.

A large number of capsules can be filled simultaneously by using a manifold of the hollow fibers which are inserted into an equal number of capsules carried by a tray with an array of holes or cups similar to an "egg crate." The entire injection process will be carried out at cryogenic temperatures as shown in Figs. 4.5 and 4.6, or at room temperatures as shown in Fig. 4.7. Filling the capsules at cryogenic temperatures will ensure that there will be no disruption of the capsules because of excessive internal pressure of the fuel. If the capsules are filled at room temperature, a high external pressure would be necessary to prevent disruption of the capsule from internal pressure until the capsules were cooled enough to reduce the internal pressure to manageable values.

The primary issues involved with the fill process are that 1) the technology is unproven and undeveloped, 2) mechanical movement at cryogenic temperatures is difficult (however, high speed pumps do operate at cryogenic temperatures to pump liquid oxygen, hydrogen, etc.), and 3) achieving necessary capsule surface quality after injection through its wall may be difficult.

4.1.5 Developing a Uniform DT Layer

Following the fill process, the DT fuel in the capsule must be formed into a solid layer inside the capsule. The layer must be very uniform and must be maintained until the target is irradiated in the reactor chamber or the layer must be re-formed before the target is injected into the chamber. In this section, the various methods of forming the solid DT layers are discussed and the reasons for choosing a particular technique are presented.

4.1.5.1 Layering Options

Some of the most stringent requirements imposed on IFE targets are on their geometry (i.e., the limits of surface roughness, wall thickness variations, concentricity of inner and outer surfaces, and volumetric uniformity of the capsule materials). The limits are particularly stringent when applied to the fuel layer inside the capsule. The fuel layer is required to be the correct thickness (i.e., correct quantity of fuel), and uniformity. If the capsule is filled with fuel in either liquid or gaseous form, in a subsequent step the fuel must be frozen into a uniform layer on the inner surface of the capsule.

Several techniques have been developed to cause the original freezing process to produce a uniform layer or to remelt and/or vaporize the fuel and implement a refreeze process leading to a very uniform layer. Table 4.5 presents the techniques considered viable for producing uniform

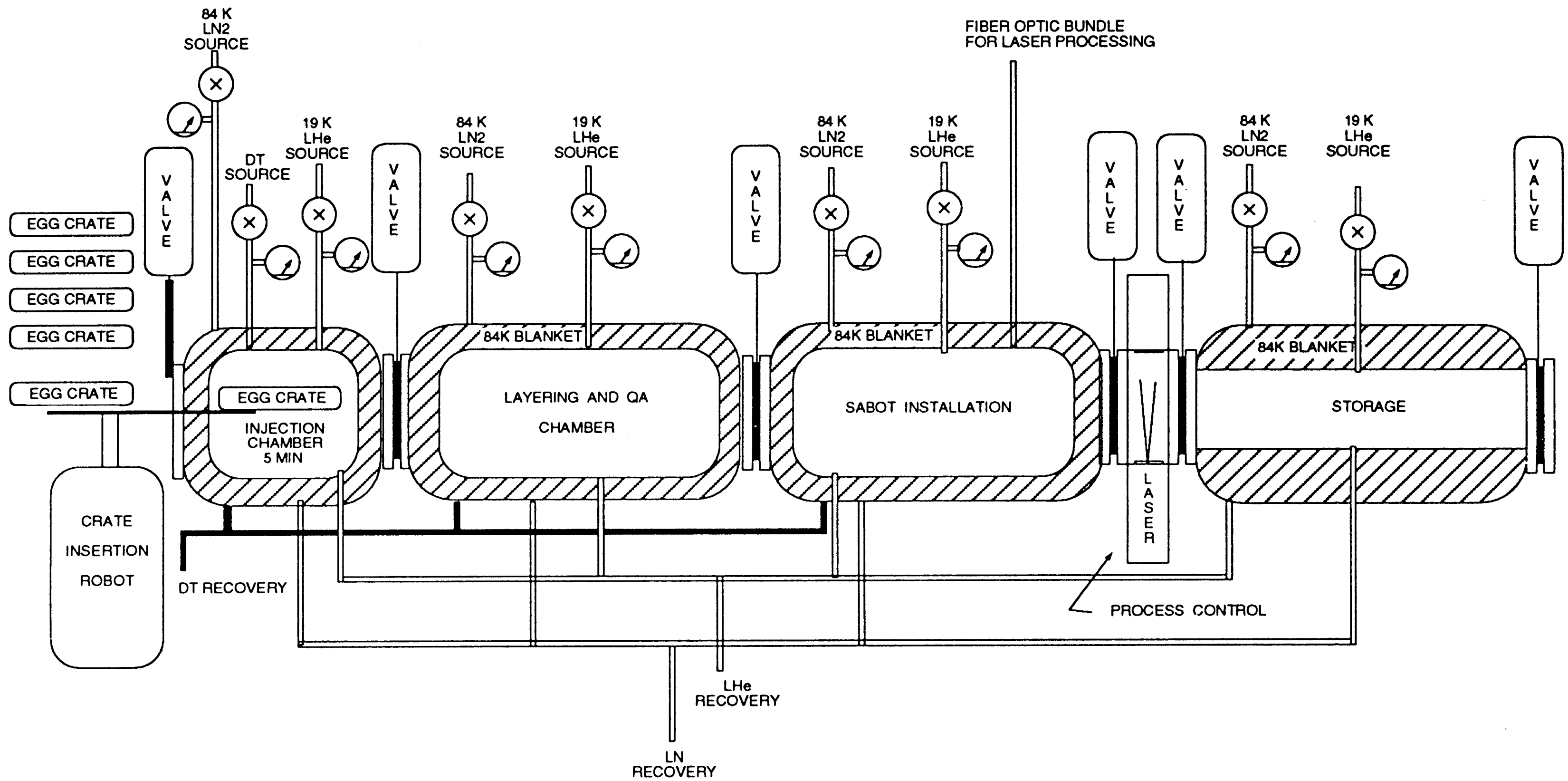

Fig. 4.5. Target produciton line using cryogenic injection fill.

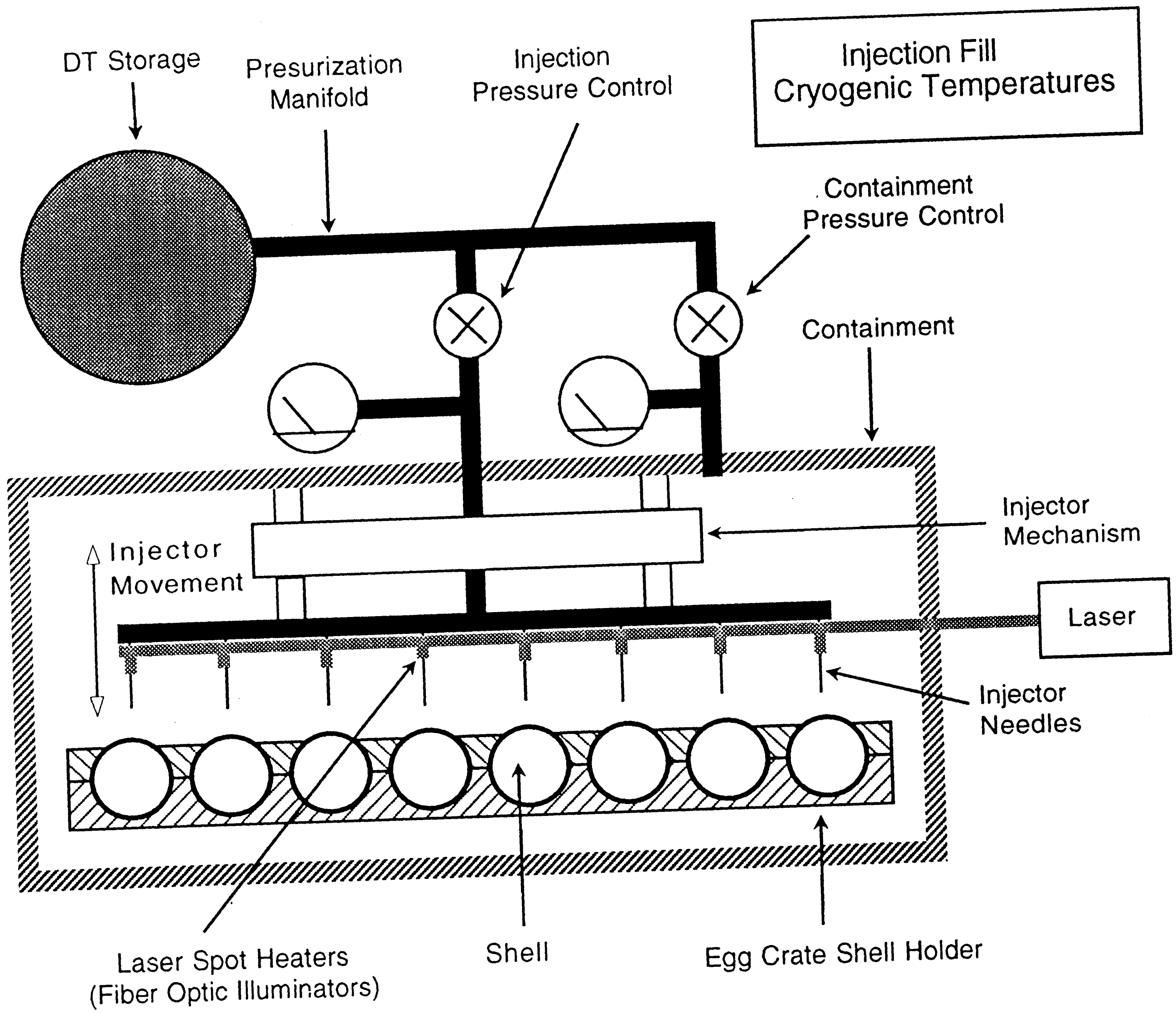

Fig. 4.6. Schematic of injection fill equipment operating at cryogenic temperatures.

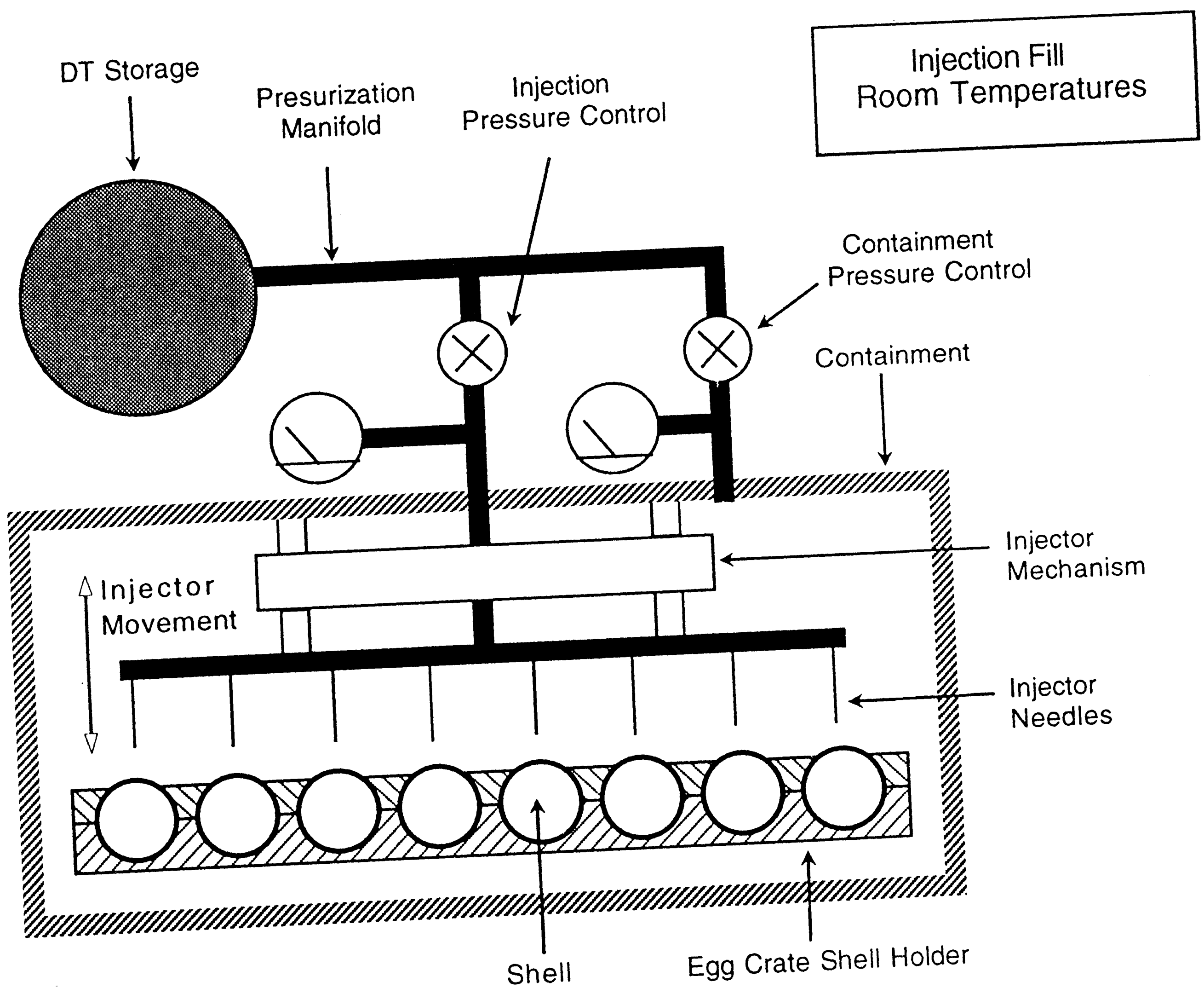

Fig. 4.7. Schematic of injection fill equipment operating at room temperature. Higher pressure fill lines are required, but laser spot heating is not.

Table 4.5. Methods for Producing a Uniform Fuel Layer in the Capsule

Technique	Advantages (+) and Disadvantages (-)
Pulse Laser / rf Heating / Refreezing	+ Target temperature regulated (intensity-graded laser) to produce uniform layer + Can be the last step prior to delivery to transport system + Simultaneous interferometric monitoring possible
Cold Gas Jets	+ Short time constant (seconds or less) - Insertion removal problems - Control problems with large numbers of capsules
Beta Layering	+ Forms a uniform DT layer automatically by self-distribution of fuel in the layer - Requires holding the capsule for a long time (4 hours)

layers in reactor-scale capsules together with some of the advantages and disadvantages of each. The major techniques are 1) laser or rf heating and refreezing,[4.6] 2) temperature controlled gas jets impinging on the capsule to cause melting/refreezing and uniform layering,[4.7] and 3) using the heat from the beta decay of tritium to cause slow migration of fuel from thick to thin portions, a process known as beta layering.[4.8]

Figure 4.8 illustrates the beta-layering technique in schematic form. The fuel filled capsule is held at a low enough temperature that the DT fuel is in a solid layer although it may be very irregular. If the capsule is held at the low temperature for a long period of time (4 hours) the energy deposited in the DT by the beta electrons from the decaying tritium causes some of the DT to be evaporated from the thicker portions and redeposited in the thinner regions of the solid DT. Because there is more tritium in the thicker parts of the layer, more energy will be deposited in the thick parts per unit time than is deposited in the thin parts. Thus, DT preferentially moves from the thick regions to the thin regions and gradually produces a uniform layer. The inner surface of the DT layer seeks the shape of a spherical isotherm. Definitive studies to determine whether or not the beta-layering technique will produce thick layers of sufficiently good quality are now in process at Los Alamos National Laboratory. Although the fuel layers seem to be adequately uniform, the poor surface quality (~ 1 μm) is still an issue. In addition, the long time required for the process to cause transport of the DT into a uniform layer reduces the attractiveness of the technique as a uniform layer generating method for reactor target production. Perhaps beta-layering could be supplemented with another method giving greater control.

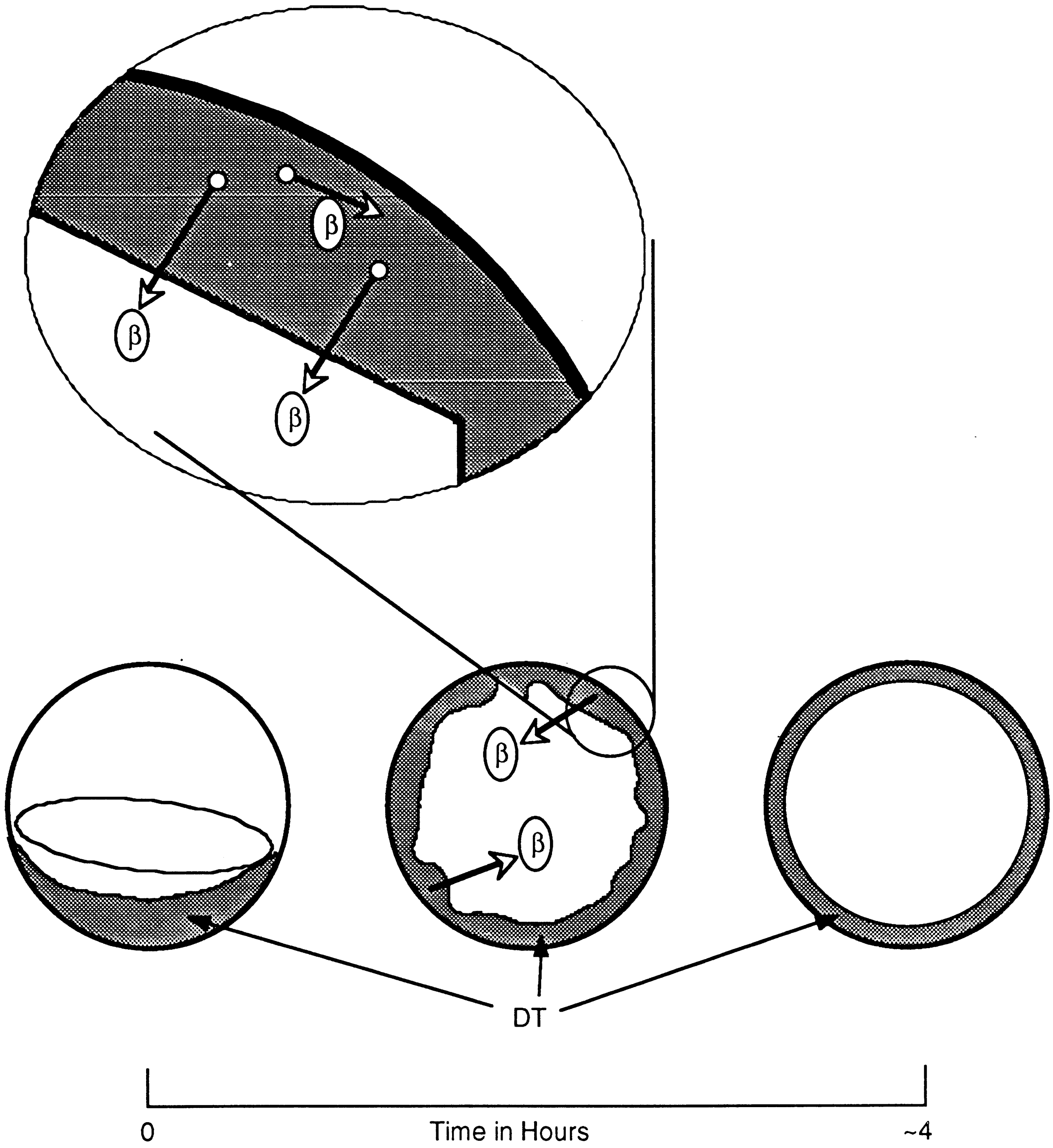

Fig. 4.8 Schematic of beta-layering process for establishing a uniform fuel layer.

The use of temperature-controlled cold gaseous helium jets for freezing and producing uniform layers of fuel in fusion targets has been analyzed and experimentally demonstrated.[4.7] Figure 4.9 shows schematically how a cold gas system operates. Gas jets impinging on the capsule from top and bottom provided the cooling to freeze the fuel into a solid layer in the capsule. By adjusting the relative temperatures of the jets, the fuel can be caused to migrate properly to form a uniform layer in the shell. The capsule could be levitated on the lower jet to avoid contact with any surfaces which could perturb the process and lead to nonuniform layers. However, the perceived transport, suspension, and control problems make it unlikely that the gas jet process could be used by itself to generate uniform layers in production targets.

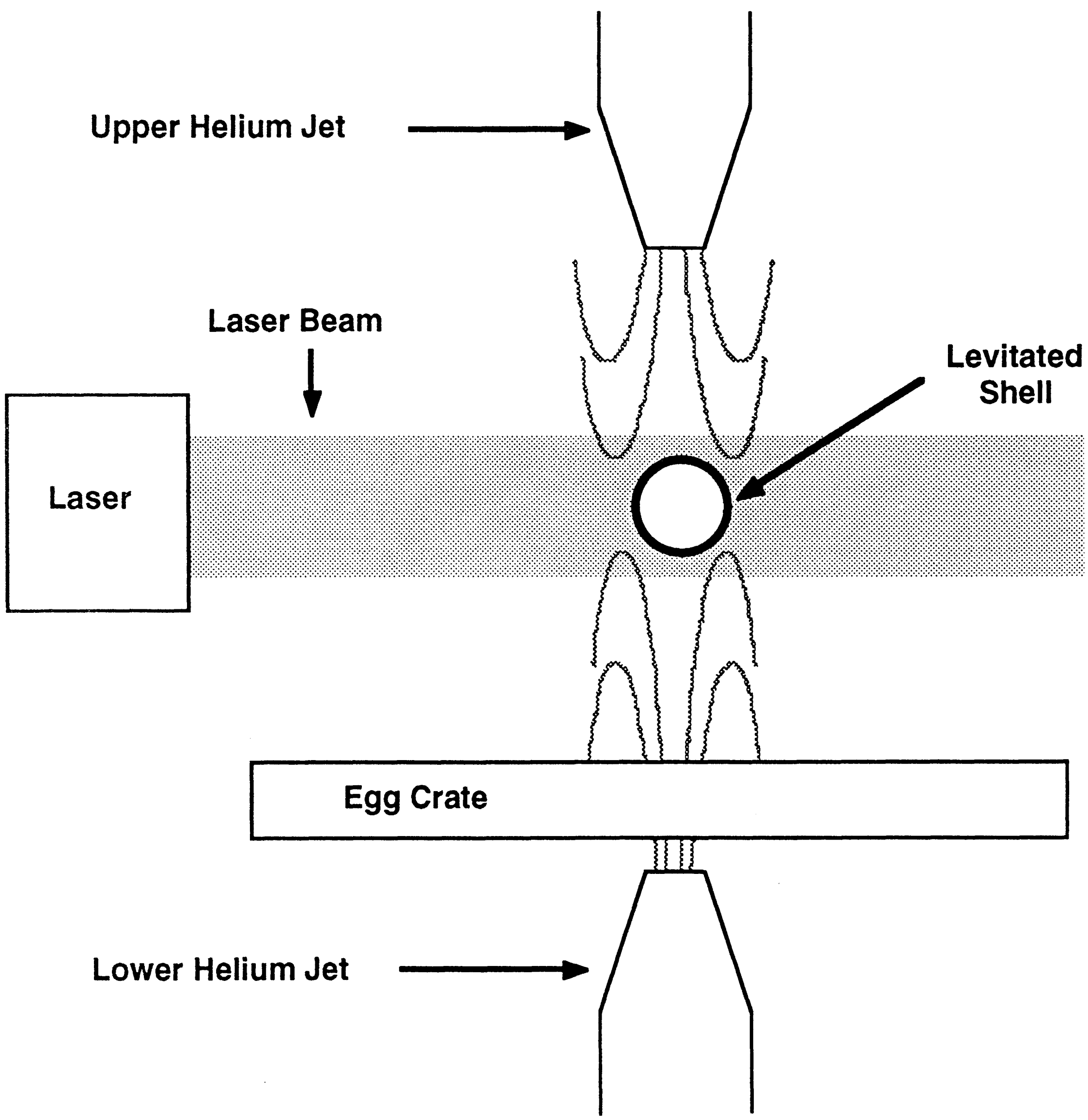

Fig. 4.9. Use of cold gas jet and pulsed laser to form a uniform fuel layer.

4.1.5.2 Selected Layering Option

For our reference design, we combine the use of gas jets to levitate the capsule with a pulsed laser for rapid heating and refreezing. This technique has been demonstrated experimentally at small scale with thin fuel layers.[4.9] We proposed that this could be the last step just prior to insertion into the sabot and transport to the chamber. We also note that simultaneous interferometric monitoring would be possible during the layer step.

4.1.6 Capsule Handling and Transport

Some of the capsule handling and transport considerations are summarized in Table 4.6. After they are formed, the capsules will be handled and transported in egg-crate type trays holding approximately 2000 capsules in each tray. The trays will nominally be about 35 cm by 35 cm and will be designed for handling by conveyers, robots, and other automated equipment. The construction of the egg-crate trays is shown schematically in Fig. 4.10. The construction of the trays will permit handling by conveyers, robots, and other automated equipment needed to move the filled trays through the various stages of the target fabrication process. The trays will also permit automated stacking for storage and retrieval of the finished targets. To deliver targets one-at-a-time to the reactor, the trays must be unloaded and each target inserted into a sabot. The sabot is used to protect the target during transport from the production facility to the target injector and during acceleration by the injector. The halves of the sabot will be ejected prior to entering the reactor chamber, and the target will continue to the irradiation point in a completely uncovered state.

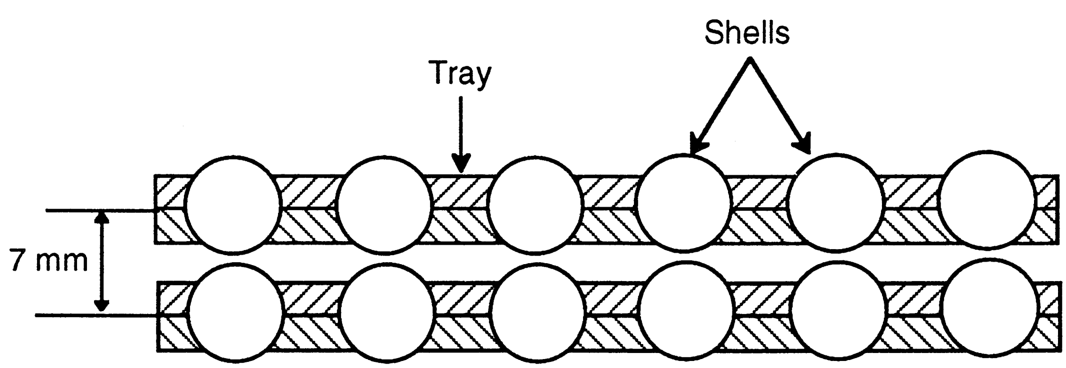

Fig. 4.10. Cross section of transport trays showing shell placement and tray spacing during storage.

Table 4.6. Capsule Handling and Transport Issues

- Mechanisms operating at cryogenic temperatures:
  - Gate valves between chambers
  - Conveyer belts between chambers
  - Robot arm inserting trays into fuel fill chamber
  - Device to unload trays from storage into reactor transport
- Material limitations at cryogenic temperatures and in the presence of tritium (damage from beta radiation)
- Low mass (small size) of moving parts to minimize thermal shock to systems

4.1.7 Quality Assurance

Because the target fabrication processes must be completely industrialized by the time an IFE reactor power generation plant is built, there is no need to do a detailed characterization of each target. It will only be necessary to statistically monitor the various processes to ensure that the processes are not degrading with time. As is shown in Fig. 4.11, a laser interferometer will be used to generate real-time interferograms or holograms, which will be "read" by a high speed camera (e.g., a CCD array camera) and compared by a computer with a hard-wired, built-in pattern to determine if a given target matches the reference pattern within some predetermined limits. If differences exceed the chosen limits of size, wall and/or layer thickness, uniformity of wall, sphericity, or other parameters, alarms can alert operating personnel to potential problems. Because the target production rate is relatively low, there is sufficient time (~150 ms per target) to make all process determinations by computer. With exception of total mechanical failure of a part or system, the systems and processes should only be expected to change over long periods of time. Thus, human intervention can reset parameters to prevent slow problem build-up to catastrophic failure situations.

4.1.8 Target Protection by Sabots

During the process of acceleration and transport to the outer wall of the reactor chamber, the targets should be protected by either a thick coating of frozen gas or by a solid sabot. If the choice is to protect by a thick cryogenic layer, it must be permitted to ablate during the travel to the irradiation point in the chamber. This would protect the actual target from the high temperature ambient atmosphere in the chamber and also afford protection during the transport and acceleration phases before the target reaches the wall of the reactor chamber.

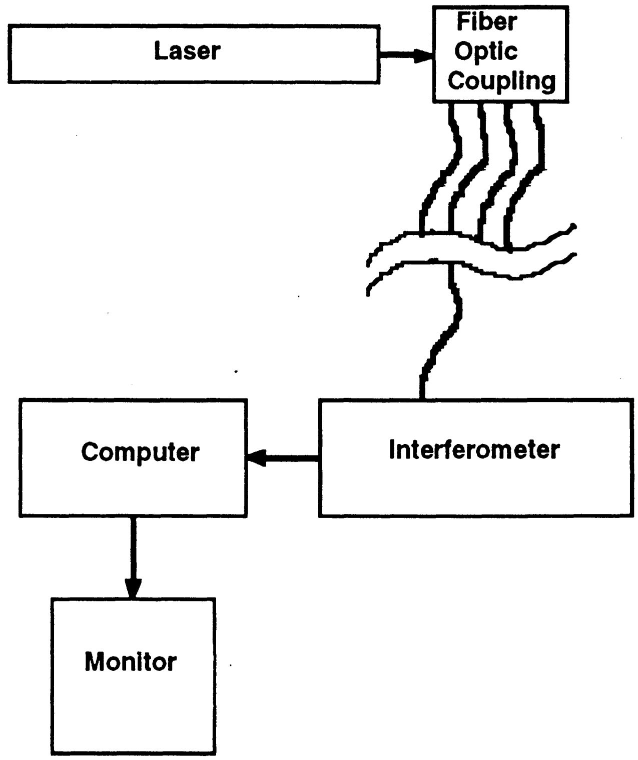

Fig. 4.11. Schematic of interferometric technical for monitoring capsule quality.

If the choice were to use a sabot around each target for protection during acceleration and transport phases, the sabots should be ejected from the target prior to entry into the chamber. The sabots would be re-usable and would not add to the gas loads and contaminants dumped into the chamber at each shot. It is also advantageous to remove the sabot prior to entry into the chamber in order to keep the sabot material out of the high radiation environment.

4.1.9 Target Storage

With two production lines, each operating at half capacity, it should not be necessary to store more than 6000 finished targets in each line for a total of 12,000 targets (~30 g of tritium). This would provide for 1/2 hour of reactor operation in the event of a failure of one production line. The probability is high that the remaining line could be brought to full-up capacity in the half-hour provided by the stored targets. Alternatively, if the production facility were to have two operating lines and a third line on ready stand-by, the idle line could be brought into operation very quickly, providing sufficient redundancy for almost any foreseeable problem. In this case, the stored target inventory could probably be reduced to half or even a third (i.e., perhaps 4000 target with a tritium inventory of ~ 10 g). Because the target production processes will have been tested and perfected, reliability should be very high by the time an operating target facility is constructed.

4.1.10 Tritium Inventory

The tritium inventory of the entire target production facility can be determined within the bounds of the assumptions made for target storage, target transport during fabrication, fill process tritium requirements, and tritium in pipes leading to the fill stations. There will be a minimum of two independent parallel process lines each operating at half the maximum production rate. The targets will move into the fill chamber in a 2000-capsule tray and a 2000-needle injection unit will fill the entire batch at one time. The fill time is less than 1 minute, but 10 minutes will be scheduled to allow for opening of valves, moving trays in and out, and for the insertion and removal of injectors. After filling, each tray of capsules will contain about 5 g of tritium. The tritium fill reservoir is assumed to contain 20 times the capacity of a single tray or about 100 grams of tritium. High pressures will not be required in the injection fill system because the fill is done at cryogenic temperatures at which the DT pressure will be very low.

Table 4.7 provides a tabulation of the tritium inventory for the IFE fusion reactor target production facility. The total tritium inventory for the target production facility is estimated to be about 300 g. Note that this does not include the tritium inventory associated with the recovery and processing of tritium generated in the breeding blanket since that is accounted for with the reactor and its enclosure.

4.1.11 Production Facility Building

Throughout this entire design study the issue of cost of building and footprint has been an underlying consideration. We propose that the capsule production, fill system, transport, storage, sabot production and loading, and other target handling functions will all be accomplished in clean (10-100 class), enclosed "boxes." Thus, it will not be necessary to build the target production facility building to clean room specifications. It will be sufficient to have the entire facility at 10,000 to 100,000 class cleanliness.

The entire apparatus in which targets are filled, transported, manipulated, and stored will be constructed for total containment of the tritium so the building itself need not be more costly than ordinary construction. This, in addition to the absence of formal clean rooms in the building, should help minimize the cost of the facility.

4.1.12 Summary

The follow points summarize the features of the target production facility design:

- Our design approach will lead to high reliability due to 100% redundancy of process lines.
- The tritium inventory is minimized by using fill and layering techniques that can be completed in seconds instead of hours.

- A small capsule storage inventory is judged to be acceptable because of the redundancy and high reliability.
- The required building is compact, which should lead to acceptably low cost.
- Much of the technology is unproven and requires development.
- The payoff in pursuing these innovative target production approaches is very high in terms of reducing the tritium inventory and the size and cost of production equipment and buildings.

Table 4.7. Total Tritium Inventory

Process Step	Tritium Inventory (grams)
Injection Step	
2 tritium reservoirs @ 100 grams each	200
2 trays of capsules @ 5 grams each	10
Layering and Q/A Steps	
2 trays of capsules @ 5 grams each	10
Sabot Loading	
2 trays of capsules @ 5 grams each	10
Storage of Complete Targets	
12,000 @ 2.4 mg each	29
Transport Chain to Chamber	
50 meters @ 1 m/sec = 50 seconds	
50 seconds of targets @ 6.7 Hz = 335 targets	
335 targets @ 2.4 mg/target = approx.	1
Piping and Purge Lines	
500 m of 1-cm diameter piping at 3 atm.	40
Total Tritium Inventory	**300**