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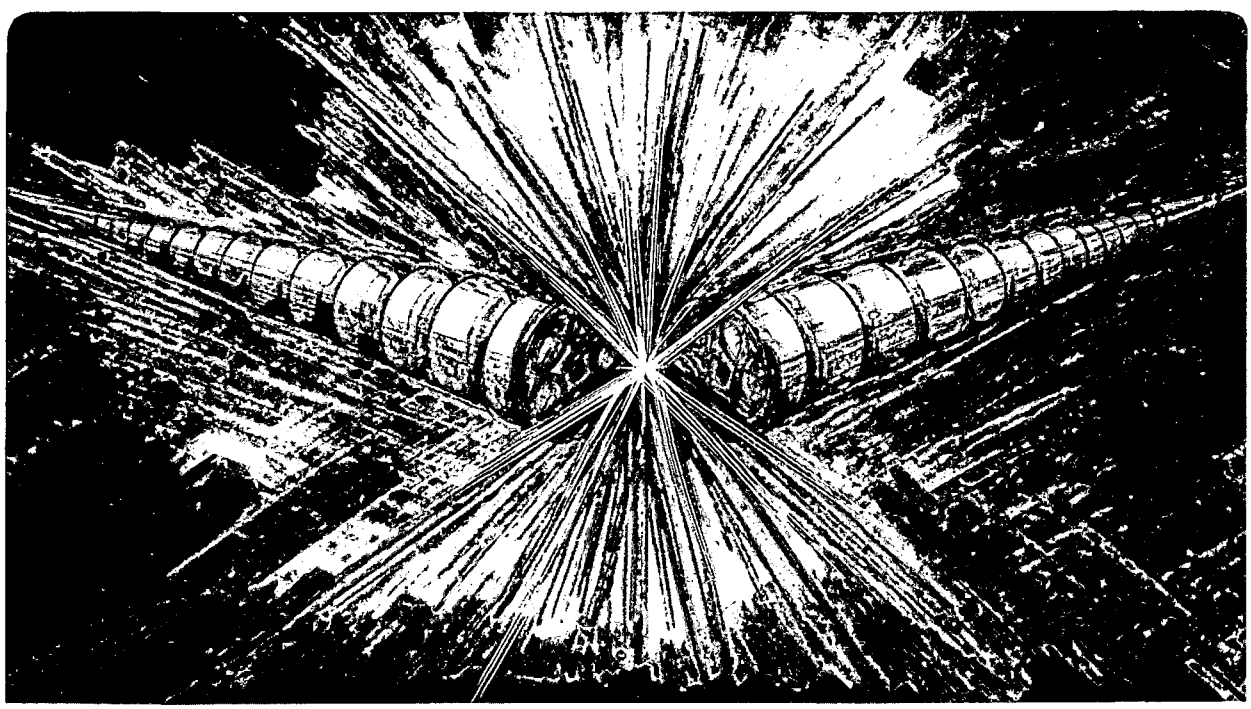

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GAS DYNAMICS MODELING OF THE HYLIFE-II REACTOR

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Abstract

Gas dynamics in the IFE reactor, HYLIFE-II is modeled using the code, TSUNAMI. This code is a 2-D shock-solver that uses the Godunov method with operator splitting. Results from a cylindrically symmetric simulation indicate an initial, low density, burst of high energy particles enters the final focus transport lens within 40 microseconds after the blast, much faster than the proposed 1 millisecond shutter closing time. After approximately 100 microseconds the chamber debris flux levels off to one eighth its peak value and maintains this intensity until the shutter closes. Although initial protective jet ablation is considered, neither secondary radiation nor condensation are modeled. Therefore results are conservative.

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1.0 Introduction

Inherent in any ICF reactor concept is the need to protect the chamber wall from fusion products and target debris. The HYLIFE-II design, proposed by R. W. Moir, et al. [1], uses a renewable first wall

concept. In this design a slab type arrangement of oscillating Flibe, Li_2BeF_4 jets creates a series of annuli through which the beam passes in final transport. After fusion approximately 2/3 of the energy will be given off as 14 Mev neutrons. The neutrons heat the Flibe jets volumetrically and cause disassembly. X-ray energy absorption, however, occurs within only 10 microns of the surface. This surface heating leads to Flibe vaporization and ionization. The resulting hot, ablated material rebounds back toward the center of the annular channels where it encounters the expanding debris. The mixture thermalizes and reradiates, causing more jet vaporization, before expanding outward, Chen et al. [2]. Venting follows, with some of the gas escaping through the port while the rest passes throughout the jet arrays and condenses. Previous results from Liu, Peterson, and Schrock [3], focused on the chamber interior, considering the problems of venting through the jets as well as potential impact to the first structural wall. Additional, strategically located, sprays were suggested to ensure the reactor chamber will return to its original $3*10^{13}cm^{-3}$ Li_2BeF_4 particle density before the next shot.

To ensure the absence of excessive loss from stripping, the final focus section of a heavy ion driver has a particle density limit of only about 10^{10} cm^{-3}. A shutter system proposed by P. A. House [4] would close off the beam port 1 millisecond after fusion. But this would only limit, not eliminate, the amount of chamber material reaching the final focus region. Once in the beam tube, this high energy Flibe can interfere with beam propagation or corrode tube walls.

The goal of this study is to analyze the gas that will penetrate the final focus region of a heavy ion driver and find ways to reduce its fluence. The study assumes a 350 MJ yield with 2/3 the energy goes in neutrons, and the remaining third is divided equally between 350 eV x-rays and target debris. It uses the gas dynamics code, TSUNAMI developed at UC-Berkeley [2]. The simulations span one millisecond, the suggested shutter closing speed, and assume a 3 m radius for the chamber and .07 m radius for the port [4]. Although the results are applied to a HYLIFE-II type reactor, a similar analysis could be performed for other renewable first wall concepts.

2.0 TSUNAMI Code

The gas dynamics code TSUNAMI applies the Godunov finite difference approach to simulate shock problems in 2-dimensions [2]. This Eulerian model employs a real gas equation of state for Flibe vapor developed by Chen [2] and includes the effect of initial jet ablation by target x-rays. Excluded is any subsequent radiative transfer that occurs once the ablated Flibe has rebounded toward the chamber center and thermalized. Energy into condensation and ionization are also omitted.

3.0 Discussion of Results

The Hylife-II reactor chamber is modeled using a 2-dimensional, cylindrical grid. The beam entrance is located along the z-axis and the Flibe jets are modeled as annuli extending radially around this axis. The current Hylife-II design incorporates an annular jet arrangement for the first 1.5 meters that extend axially

from the pellet to the port. However directly in front of the port a mesh of first vertical and then horizontal jets is suggested. But, due to the cylindrical geometry restriction of the code, this cross-hatch of protective Flibe jets must be modified. The simulation models this combination of vertical and horizontal jets as adjacent rows of concentric annuli. Each annulus contains three spaces. The first is a cylinder located in the center and represents the beam path of interest. Outside this are two annular spaces which represent the channels through which adjacent beams propagate.

Values of density, velocity, pressure, temperature and specific energy are recorded at the beam entrance. Preliminary results for a half chamber simulation indicate a burst of high energy, low density particles entering the port, figures 1 and 2. The energy/density peak occurs approximately 40 microseconds after the blast and tapers off by 100 microseconds. It remains at that new level until a proposed shutter closes, one millisecond after ignition. Similar behavior is seen for pressure, temperature, and velocity profiles.

This 40 microsecond spike is due to x-ray ablated Flibe and high energy pellet debris. Since the code treats all chamber material as Flibe, including the pellet debris, the source of this initial burst cannot be clearly identified. After fusion, calculations indicate 2.4 grams of Flibe are ablated in the entire chamber. Combined with 9.5 grams of pellet material and .5 grams of chamber vapor, this concentrates 116.6 MJ, one third the total yield, into 12.4 grams of material. As a result, an initial burst of very high temperature, high velocity particles will reach the final focus section before the proposed shuttering system, located 3m away, can close. Therefore,

some pumping of the beam lines will be required to ensure beam focusing on successive shots. Assuming a one millisecond duration, flow rates are then integrated. Results for one .07m beam port radius show that .551 grams of Flibe and 3.75MJ enter the final focus section of each heavy ion driver channel per shot. With a 6 Hz shot repetition rate [1], pumping totals will reach 286 kg of Flibe per day per beam. The current Hylife-II design calls for single sided illumination with an array of 12 ion beams passing through a rotating shutter to focus onto the D-T pellet injected into the chamber center [1].

TSUNAMI movie histories indicate that the current Hylife-II jet arrangement preferentially directs vapor toward the port. Therefore, to reduce the pumping requirement, an alternative, sloped jet arrangement is studied as shown in figures 3 and 4. While port data give higher peak values (figure 5) the time integrated results show a 40% decrease in mass into the beam lines when a tapered array is chosen over a straight design (table 1). Average pressure and density at the beam port also decreased with this tapered geometry. Temperature and energy, however, increased (table 2).

These values, though, are conservative. Due to neglect of secondary radiation and ionization, the energy per particle is considerably overestimated. This leads to higher temperature and velocity values. The totals shown at the port are calculated by integrating the mass and energy flux values calculated at the port over a 1 millisecond time period. Since the velocities are too large, the integrated results shown should be considered upper bounds. Ionization is of particular importance. If all chamber material,

including the debris, is treated as Flibe, complete ionization would require more energy than the 116.6 MJ available.

In addition to the energy/velocity overestimate, two other sources of error exist. First, condensation is neglected. All Flibe vapor striking the jets bounces off and none condenses. And, second, the Hylife-II jet array tends to preferentially direct vapor towards the port. This combination of energy overestimate, condensation neglect and jet arrangement considerably overestimates results.

4.0 Conclusion

A two-dimensional gas dynamics simulation of the HYLIFE-II reactor chamber is performed. Results show that the yield energy carried by x-rays and target debris will be concentrated in a small amount of mass, 6.2 grams for a half chamber simulation. Consequently, an initial burst of high energy, low density particles will penetrate the beam tube, peaking by approximately 40 microseconds after the blast.

Data is then integrated over a 1 millisecond interval, corresponding to a proposed beam port shutter closing. Totals indicate that for a 6 Hz repetition rate, 286 kg of Flibe will enter the beam tube daily. This decreases to 187 kg when an alternative, tapered Flibe jet array is employed. These estimates should be regarded as a very conservative upper bound since the important energy loss to ionization and secondary radiation has been ignored in the current version of TSUNAMI.

5. Acknowledgments

The author greatly appreciates discussions with R. W. Moir, Per F. Peterson, Ed Lee and X. M. Chen.

6.0 References

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List of Figures

Figure 1:
Density evaluated at beam port as a function of time for 1msec trial, port lies 3m from chamber center

Figure 2:
Specific energy calculated at beam port as a function of time for 200 microseconds, port lies 3m from chamber center

Figure 3:
Temperature contours of straight jet array taken 10 microseconds after fusion

Figure 4:
Temperature contours of tapered jet array taken 10 microseconds after fusion

Figure 5:
Mass flux calculated at beam port as a funtion of time for 200 microseconds, results for both tapered and straight jet arrays shown

Table 1:
Average and peak flow properties evaluated at beam port for a 1msec trial, both tapered and straight protective jet arrays included

Table 2:
Values integrated over a 1msec time interval for mass and energy that enter a .07m radius beam port per shot, both tapered and straight protective jet arrays included

Figure 1 Density at Port

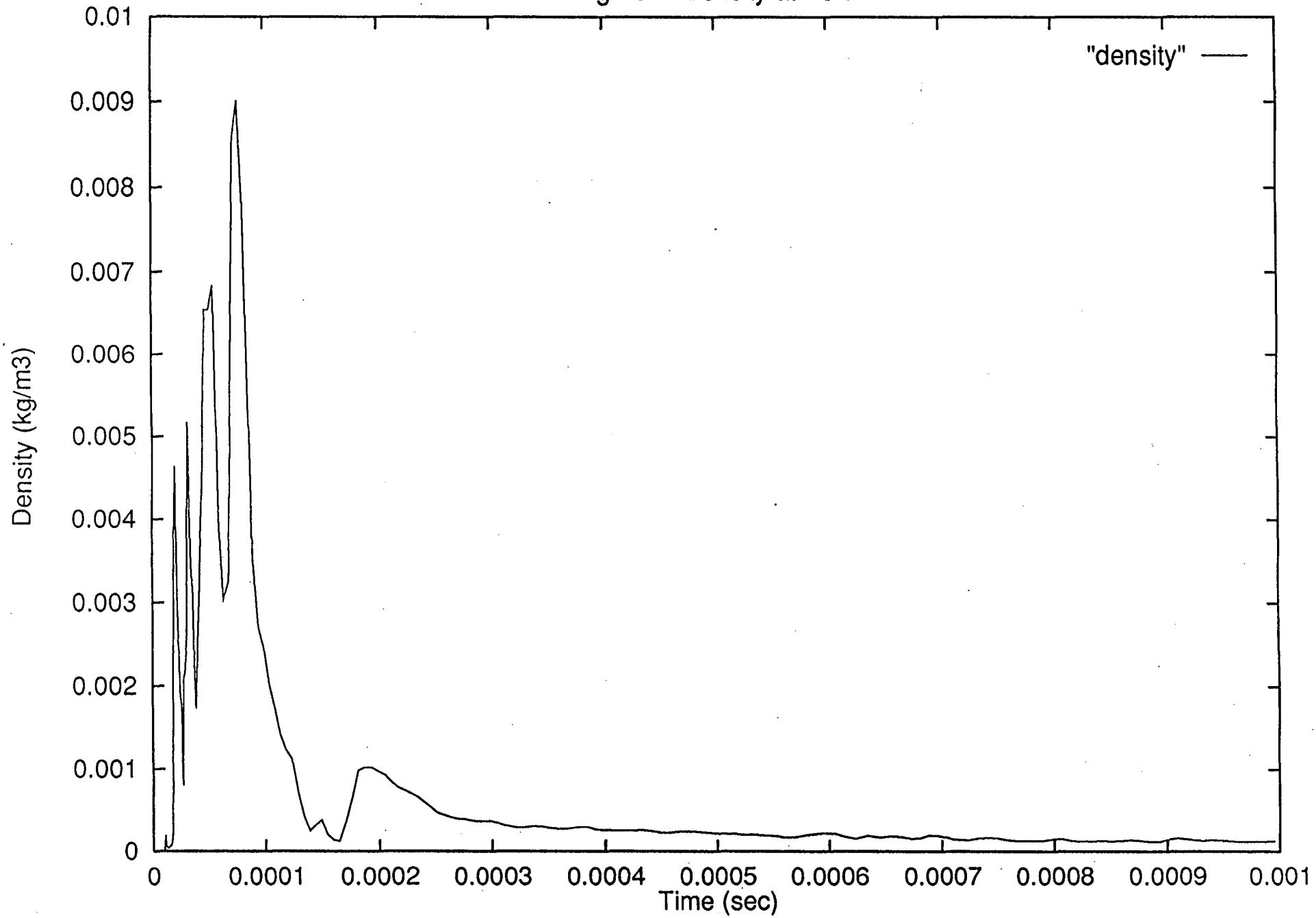

Figure 2 Energy at Port

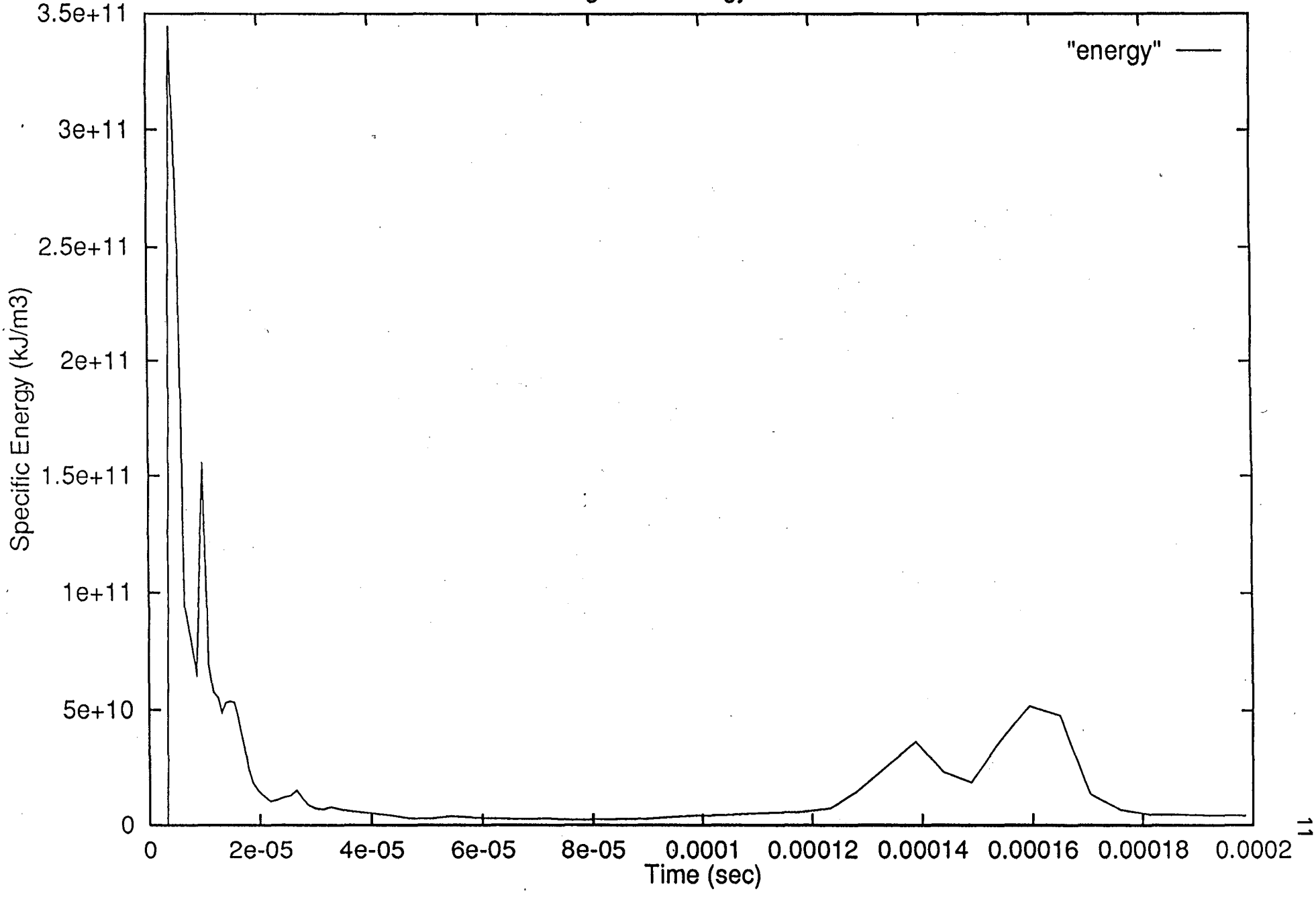

Figure 3
Straight Array, Temperature at 10 microseconds

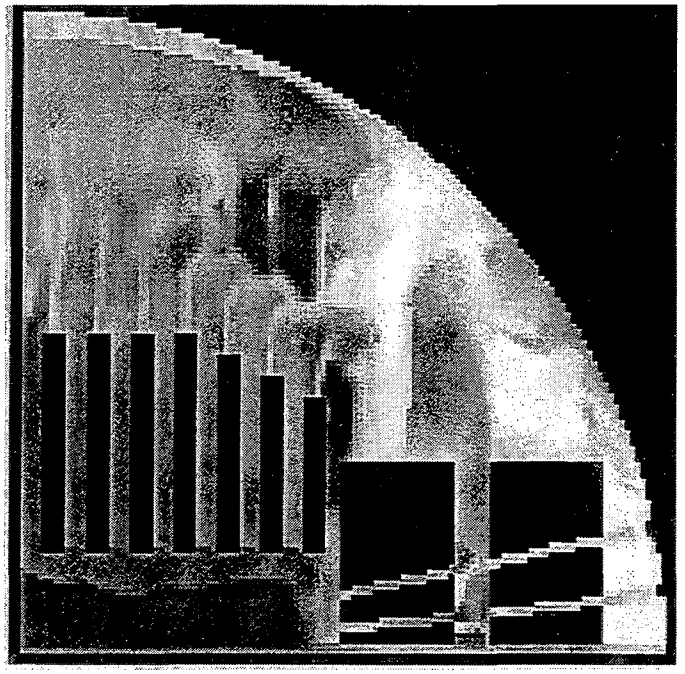

Figure 4

Sloped Array, Temperature at 10 microseconds

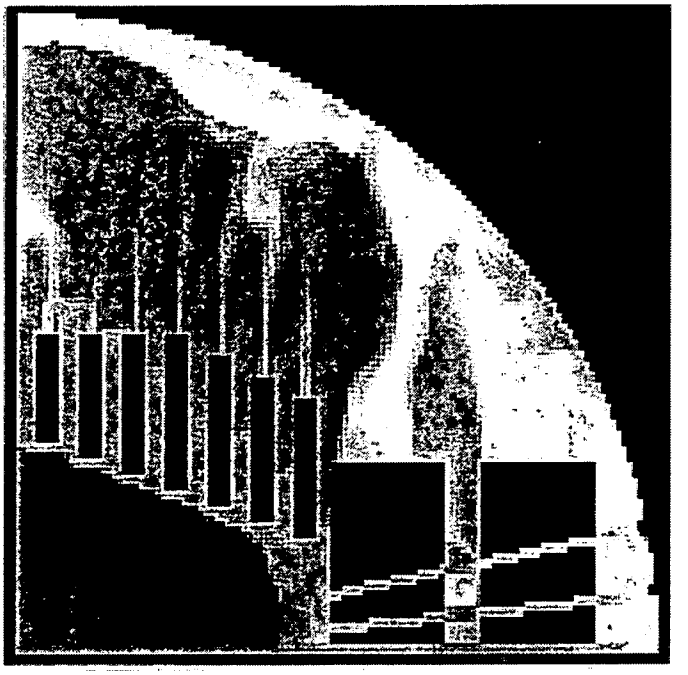

Figure 5 Port Mass Flux for Two Geometries

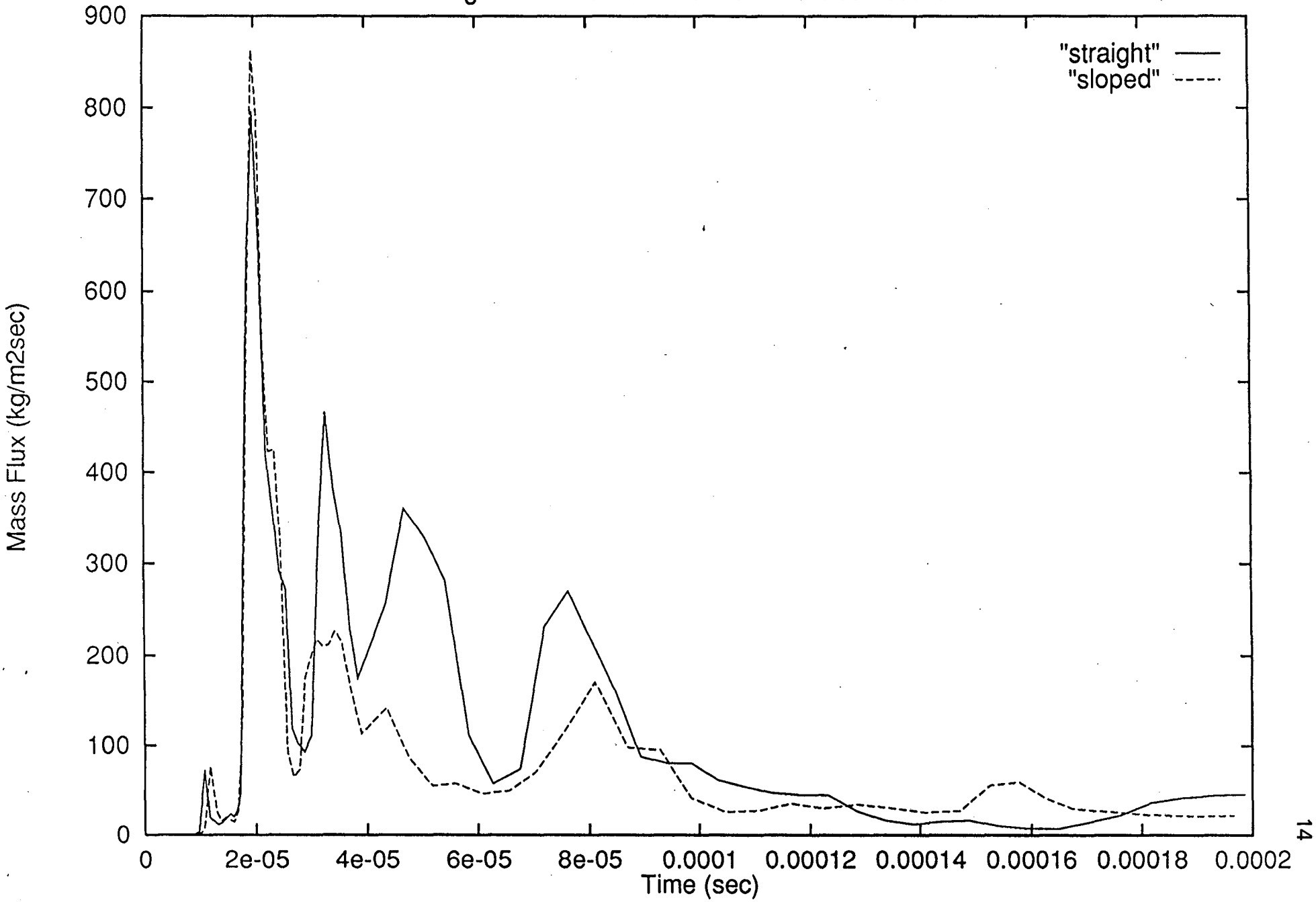

Table 1

	Straight Jet Array	Sloped Jet Array
mass flux (g)	.551	.361
energy flux (MJ)	3.75	4.30

Table 2

	Straight Jet Array		Tapered Jet Array	
	average	maximum	average	maximum
pressure (Pa)	$1.36*10^{6}$	$1.74*10^{7}$	$1.06*10^{6}$	$9.93*10^{6}$
temperature (K)	$2.22*10^{7}$	$1.40*10^{8}$	$3.10*10^{7}$	$4.90*10^{7}$
density (kg/m3)	$6.40*10^{-4}$	$5.17*10^{-3}$	$2.69*10^{-4}$	$4.90*10^{-3}$
velocity (m/s)	$8.14*10^{4}$	$7.92*10^{5}$	$1.08*10^{5}$	$4.42*10^{5}$

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