MONOLITHIC COIL TOKAMAK

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Presented at the
TAERF No. 40
April 1985

Publication No. PN-129
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Center for Fusion Engineering

In TAERF Progress Report #39 we reported on work on the evaluation of the performance of a monolithic tokamak field coil of a geometry and size suggested by Dr. Marshall Rosenbluth as having a good chance of ohmically heating to ignition. The configuration is shown in Fig. 1.

As reported earlier, a finite-element computer analysis is being used in the evaluation in the following way. An inner radius R_i is chosen and the bore is assumed to either be empty or filled with steel. The conductor is selected and its electrical conductivity and mechanical properties as functions of temperature are provided. The initial temperature is set to ambient or liquid nitrogen (LN_2), and the coil current necessary to produce the desired magnetic field strength is established rapidly (in a fraction of a second). The finite element computer code determines the current distribution and calculates how it evolves over time as the conductor heats unevenly. In addition, the computer code provides the temperature and stress distributions as they evolve over time. The hot spot temperature and maximum stress (which generally occur at the same point) will determine how long the coil can operate at the particular field level for which the analysis is being made. Thus these quantities are plotted as functions of time, and the addition of temperature and stress limits to these curves can define allowable operating conditions of field and duration for each configuration and material.

Three of the geometries analyzed thus far, along with the meshes used in the finite-element analyses, are shown in Fig. 2. These geometries were analyzed using two conductor materials, copper and aluminum, and with either a void or steel in the central hole. All analyses were made assuming an initial temperature of -196°C, which is the boiling temperature of LN_2 at atmospheric pressure.

The temperatures versus time are plotted for copper in Fig. 3 and aluminum in Fig. 4. The temperature is essentially independent of whether there is steel in the core.

The von Mises stresses versus time are presented for copper in Fig. 5 a-d and for aluminum in Fig. 6 a-f. Note that in each case, "no core" means a void in the central hole and "with core" means steel in the central hole. With steel in the central core the stress carried by the conductor itself is reduced substantially because the steel supports a major fraction of the stress.

The results of Figs. 5 and 6 show that the monolithic coil tokamak is capable of operation at flux densities in the 20T range for intervals of 5 to 20 seconds.

Future work will be along the following lines:

1. Attention will be focussed on a single configuration to make more efficient the process of relative evaluation of geometries, materials, and operating procedures.

2. Different materials will be examined for improvement in performance. High strength conducting alloys and composite materials appear to have the most promise.

3. The assumption of rapidly established current is efficient from a calculational viewpoint, but it gives the most severe duty on the materials. The computer code will be modified to provide a more realistic representation of the current buildup as it would occur with a practical power supply such as a homopolar generator or a rectifier power supply.

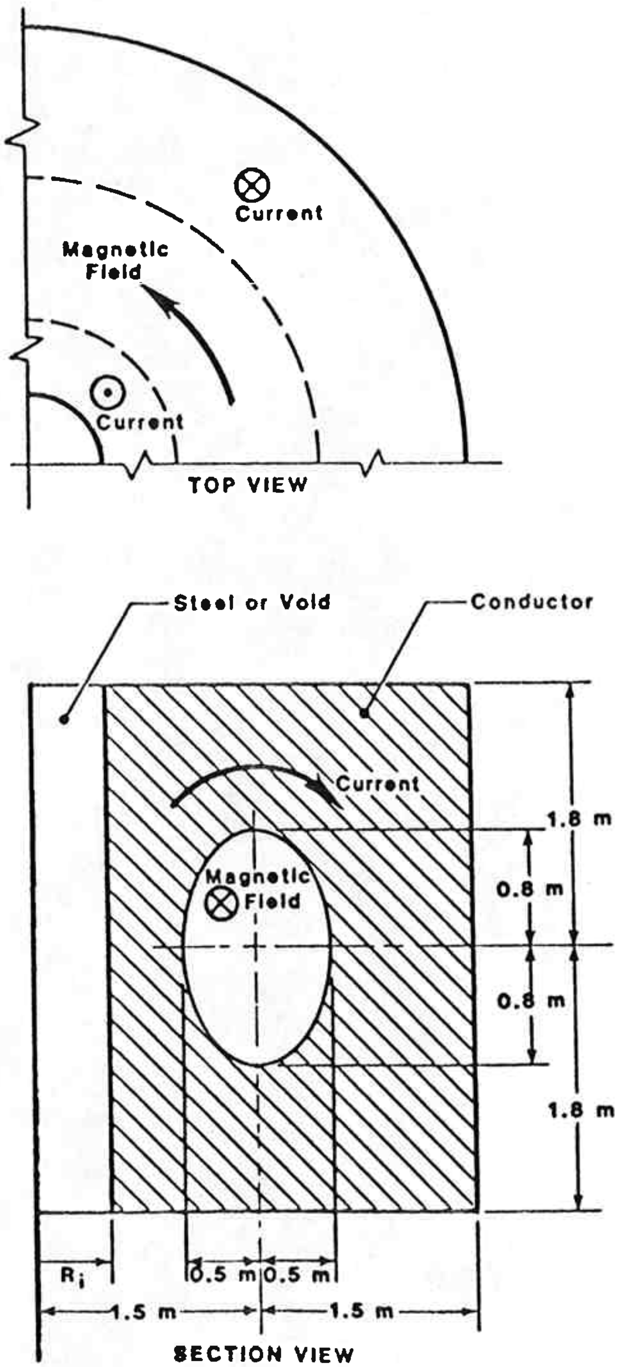


Fig. 1. Monolithic coil geometry for analysis.

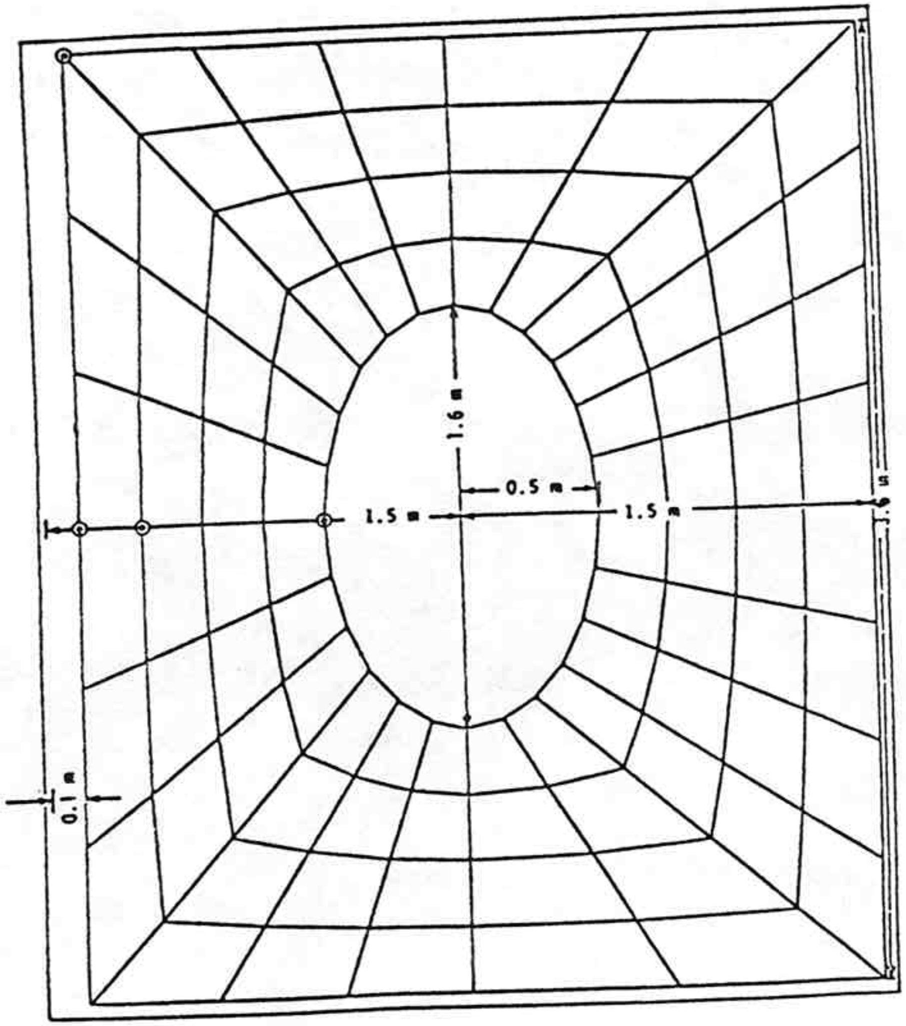


Fig. 2a

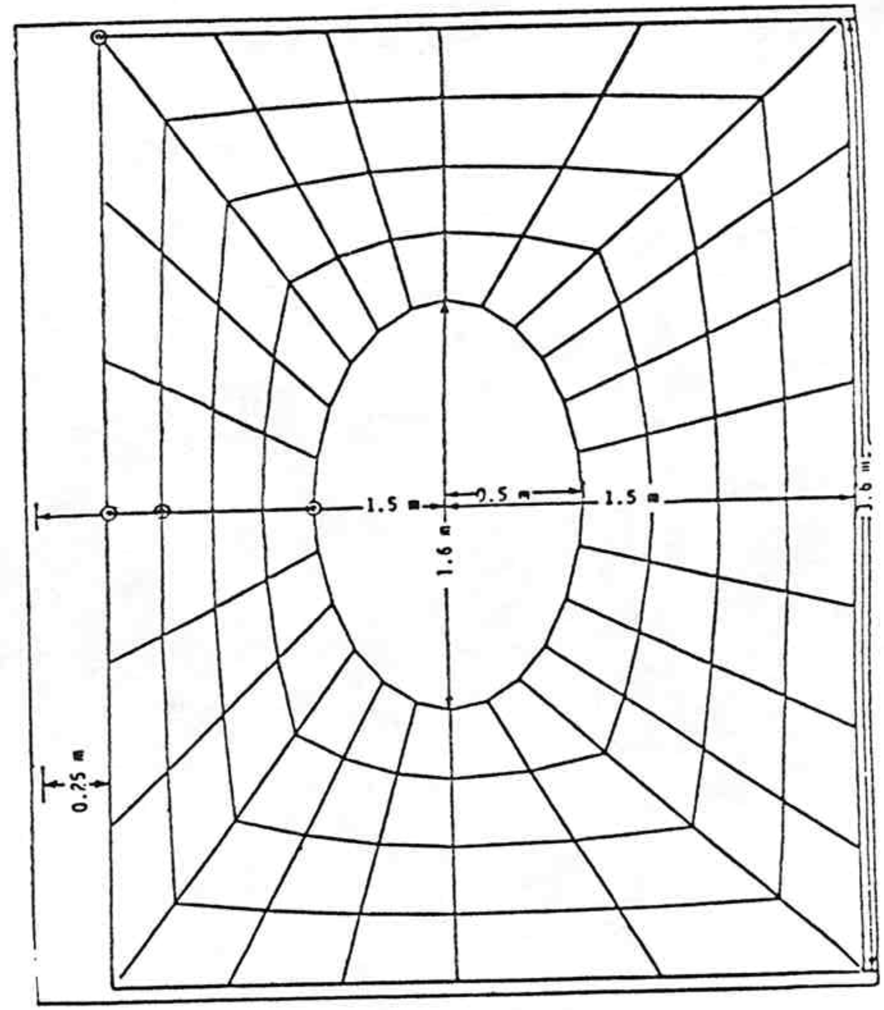


Fig. 2b

Fig. 2. Three geometries used in analyses.

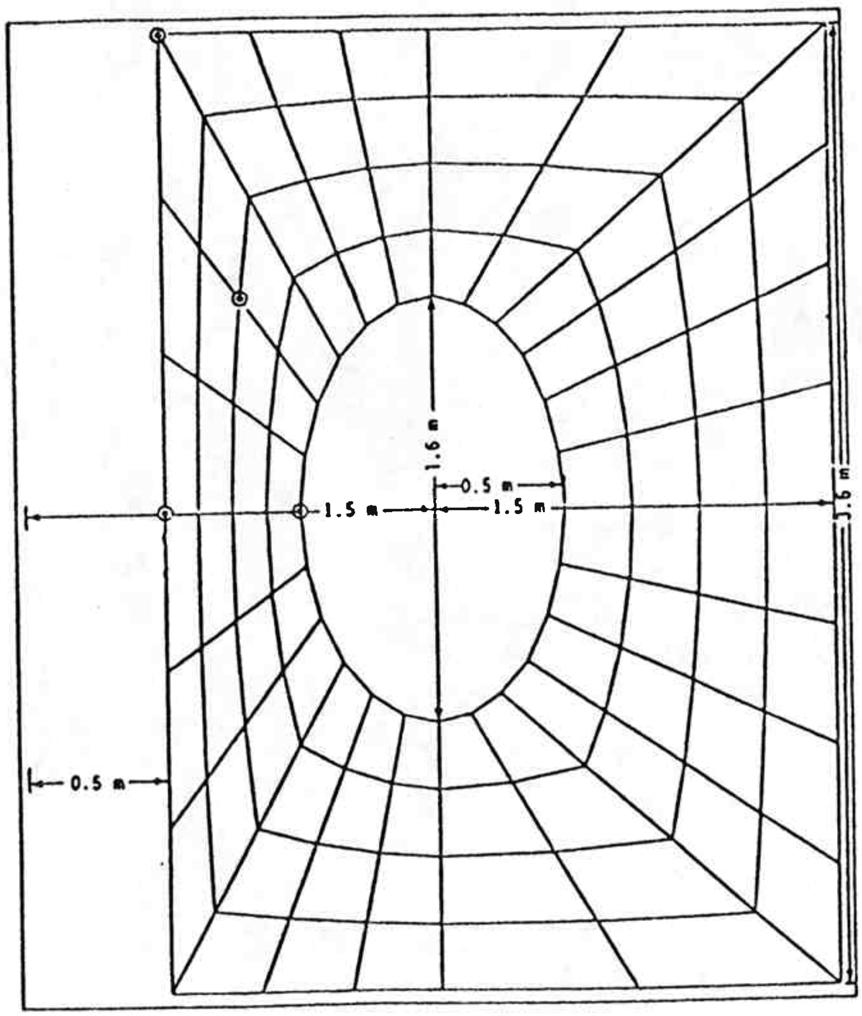


Fig. 2c

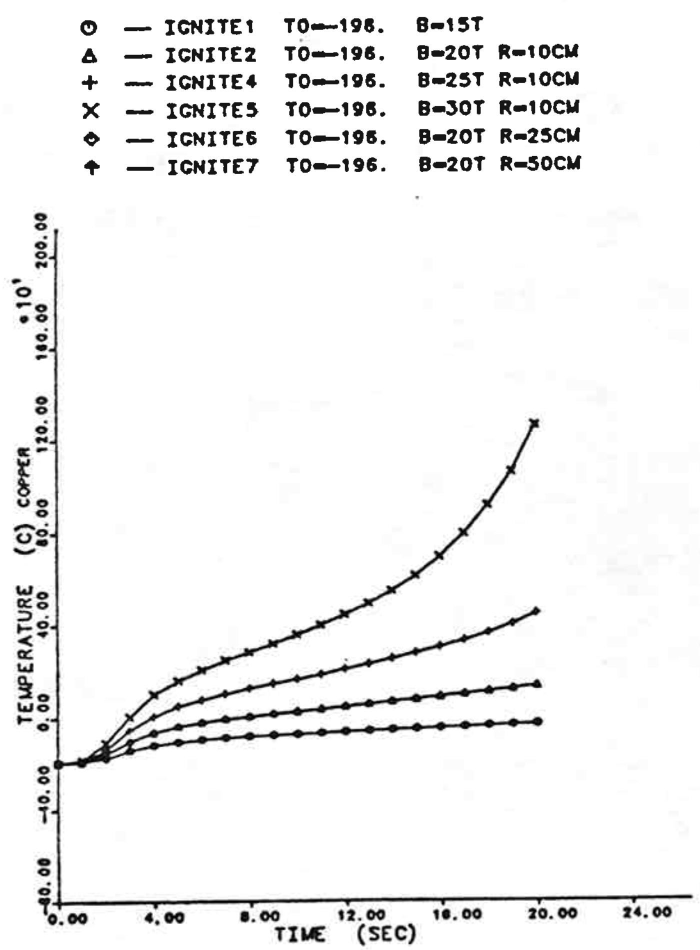


Fig. 3. Temperature as a function of time for copper at several field strengths.

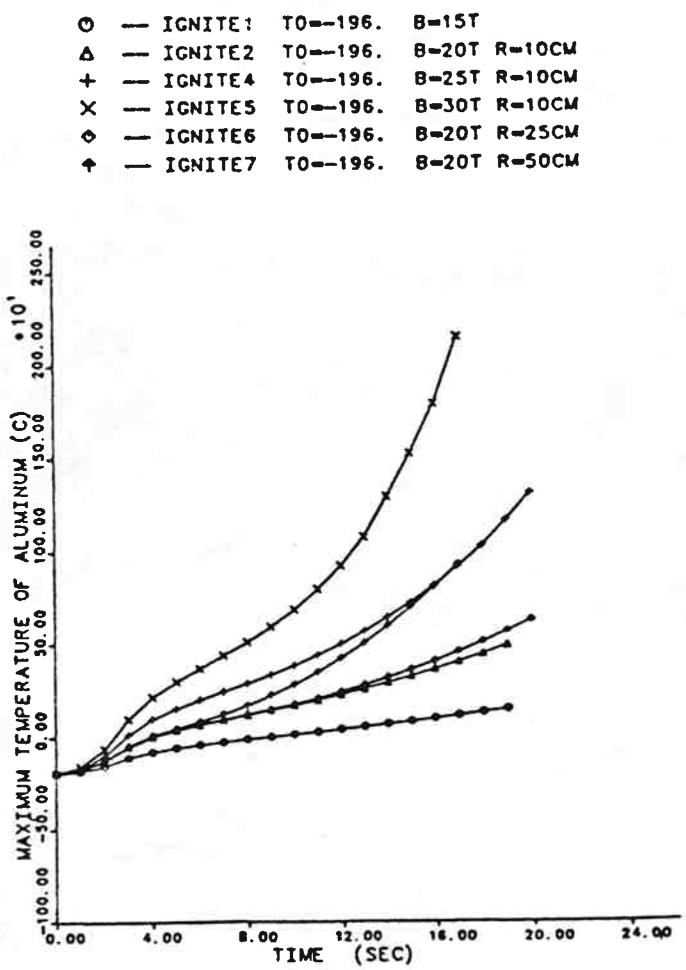


Fig. 4. Temperature as a function of time for aluminum in three geometries and at several field strengths.

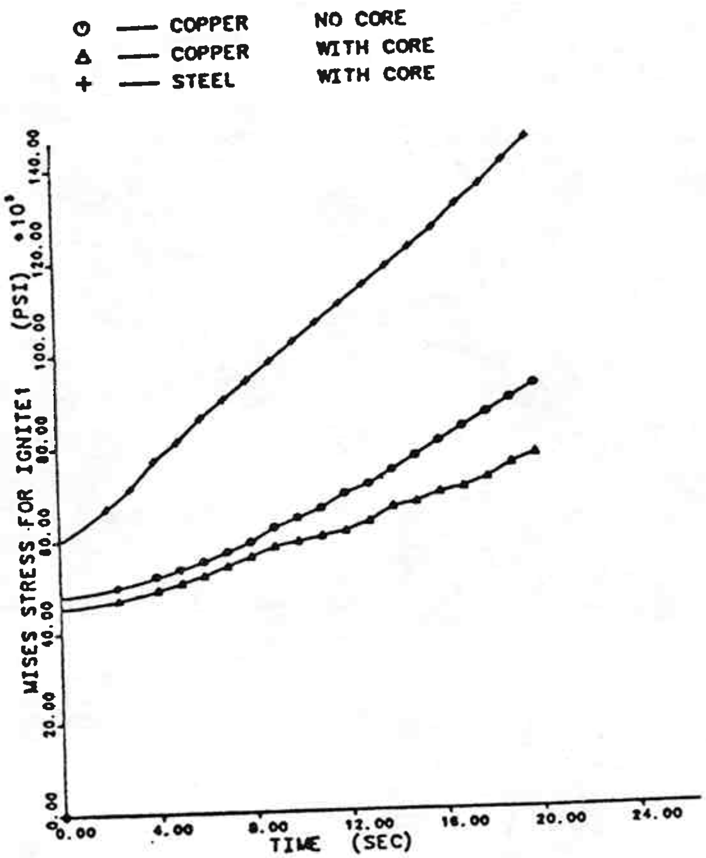


Fig. 5a

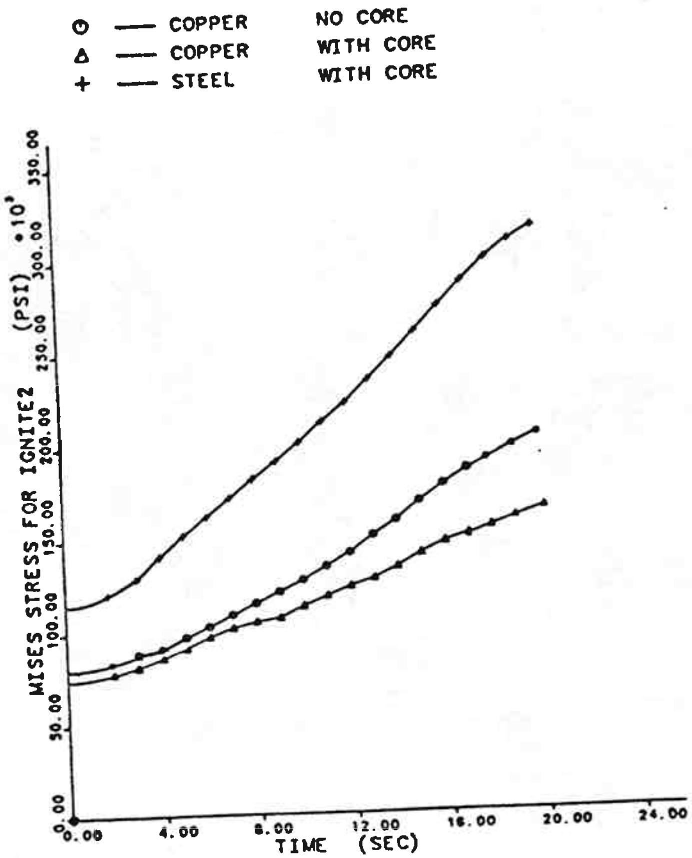
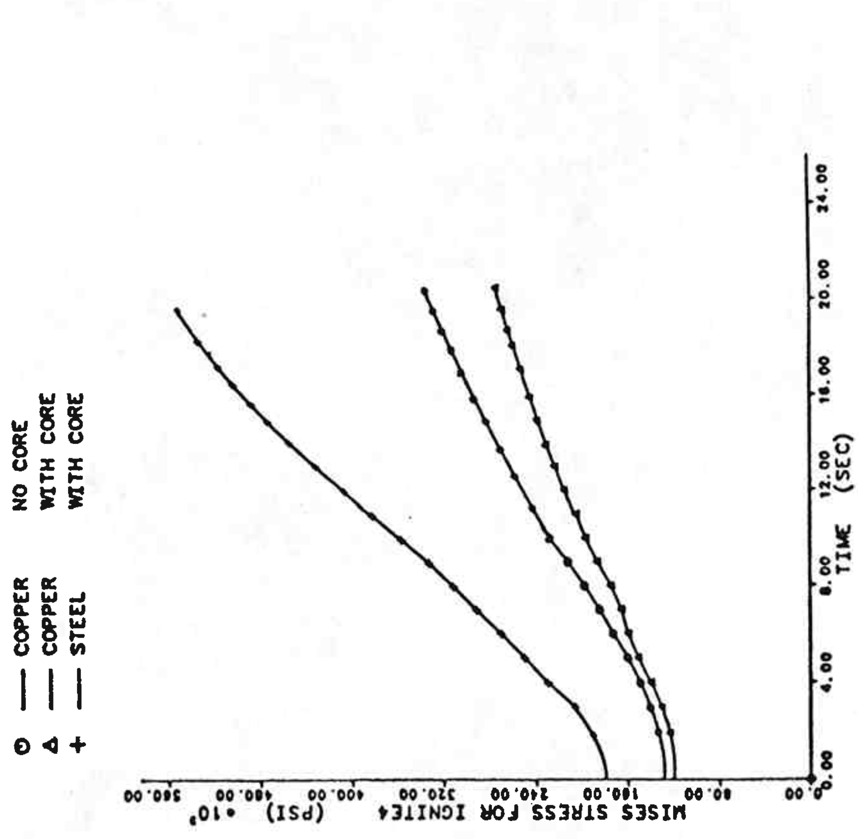


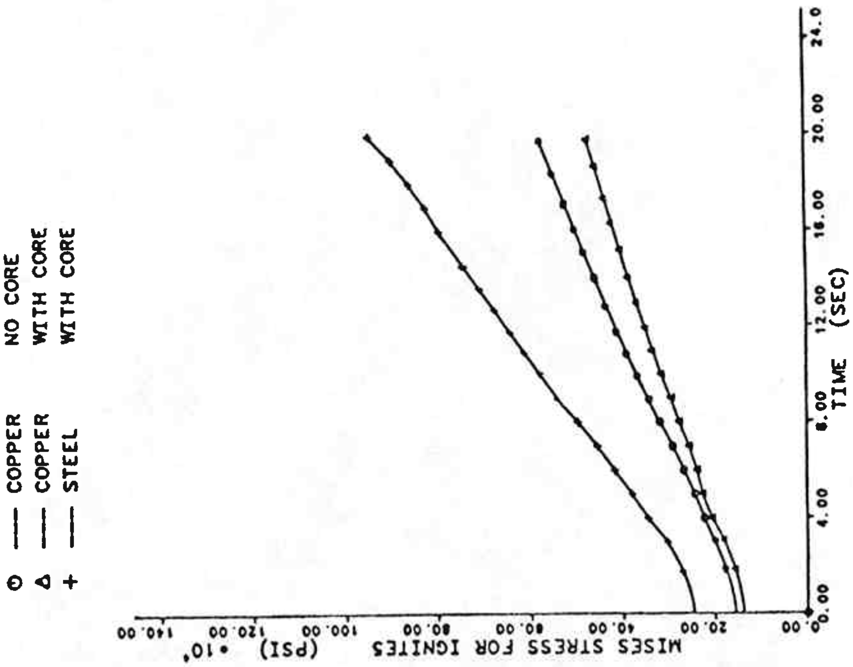
Fig. 5b

Fig. 5. Stresses as functions of time for copper.



⊖ —— COPPER NO CORE
Δ —— COPPER WITH CORE
+ —— STEEL WITH CORE
MISES STRESS FOR IGNITE4 (PSI) •10
0.00
80.00
160.00
240.00
320.00
400.00
480.00
560.00
TIME (SEC)
0.00
4.00
8.00
12.00
16.00
20.00
24.00

Fig. 5c



⊖ —— COPPER NO CORE
Δ —— COPPER WITH CORE
+ —— STEEL WITH CORE
MISES STRESS FOR IGNITE5 (PSI) •10
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
TIME (SEC)
0.00
4.00
8.00
12.00
16.00
20.00
24.0

Fig. 5d

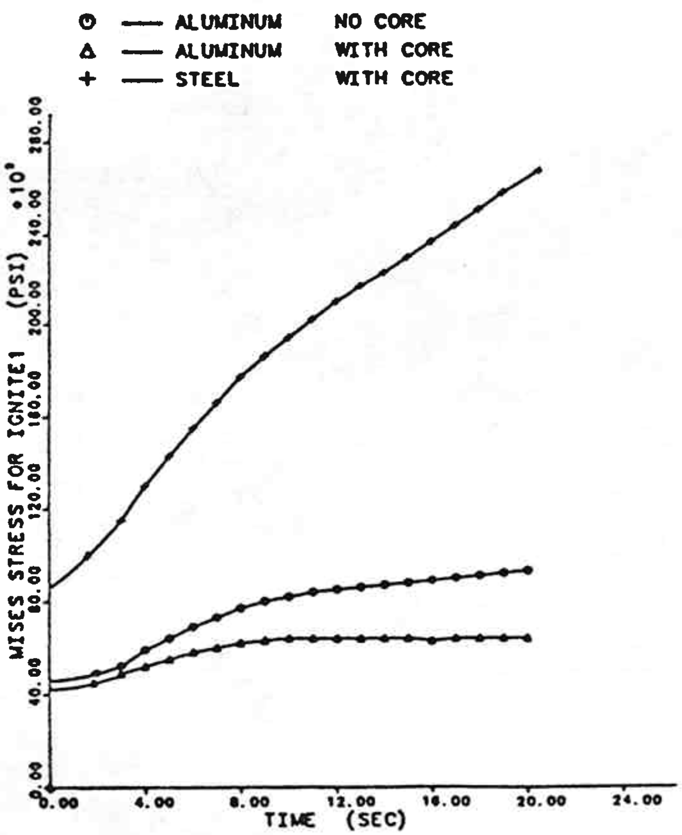


Fig. 6a

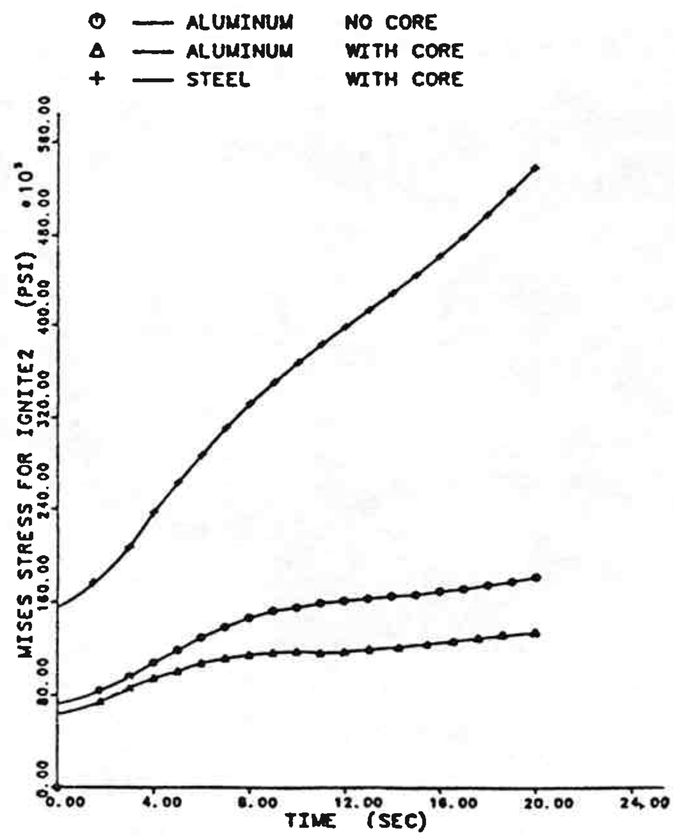
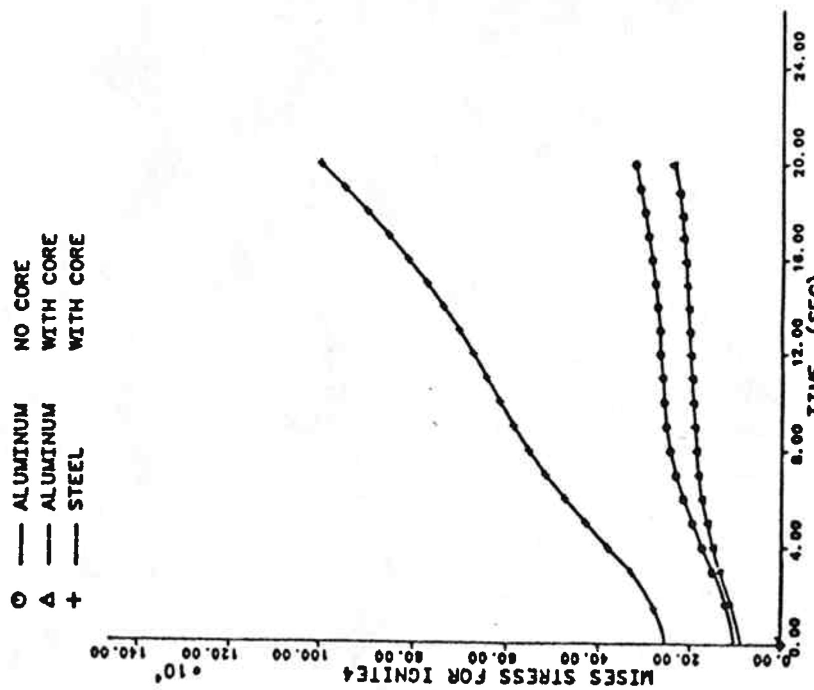


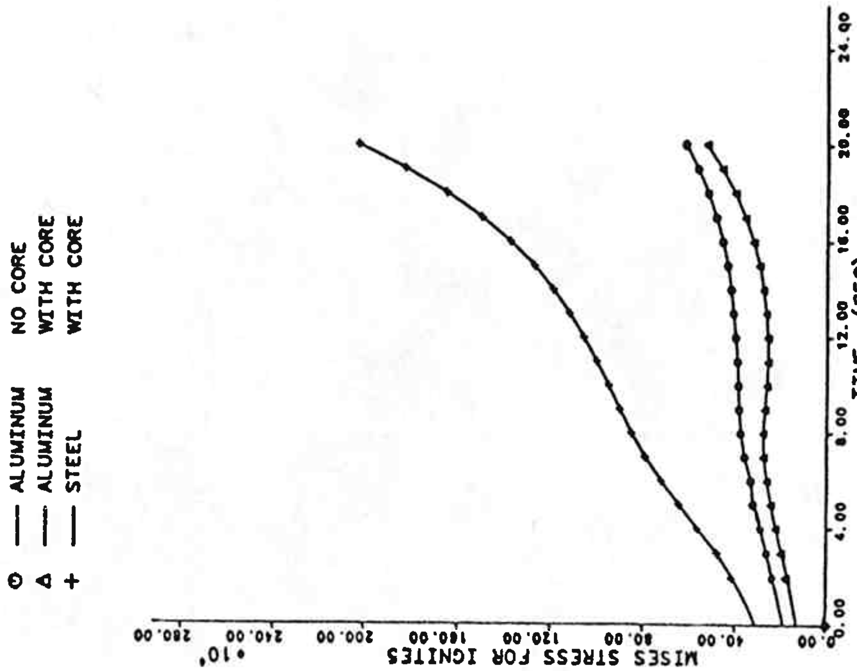
Fig. 6b

Fig. 6. Stresses as functions of time for aluminum.



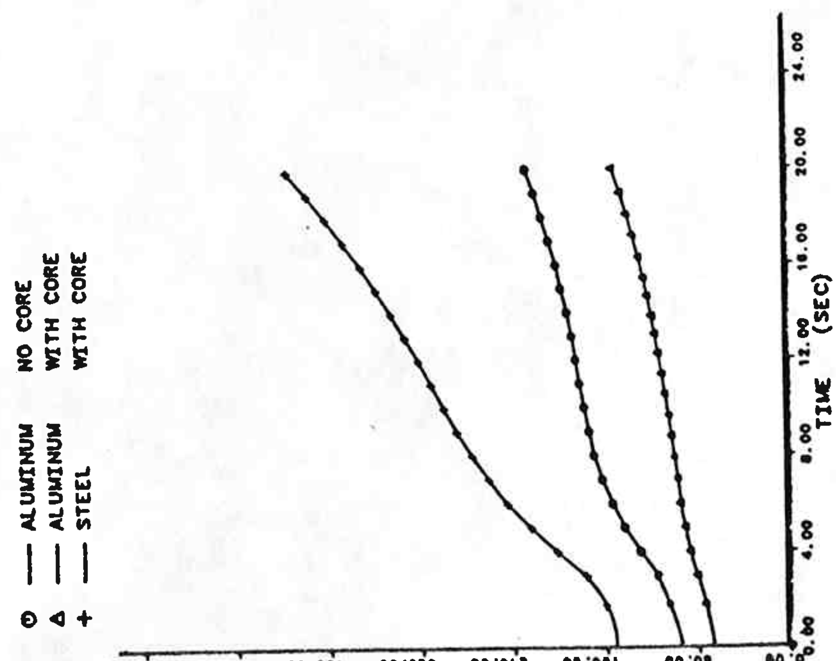
ALUMINUM NO CORE
ALUMINUM WITH CORE
STEEL WITH CORE
MISES STRESS FOR IGNITE4
*10¹
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
TIME (SEC)
0.00
4.00
8.00
12.00
16.00
20.00
24.00

Fig. 6c



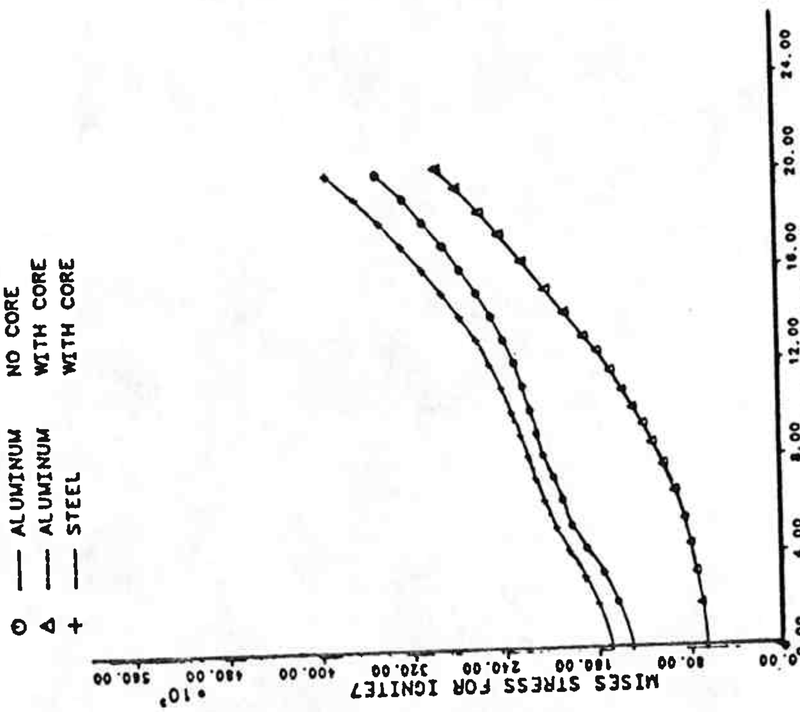
ALUMINUM NO CORE
ALUMINUM WITH CORE
STEEL WITH CORE
MISES STRESS FOR IGNITE5
*10¹
0.00
40.00
80.00
120.00
160.00
200.00
240.00
280.00
TIME (SEC)
0.00
4.00
8.00
12.00
16.00
20.00
24.00

Fig. 6d



⊙ —— ALUMINUM NO CORE
△ —— ALUMINUM WITH CORE
+ —— STEEL WITH CORE
MISES STRESS FOR IGNITE6 (PSI) *10³
0.00
80.00
160.00
240.00
320.00
400.00
480.00
560.00
TIME (SEC)
4.00
8.00
12.00
16.00
20.00
24.00

Fig. 6e



⊙ —— ALUMINUM NO CORE
△ —— ALUMINUM WITH CORE
+ —— STEEL WITH CORE
MISES STRESS FOR IGNITE7 *10³
0.00
80.00
160.00
240.00
320.00
400.00
480.00
560.00
TIME (SEC)
4.00
8.00
12.00
16.00
20.00
24.00

Fig. 6f