N93-20150

APPLICATION OF THE
MESA REACTIVE HYDROCODE
TO SPACE VEHICLE
EXPLOSIVE ORDNANCE DEVICES

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NASA AEROSPACE PYROTECHNIC SYSTEMS WORKSHOP
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THE AEROSPACE CORPORATION

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I AM GOING TO DISCUSS SOME OF THE WORK THAT I AND MY COLLEAGUES, JIM GAGEBY AND ROBERT CHIU, HAVE BEEN DOING AT AEROSPACE TO CONSTRUCT DETAILED COMPUTATIONAL MODELS OF THE DYNAMIC BEHAVIOR OF VARIOUS EXPLOSIVE ORDNANCE DEVICES USED ON SPACE VEHICLES.

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OUTLINE

- GOALS
- BASIC CONCEPTS
  - NUMERICAL METHODS
  - EXPLOSIVES AND DETONATIONS
- INTRODUCTION TO MESA
- MESA CAPABILITIES
  - EXAMPLES OF APPLICATIONS
- CONCLUSIONS

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MY PRESENTATION WILL FIRST LOOK AT THE GOALS WE ARE PURSUING, AND THEN DISCUSS SOME OF THE BASIC PRINCIPLES BEHIND THIS KIND OF MATHEMATICAL MODELING, AND WHAT PHYSICS IS INCLUDED. I WILL GO ON TO DISCUSS THE MESA CODE THAT WE HAVE BEEN USING, ITS HISTORY, AND CAPABILITIES. THE MAJORITY OF MY TIME WILL BE SPENT SHOWING YOU THE RESULTS OF A SAMPLE CALCULATION. I WILL USE THE EXAMPLE TO ILLUSTRATE FEATURES OF THE CODE AND TO SHOW THE DIFFERENT TYPES OF PROBLEMS WE CAN ADDRESS. FINALLY, I WILL DISCUSS THE EFFECTIVENESS OF THIS MODELING, WHAT WE HAVE ACCOMPLISHED THUS FAR, AND WHERE I THINK WE ARE HEADING IN THE NEAR FUTURE.

GOALS

PROVIDE ANALYTICAL TOOLS FOR

- IMPROVEMENT OF EXPLOSIVE ORDNANCE DESIGN
  - UNDERSTAND DEVICE FUNCTION
  - PREDICT PERFORMANCE
- ASSISTANCE WITH FAILURE ANALYSIS
  - UNDERSTAND MECHANISMS
  - DIRECT CORRECTIVE ACTIONS

THE GOALS OF THE COMPUTATIONAL EFFORTS IN THE EXPLOSIVE ORDNANCE SECTION AT AEROSPACE ARE TO PROVIDE OUR INDUSTRY WITH ANALYTICAL TOOLS TO IMPROVE EXPLOSIVE ORDNANCE DESIGN BY BEING BETTER ABLE TO UNDERSTAND THE DEVICE FUNCTIONING AND TO BETTER PREDICT THE EFFECTS ON PERFORMANCE CHARACTERISTICS OF VARIOUS SPECIFIC DESIGN FEATURES.

THESE ANALYTICAL TECHNIQUES WILL ALSO ASSIST US IN FAILURE ANALYSIS BY HELPING TO UNDERSTAND AND IDENTIFY FAILURE MECHANISMS. THEY WILL ALSO MAKE EFFICIENT AND EFFECTIVE CORRECTIVE ACTIONS EASIER TO IDENTIFY AND SELECT.

THIS WORK IS FOCUSSED ON BRINGING POWERFUL ANALYTIC AND COMPUTATIONAL TECHNIQUES FROM THE WEAPONS DEVELOPMENT INDUSTRY TO BEAR ON PROBLEMS INVOLVING THE EXPLOSIVE ORDNANCE SYSTEMS THAT ARE USED IN THE SPACE INDUSTRY. CONCEPTUALLY, THERE ARE MANY SIMILARITIES: BOTH KINDS OF SYSTEMS ARE MECHANICAL DEVICES THAT EMPLOY EXPLOSIVES TO DO WORK IN A PRECISE AND RELIABLE MANNER. THE MAJOR DISTINCTION IS IN THEIR SIZE, WHICH I WILL COME BACK TO LATER IN THE PRESENTATION.

BASIC MATHEMATICS

- PARTIAL DIFFERENTIAL EQUATIONS FOR COMPRESSIBLE FLUIDS

$$\frac{\partial \rho}{\partial t}+\nabla\cdot(\rho v)=0 \qquad \frac{\partial v}{\partial t}+(v\cdot\nabla)v+\frac{\nabla P}{\rho}=0 \qquad \frac{\partial s}{\partial t}+(v\cdot\nabla)s=0$$

  - STRENGTH/STIFFNESS TERMS CAN BE ADDED

- JUMP CONDITIONS DEFINE DISCONTINUITIES IN STATE VARIABLES

$$[\rho(v-D)]_1^2=0 \qquad [1/2(v-D)^2+h]_1^2=0 \qquad [P+\rho(v-D)^2]_1^2=0$$

- ADIABATIC CONSTRAINT + JUMP CONDITIONS = HUGONIOT

$$e_1-e_2=1/2(V_2-V_1)(P_1+P_2) \qquad h=e+PV \qquad V=\frac{1}{\rho}$$

  - DEFINES LOCUS OF ATTAINABLE STATES FOR EACH MATERIAL

THE COMPUTER CODE THAT I WILL BE DISCUSSING IS A MEMBER OF A FAMILY OF COMPUTATIONAL FLUID DYNAMICS CODES THAT MAKE NO APPROXIMATIONS TO THE EQUATIONS OF MOTION THAT WOULD PREVENT THE EXISTENCE OF SHOCK WAVES. THESE PROGRAMS HAVE BEEN IN EXISTENCE SINCE THE 1950'S, BUT A NEW GENERATION OF PROGRAMS OVER THE LAST FEW YEARS HAS TAKEN ADVANTAGE OF PROGRESS IN MATERIALS AND NUMERICAL METHODS TO MAKE THE CODES MORE POWERFUL. OF COURSE, NEW COMPUTER HARDWARE HAS ALSO CONTRIBUTED TO ALLOWING THESE TECHNIQUES TO BE IMPLEMENTED.

THE EQUATIONS TO BE SOLVED ARE THE TIME DEPENDENT NONLINEAR EQUATIONS OF MOTION FOR COMPRESSIBLE FLUIDS. THE JUMP CONDITIONS ARE THE EQUATIONS FOR CONSERVATION OF MASS, ENERGY, AND MOMENTUM ACROSS MATERIAL INTERFACES, AND DEFINE SHOCK WAVES. THE ADDITIONAL CONSTRAINT OF ADIABATIC FLOW OVERDETERMINES THE SYSTEM AND ONLY A LIMITED SET OF THERMODYNAMIC STATES ARE ALLOWABLE FOR A SHOCKED MATERIAL. THE CURVE DEFINING THESE STATES IS CALLED THE HUGONIOT CURVE.

BASIC NUMERICAL METHODS

- SOLVE PARTIAL DIFFERENTIAL EQUATIONS FOR COMPRESSIBLE FLUIDS
  - TIME DEPENDENT, NONLINEAR
  - STRENGTH / STIFFNESS TERMS CAN BE ADDED AS CORRECTIONS
- FINITE DIFFERENCE ALGORITHM
  - SPACE DIVIDED INTO CELLS TO FORM A MESH
  - TIME DIVIDED INTO STEPS DETERMINED BY WAVE SPEEDS AND MESH
- LAGRANGIAN - COORDINATES IDENTIFIED WITH MASS ELEMENTS, MESH MOVES WITH MATERIAL
  - FASTER INTEGRATION
- EULERIAN - COORDINATES FIXED IN SPACE, MATERIAL FLOWS THRU
  - MORE ACCURATE FOR LARGE MOTIONS

THE FLUID DYNAMICS EQUATIONS ARE SOLVED FOR THE ENTIRE SYSTEM BY EXPLICIT INTEGRATION IN A FINITE DIFFERENCE ALGORITHM. FINITE DIFFERENCE METHODS ARE SIMILAR TO FINITE ELEMENT FORMULATIONS OF STRUCTURAL PROBLEMS BUT HAVE SOME ADVANTAGES IN EFFICIENCY FOR TIME DEPENDENT PROBLEMS. IN THIS TECHNIQUE, SPACE IS DIVIDED INTO CELLS THAT FORM THE COMPUTATIONAL MESH, AND TIME IS DIVIDED INTO STEPS FOR INTEGRATION PURPOSES. THE TIME STEPS ARE DETERMINED BY THE SIZE OF THE STRUCTURE, THE MATERIAL PROPERTIES INVOLVED, PARTICULARLY SOUND SPEEDS. THE MESH CELL SIZES ALSO IN TURN AFFECT RESOLUTION AND ACCURACY OF THE RESULTS AND THE RUNNING TIME OF THE CALCULATION. THE SETUP OF A PROBLEM IS THEREFORE A COMPLEX PROCESS IN WHICH ALL OF THE PHYSICAL AND MATHEMATICAL ELEMENTS INTERRELATE.

DEALING WITH DETONATIONS

- SHOCK WAVES FROM EXPLOSIVE DETONATION EXPLICITLY MODELED
- EQUATIONS OF STATE DETERMINED FROM
  - EXPERIMENTAL DATA
  - CALCULATION FROM DENSITY, HEAT OF FORMATION AND CHEMICAL COMPOSITION
- WORK DONE BY SHOCK WAVE INTERACTIONS AND PRODUCT GAS MOTION
- DETONATION PRESSURES = 3 - 5 MILLION PSI
- DETONATION VELOCITIES = 15,000 - 25,000 FEET PER SEC
- AVERAGE SIZE STEP = 1 NANOSEC
  - CALCULATION TIME = 10 -20 MICROSEC, CAN BE LONGER
  - TOTAL DEVICE FUNCTION TIME = 20 MILLISEC

THE DISTINGUISHING FEATURE OF THE MODELS THAT WE WOULD LIKE TO BUILD, COMPARED WITH OTHER STRUCTURES OR MECHANISMS, IS THE PRESENCE OF THE EXPLOSIVE COMPONENTS IN THE DEVICES. THE FACT THAT WE ARE STARTING WITH A CODE THAT CAN TREAT SHOCK WAVES ALLOWS US TO EXPLICITLY MODEL THE DETONATION OF THE EXPLOSIVE, AND TO ALLOW THE SHOCKS TO PROPAGATE INTO THE OTHER MATERIALS IN THE SYSTEM. THE PRINCIPAL MEANS OF INITIATING MOTION IN A MECHANISM IS BOTH BY SHOCK AND BY PRODUCT GAS EXPANSION. THESE MODES INCLUDE BOTH ENERGY AND MOMENTUM TRANSFERS BETWEEN THE EXPLOSIVE DRIVER AND THE OTHER INERT COMPONENTS.

ONE OF THE IMPORTANT INPUTS TO THE CODE IS THEREFORE EQUATION OF STATE DESCRIPTIONS OF THE EXPLOSIVES IN BOTH THEIR UNREACTED AND REACTED FORMS. THIS INFORMATION IS CONTAINED IN A DATABASE FOR A VARIETY OF MATERIALS, BUT BY NO MEANS ALL THAT WE USE. FOR SOME THERE IS EXPERIMENTAL DATA THAT HAS BEEN DETERMINED DIRECTLY, AND FOR OTHERS THERE ARE CALCULATED PARAMETERS BASED ON KNOWN DENSITY, HEAT OF FORMATION, CHEMICAL COMPOSITIONS AND OTHER CHEMICAL AND THERMODYNAMIC PROPERTIES.

THE PRESENCE OF THE EXPLOSIVES MAKES THE CALCULATIONS PARTICULARLY SENSITIVE TO NUMERICAL DETAILS THAT MAY BE OF LESSER IMPORTANCE IN OTHER SYSTEMS. SHOCK PRESSURES BEHIND DETONATION FRONTS ARE ON THE ORDER OF 3-5 MILLION PSI, AND DETONATION SHOCK VELOCITIES ARE BETWEEN 15000 AND

25000 FPS. THESE FACTS LEAD TO NUMERICAL INTEGRATION SCHEMES THAT MUST ACCOMMODATE TIME STEPS OF APPROXIMATELY 1 NANOSEC. MESHES CONTAINING 40000 CELLS ARE ON THE SMALL SIDE FOR ACCEPTABLE ACCURACY, AND REASONABLE AMOUNTS OF COMPUTER TIME ACHIEVE TOTAL CALCULATION TIMES, OR SYSTEM MOTION, OVER ONLY A FEW TENS OF MICROSECONDS. NORMAL DEVICE FUNCTION TIMES ARE THAT SAME NUMBER OF MILLISEC., AND THE CALCULATIONS CAN BE FOLLOWED TO THESE TIMES, BUT RUN TIMES ARE VERY LONG, AND THE COMPUTATIONAL MESH MUST BE PERIODICALLY REDRAWN TO FOLLOW THE MATERIALS. THIS ALSO IS ONE OF THE FEATURES THAT MAKES IT NONTRIVIAL TO APPLY HYDROCODES LIKE MESA TO SPACE VEHICLE ORDNANCE DEVICES. THEIR SMALL SIZE CAN CAUSE NUMERICAL INSTABILITIES BECAUSE OF THE VERY SHORT WAVE TRANSIT TIMES ACROSS MESH CELLS.

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MESA REACTIVE HYDROCODE

- TWO DIMENSIONAL - PLANES, CYLINDERS
  - RUNS ON SUN WORKSTATION
- 3D CODE RUNS ON CRAY
  - IN USE AT PHILLIPS LAB

NEW FEATURES IN MESA

- IMPROVED MATERIAL RESPONSE
  - DETONATION MATH MODELS
  - FRACTURE ALGORITHMS
  - PHASE CHANGES FOR CERTAIN MATERIALS
- NEW INTERFACE RECONSTRUCTION ALGORITHM FOR LARGE DEFORMATIONS AND MIXED CELLS
  - GREATER NUMERICAL STABILITY

THE CODE THAT WE HAVE CHOSEN TO USE AT AEROSPACE IS MESA. MESA WAS WRITTEN AT LOS ALAMOS NATIONAL LABORATORY, ALTHOUGH THERE ARE OTHER SIMILAR CODES DEVELOPED AT LAWRENCE LIVERMORE LABORATORY AND SANDIA NATIONAL LABORATORIES. MESA WAS ORIGINALLY DEVELOPED TO ANALYZE WEAPONS AND ARMOR SYSTEMS. THERE ARE 2 AND 3 DIMENSIONAL VERSIONS OF THE PROGRAM. THE 2D CODE IS RUNNING ON AN IN-HOUSE SUN WORKSTATION. THE 3D CODE IS STILL ONLY DESIGNED FOR THE CRAY.

SO-CALLED REACTIVE HYDROCODES (HYDRODYNAMIC CODES THAT INCLUDE CHEMICALLY REACTIVE MATERIALS) HAVE BEEN IN EXISTENCE FOR ABOUT 30 YEARS. MESA IS ONE OF THE NEW GENERATION THAT TAKES ADVANTAGE OF NEW NUMERICAL METHODS IN ADDITION TO IMPROVED KNOWLEDGE ABOUT MATERIAL RESPONSES AT HIGH RATES OF STRAIN. IT CONTAINS THE MOST ACCURATE MATHEMATICAL MODELS OF DETONATION TO GOVERN THE ENERGY RELEASE MECHANISMS, AND INCLUDES ALGORITHMS THAT ALLOW FRACTURE AND CRACKING IN ADDITION TO SPALL. FOR A SMALL NUMBER OF MATERIALS, PHASE CHANGES CAN ALSO BE MODELED. THE PRINCIPLE MATHEMATICAL IMPROVEMENT IS AN INTERFACE RECONSTRUCTION ALGORITHM THAT MAKES THE CALCULATION MORE STABLE IN THE FACE OF VERY LARGE DEFORMATIONS AND MANY CELLS CONTAINING MORE THAN ONE MATERIAL SPECIES.

ONE OF THE DIFFICULTIES IN APPLYING A CODE LIKE MESA TO SPACE VEHICLE

EXPLOSIVE ORDNANCE DEVICES IS THEIR SIZE. THE WEAPONS SYSTEMS ARE MANY TIMES LARGER, MEANING THAT CELLS CAN BE LARGER WHILE STILL ACHIEVING SUFFICIENT RESOLUTION. GIVEN DETONATION VELOCITY MAGNITUDES, AS CELLS GET SMALLER, WAVE TRANSIT TIMES GET SMALLER, AND THE TIME STEPS NEED TO BE EVEN SMALLER TO GET REASONABLE RESOLUTION OF THE DYNAMICS. CONSTRUCTING AN OPTIMAL MESH THAT IS SUFFICIENTLY ACCURATE AND YET DOES NOT CREATE NUMERICAL PROBLEMS HAS BEEN ONE OF THE TRICKIER PARTS OF OUR TASK AT AEROSPACE. DESIGNING THE PROBLEM BECOMES OF CRITICAL IMPORTANCE IN ORDER TO BE ASSURED OF PHYSICALLY REASONABLE RESULTS AND TO CONTROL RUN TIMES.

ALSO, TESTING TO VERIFY THAT THE MODEL IS REALISTIC IS STILL AN IMPORTANT PART OF THE TASK, ALTHOUGH WE HOPE THAT IT CAN BECOME A SMALLER, LESS COSTLY EFFORT AS THE ANALYTIC METHODS BECOME MORE SOPHISTICATED.

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MESA RESULTS

- **OUTPUTS**

  POSITION
  VELOCITY
  DENSITY
  PRESSURE
  INTERNAL ENERGY
  INTRINSIC SOUND SPEED
  TEMPERATURE
  STRAIN RATE
  STRESS DEVIATORS
  PLASTIC STRAIN
  PLASTIC WORK
  ELASTIC DEFORMATION
  ELASTIC WORK

- **GRAPHICAL DISPLAY OPTIONS**

  VECTORS - VELOCITY, PRINCIPAL STRESSES
  CONTOURS - ALL VARIABLES
  PROFILES - DENSITY, INTERNAL ENERGY, MOMENTUM, PRESSURE, KINETIC ENERGY

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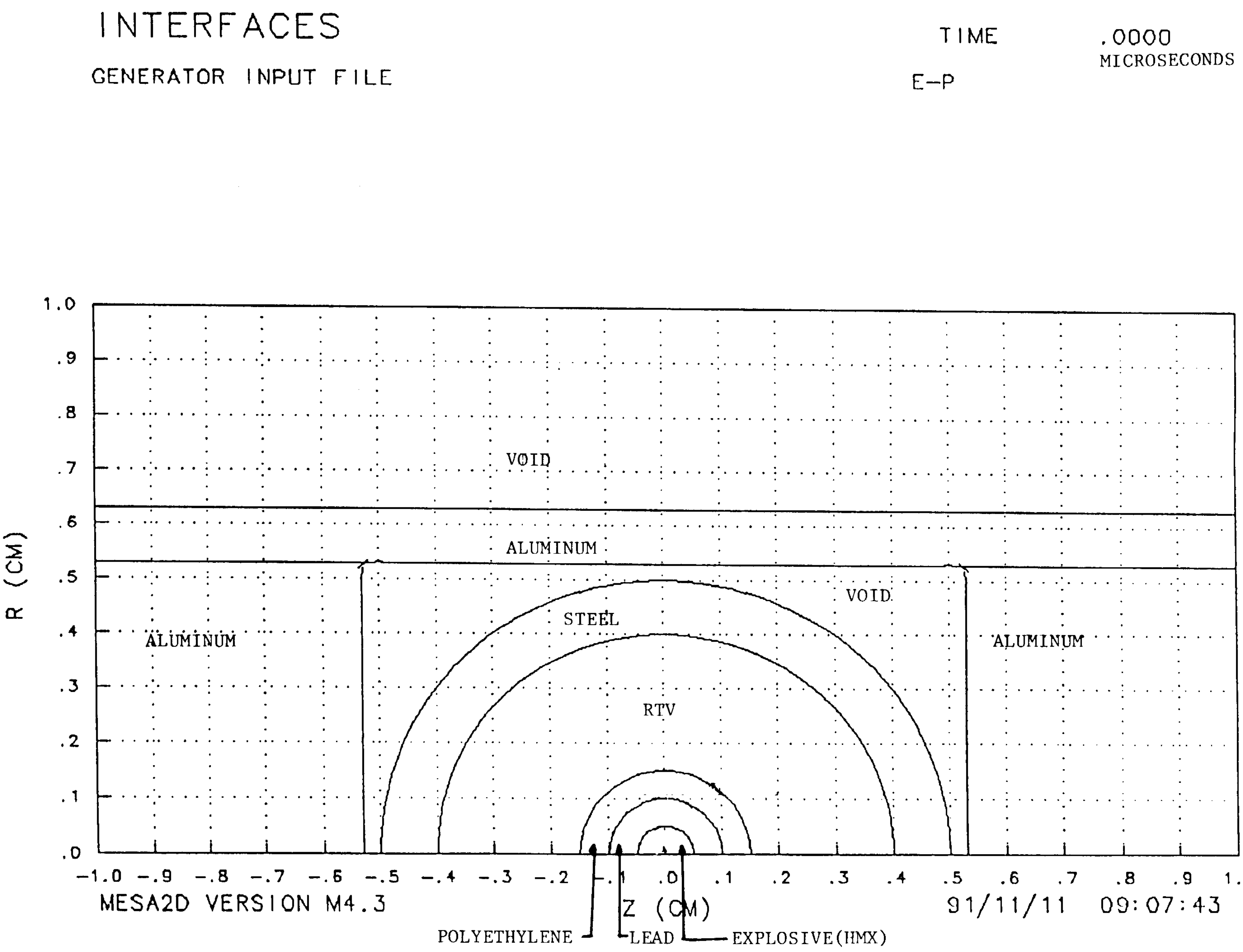
MESA SAMPLE CALCULATION

- EXPANDING TUBE SEPARATION SYSTEM MODEL
  - GENERIC STRUCTURE
  - AXIAL SYMMETRY

WE HAVE APPLIED MESA TO SEVERAL PROBLEMS SINCE WE BEGAN USING IT ABOUT 8 MONTHS AGO. THE FIRST ONE AROSE FROM A PROBLEM WITH A GROUND TEST OF SUPER*ZIP, AND IS A SIMPLIFIED EXPANDING TUBE SEPARATION SYSTEM. THIS MODEL HAS THE MAJOR FEATURES OF, BUT IS SIMPLER THAN, THE SUPER*ZIP SYSTEM. EVEN THOUGH THERE ARE MANY STRUCTURAL DETAILS THAT HAVE NOT BEEN INCLUDED IN OUR MODEL, YOU WILL SEE THAT THE SEPARATION CONCEPT AND MAJOR FEATURES OF ITS FUNCTION CAN BE DESCRIBED.


INTERFACES
GENERATOR INPUT FILE
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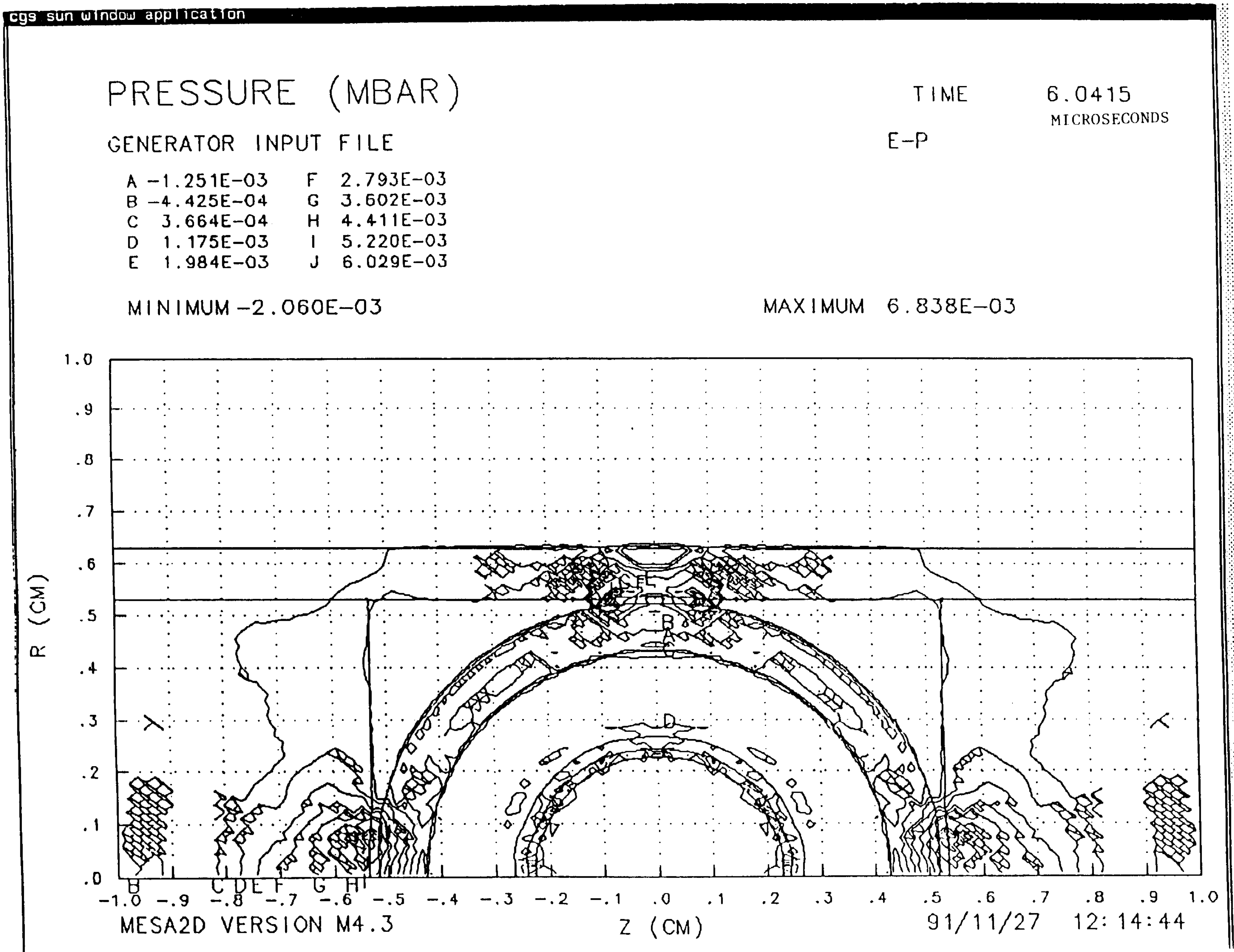
-1.0 -.9 -.8 -.7 -.6 -.5 -.4 -.3 -.2 -.1 .0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0
MESA2D VERSION M4.3
Z (CM)
91/11/11 09:07:43
POLYETHYLENE
LEAD
EXPLOSIVE(HMX)

THIS IS THE CROSS-SECTION OF 1/2 AN EXPANDING TUBE SEPARATION SYSTEM. SUCH A SLICE WOULD REPRESENT A POINT IN THE MIDDLE OF THE TUBE, AWAY FROM END EFFECTS AND THE DETONATOR BLOCK. MATERIALS HAVE BEEN CHOSEN TO PARALLEL SUPER*ZIP, ALTHOUGH MANY OF THE FEATURES SPECIFIC TO THAT DEVICE ARE ABSENT FROM THIS MODEL. IN THE ORIENTATION OF THIS MODEL, THE DOUBLER TO BE FRACTURED IS AT THE TOP OF THE CHART. THE DETONATION CORD IS AT THE CENTER BOTTOM, AND THE CALCULATION WILL BE STARTED FROM THE POINT AT WHICH IT INITIATES. THE DETONATORS ARE NOT IN THIS CALCULATION.



PRESSURE (MBAR)

TIME 6.0415 MICROSECONDS

GENERATOR INPUT FILE

E-P

A	-1.251E-03	F	2.793E-03
B	-4.425E-04	G	3.602E-03
C	3.664E-04	H	4.411E-03
D	1.175E-03	I	5.220E-03
E	1.984E-03	J	6.029E-03

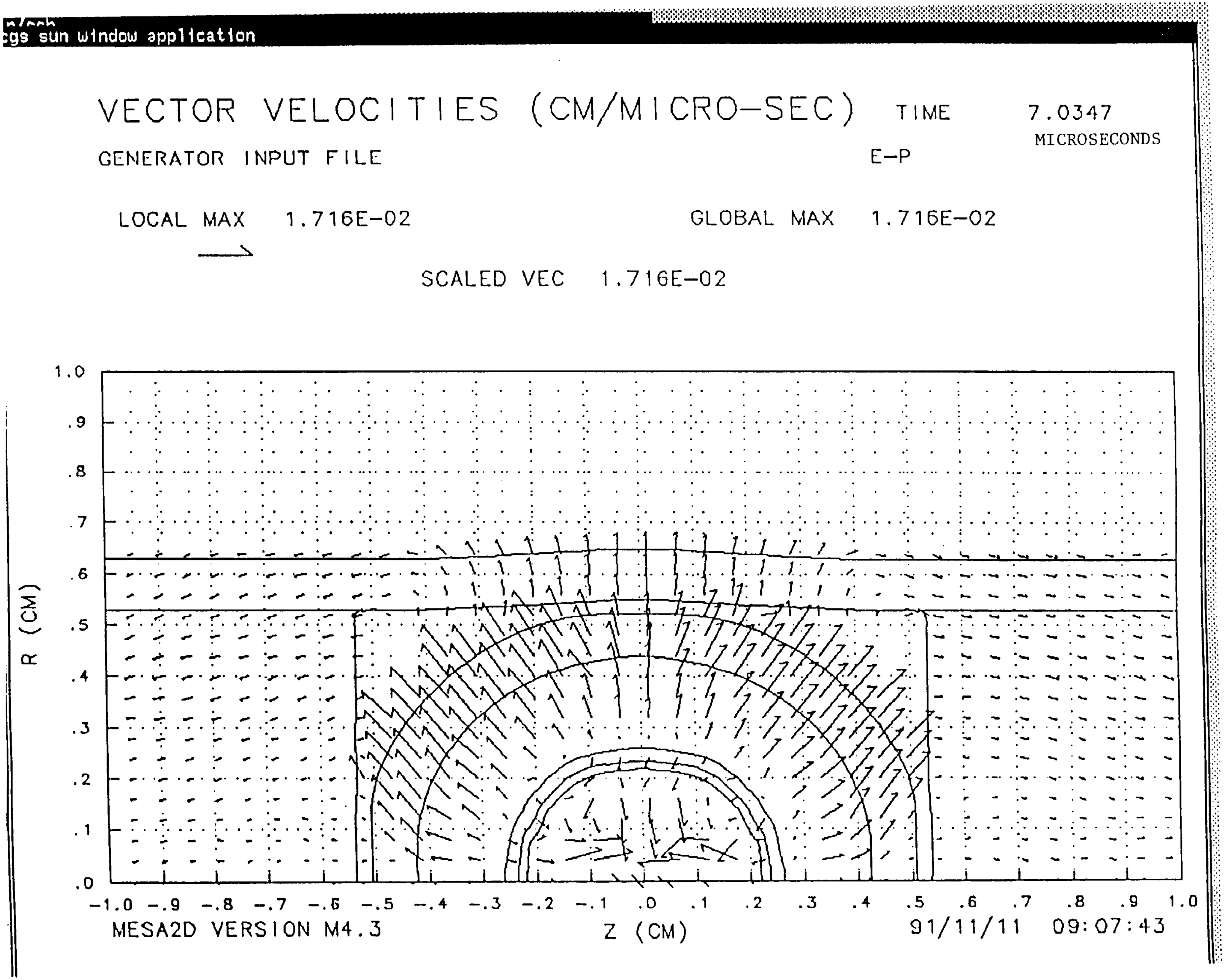
MINIMUM -2.060E-03

MAXIMUM 6.838E-03

MESA2D VERSION M4.3

91/11/27 12:14:44

AFTER THE HMX INITIATES, SHOCK WAVES PROPAGATE OUT RADIALLY TO THE SURROUNDING MATERIALS. AT A TIME APPROXIMATELY 6 MICROSEC AFTER INITIATION OF THE CORD AT THIS POINT, THEY LOOK LIKE THIS. THESE CONTOURS ENCLOSE REGIONS IN WHICH THE PRESSURE IS GREATER THAN THE LEVEL OF THE CONTOUR. SOME REGIONS ARE ALREADY IN TENSION.



cgs sun window application

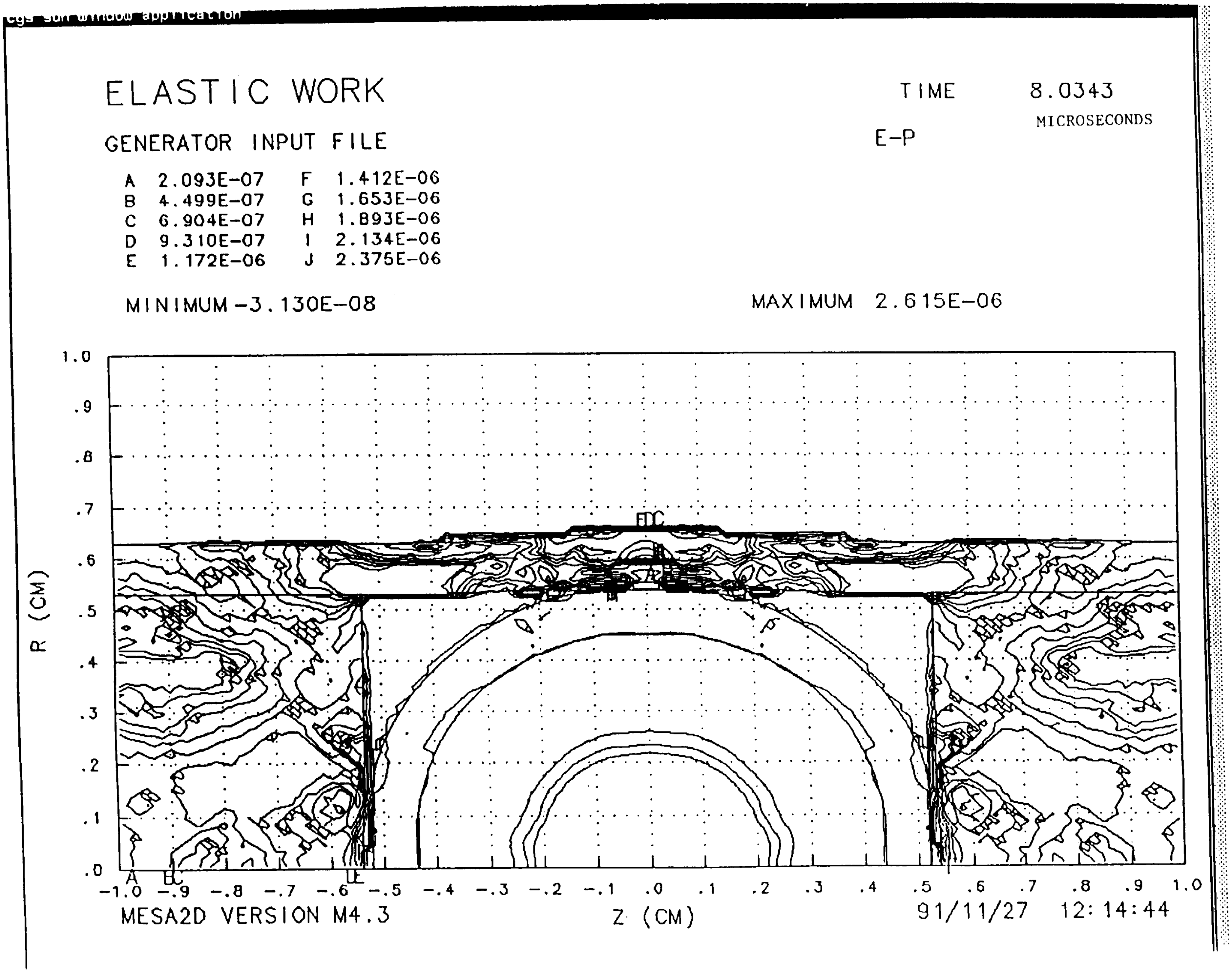
VECTOR VELOCITIES (CM/MICRO-SEC) TIME 7.0347 MICROSECONDS

GENERATOR INPUT FILE E-P

LOCAL MAX 1.716E-02 GLOBAL MAX 1.716E-02

SCALED VEC 1.716E-02

PARTICLE VELOCITIES FOR EACH MESH POINT SHOW RESULTANT MOTION OF MASS POINTS CAUSED BY THE EXPLOSIVE PRODUCT GASES EXPANDING AND BY THE PASSAGE OF THE SHOCK WAVES. MESA PLOTS ARROWS SHOWING A SCALED VELOCITY MAGNITUDE AND DIRECTION AT ALL OR A SELECTION OF MESH POINTS. BY THIS TIME, 7 MICROSEC, DEFORMATION OF THE CONTAINMENT TUBE AND OF THE DOUBLER IS BEGINNING TO APPEAR.



cgs sun window application

ELASTIC WORK

GENERATOR INPUT FILE

A 2.093E-07 F 1.412E-06
B 4.499E-07 G 1.653E-06
C 6.904E-07 H 1.893E-06
D 9.310E-07 I 2.134E-06
E 1.172E-06 J 2.375E-06

MINIMUM -3.130E-08

TIME 8.0343 MICROSECONDS

E-P

MAXIMUM 2.615E-06

MESA2D VERSION M4.3

91/11/27 12:14:44

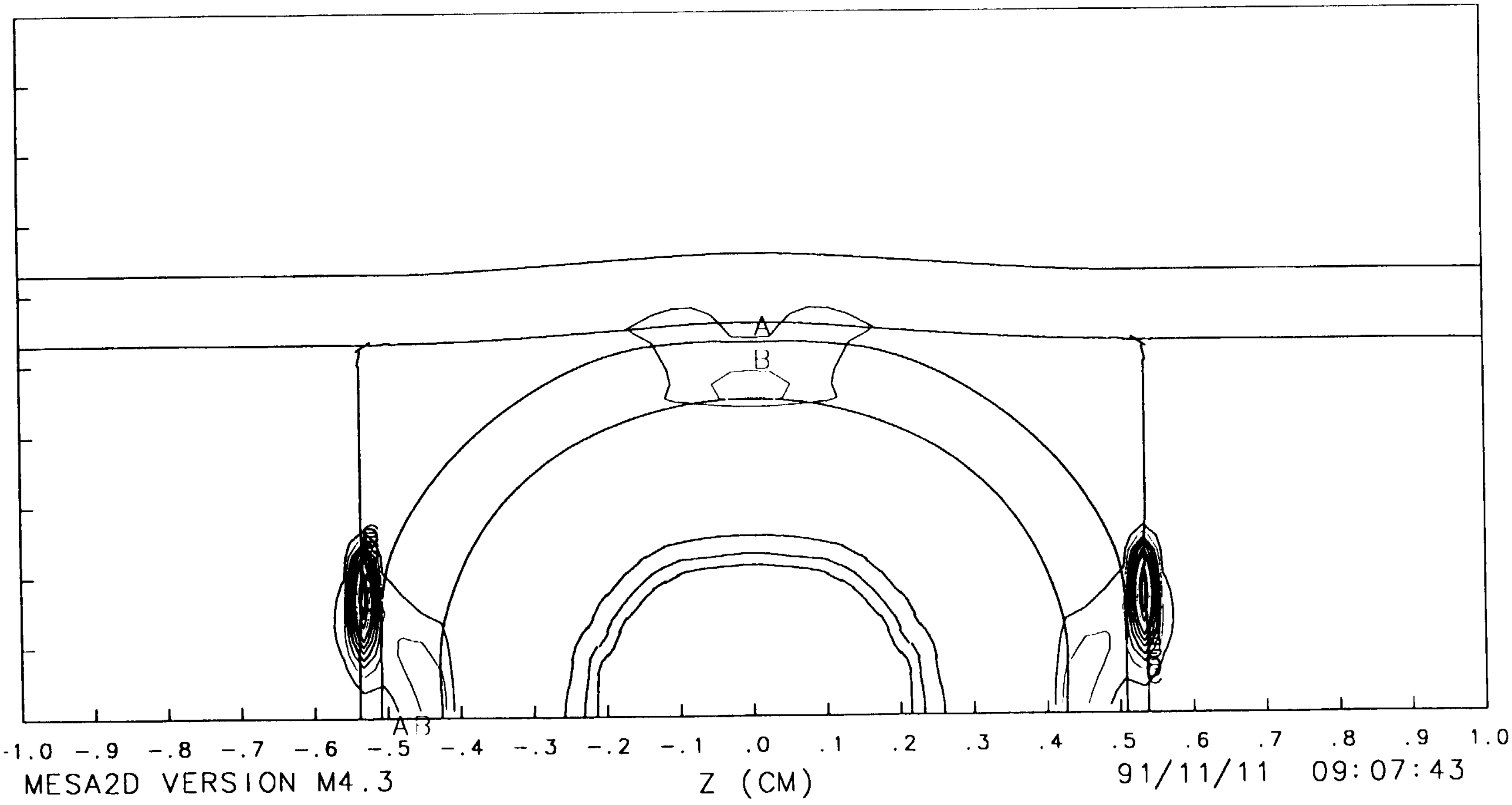
THIS PLOT SHOWS THE ELASTIC WORK BEING DONE ON THE ALUMINUM STRUCTURES. THE AL AND STEEL ARE THE ONLY MATERIALS IN THIS MODEL THAT WERE GIVEN AN ELASTIC-PLASTIC CONSTITUTIVE RELATION. THE ELASTIC WORK IN THE STEEL IS VERY SMALL BECAUSE IT IS ALREADY IN THE PLASTIC REGIME. ALL THE OTHER MATERIALS ARE TREATED AS PURE FLUIDS BECAUSE THEIR PROXIMITY TO THE EXPLOSIVE AND THE STRONG SHOCKS MAKES THEIR STRENGTH NEGLIGIBLE.

PLASTIC WORK (MBAR-CC/GM) TIME 8.0632

GENERATOR INPUT FILE FOR SUPER*ZIP 1D, CORRECTED EOS, E-P STEEL

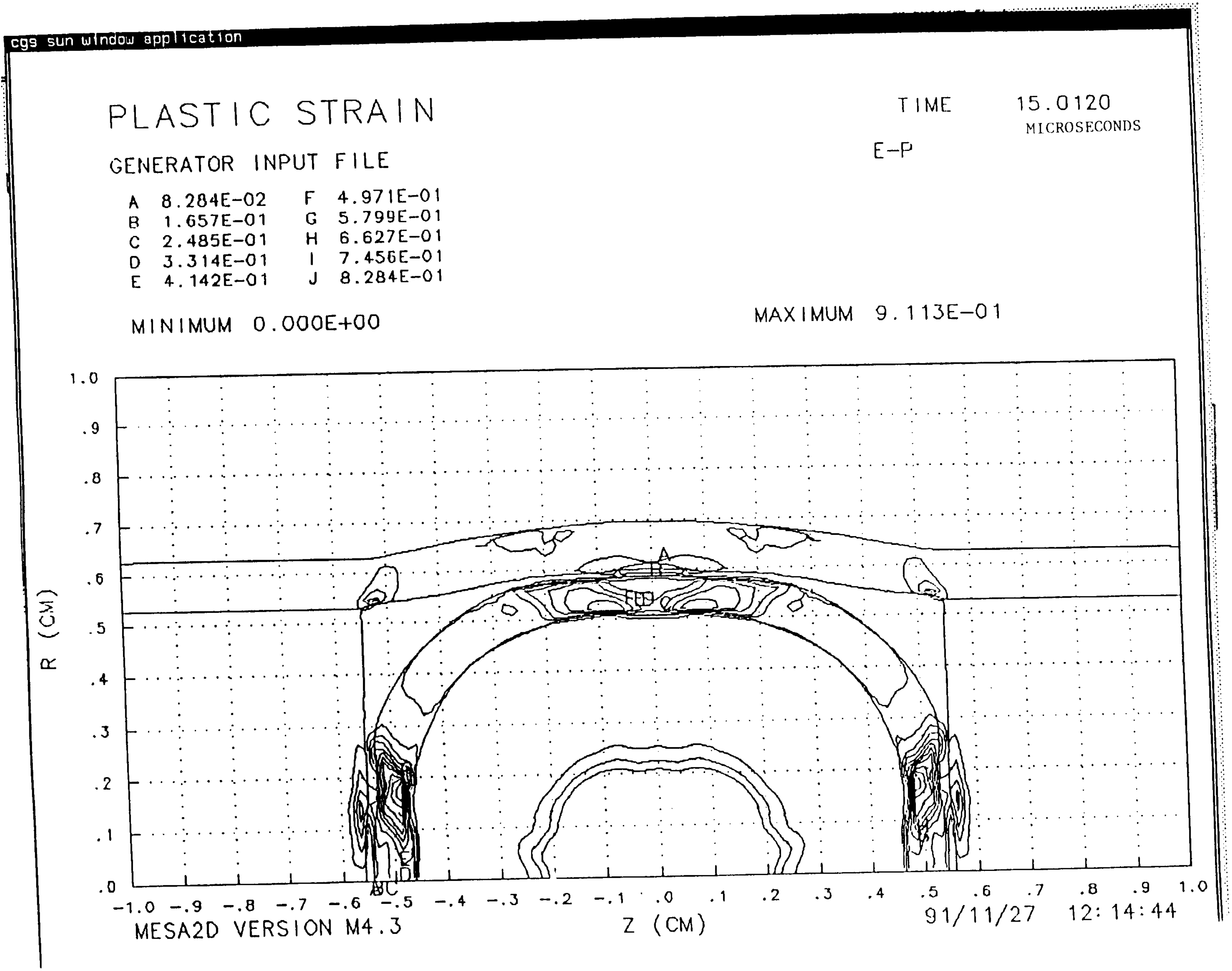
A	5.529E-05	F	3.317E-04
B	1.106E-04	G	3.870E-04
C	1.659E-04	H	4.423E-04
D	2.212E-04	I	4.976E-04
E	2.765E-04	J	5.529E-04

MINIMUM 0.000E+00 MAXIMUM 6.082E-04



MESA2D VERSION M4.3 91/11/11 09:07:43

THE NEXT PLOTS SHOW PLASTIC WORK AND PLASTIC STRAIN. COMPARING THE MAGNITUDES OF ELASTIC AND PLASTIC WORK, IT IS SEEN THAT THE PLASTIC WORK IS TWO ORDERS OF MAGNITUDE GREATER THAN THE ELASTIC. THIS IS TYPICAL OF VERY HIGH STRAIN RATE PROCESSES, AND IN MANY CALCULATIONS THE ELASTIC COMPONENT IS NEGLECTED.


cgs sun window application
PLASTIC STRAIN
GENERATOR INPUT FILE
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B 1.657E-01
C 2.485E-01
D 3.314E-01
E 4.142E-01
F 4.971E-01
G 5.799E-01
H 6.627E-01
I 7.456E-01
J 8.284E-01
MINIMUM 0.000E+00
TIME 15.0120
MICROSECONDS
E-P
MAXIMUM 9.113E-01
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R (CM)
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Z (CM)
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MESA2D VERSION M4.3
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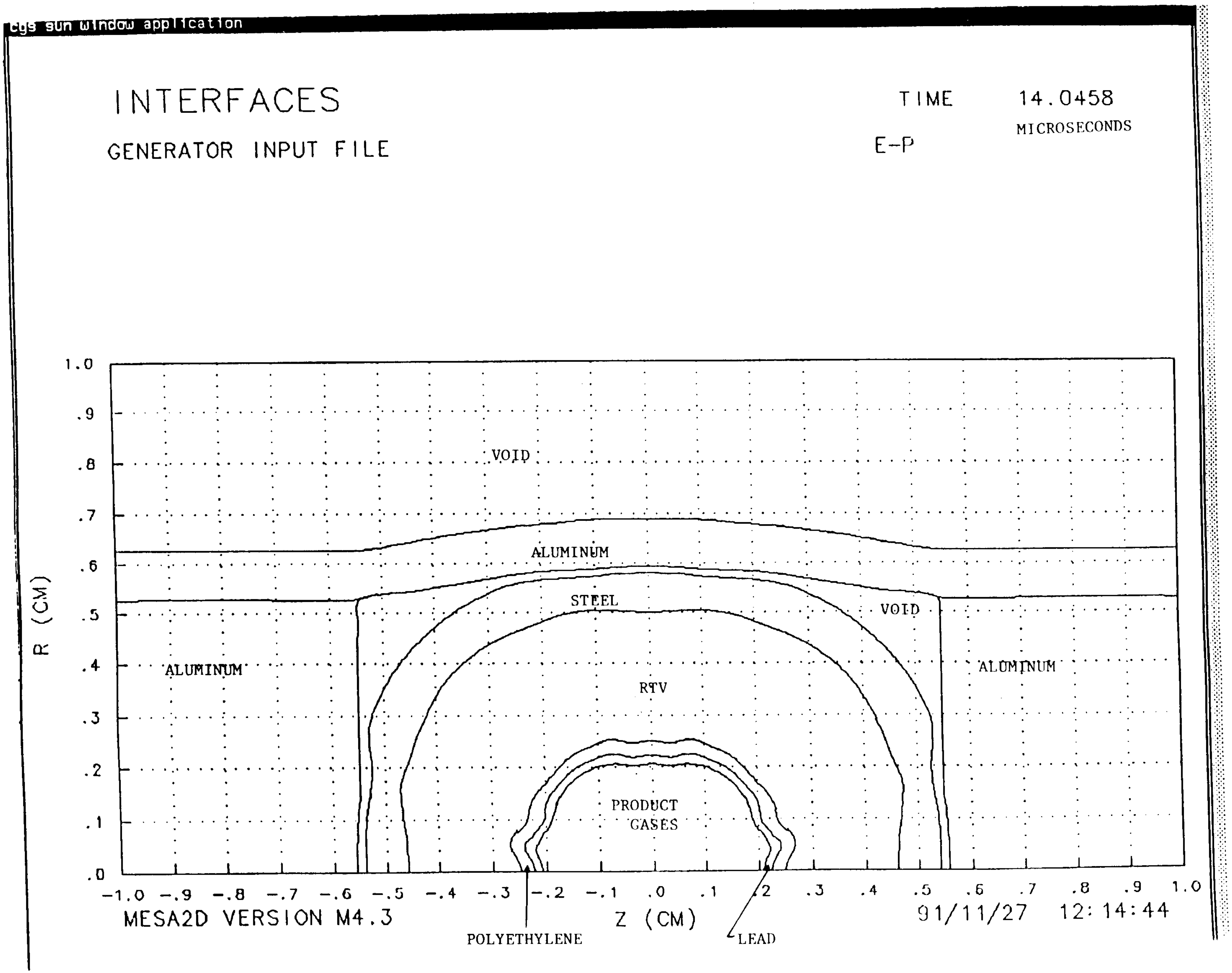
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INTERFACES
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RTV
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Z (CM)
MESA2D VERSION M4.3
91/11/27 12:14:44
POLYETHYLENE
LEAD

THIS IS THE CONFIGURATION OF THE SYSTEM AT THE FINAL TIME FOR THIS CALCULATION. THE THINNING OF THE CONTAINMENT TUBE WHERE IT CONTACTS THE STRUCTURE IS VERY APPARENT. THE DOUBLER IS BENT EVEN THOUGH THERE WAS NO NOTCH INCLUDED IN THE INITIAL MODEL. AN EXAMINATION OF THE TENSILE STRESSES IN THIS MATERIAL WOULD SHOW THAT IT FRACTURES, BUT THE MODEL DID NOT INCLUDE ANY FRACTURE CRITERIA SO THAT IS NOT SHOWN EXPLICITLY. IT WOULD BE POSSIBLE TO CARRY THE CALCULATION FURTHER IN TIME IF DESIRED. THIS EXAMPLE TOOK SEVERAL HOURS TO RUN ON THE WORKSTATION.

CONCLUSIONS

- REACTIVE HYDROCODES CAN BE APPLIED TO SPACE VEHICLE ORDNANCE DEVICES
  - QUALITATIVE AGREEMENT BETWEEN SIMPLE MODELS AND OBSERVED BEHAVIORS
  - NUMERICAL FORMULATION IMPORTANT FOR VALID RESULTS
  - MATERIALS RESPONSE DATABASE MUST BE EXPANDED

- USE OF ADDITIONAL CODE FEATURES WILL IMPROVE
  - AGREEMENT WITH TEST RESULTS
  - PREDICTIVE CAPABILITIES

WE HAVE ONLY BEEN WORKING AT THIS FOR LESS THAN A YEAR, AND ALREADY I BELIEVE WE HAVE MADE SIGNIFICANT PROGRESS AND ACHIEVED SOME VALUABLE RESULTS. WE CONCLUDE FROM THESE INITIAL CALCULATIONS THAT REACTIVE HYDROCODES LIKE MESA CAN SUCCESSFULLY BE APPLIED TO SPACE VEHICLE ORDNANCE DEVICES. EVEN SIMPLE CONCEPTUAL MODELS SHOW GOOD AGREEMENT WITH QUALITATIVE FEATURES OF OBSERVED BEHAVIOR. HOWEVER, RESULTS ARE DEPENDENT ON THE QUALITY OF THE NUMERICAL SIMULATION AND THE CALCULATIONS ARE ONLY AS GOOD AS THE MATERIALS DATA THAT GOES INTO THEM. IN ORDER TO FULLY EXPLOIT THE POTENTIAL OF THIS TYPE OF MODELING, ADDITIONAL EXPERIMENTAL WORK MUST BE DONE TO INCREASE THE MATERIALS RESPONSE DATABASE, ESPECIALLY FOR HIGH STRAIN RATES.

AS WE CONTINUE TO BECOME MORE ADEPT AT USING MESA AND TO TAKE ADVANTAGE OF ADDITIONAL FEATURES THAT WERE NOT EXERCISED IN THESE INITIAL EXAMPLES, THE AGREEMENT WITH TEST RESULTS IS EXPECTED TO IMPROVE AND THE PREDICTIVE CAPABILITIES OF THE TECHNIQUE TO BE MORE POWERFUL.

WE HAVE APPLIED MESA TO OTHER PROBLEMS IN ADDITION TO THE EXPANDING TUBE SEPARATION SYSTEMS. AMONG THESE ARE A PRESSURE CARTRIDGE AND LINEAR SHAPED CHARGES. REACTIVE HYDRODYNAMICS IS ESPECIALLY APPROPRIATE FOR SHAPED CHARGES BECAUSE THE TREATMENT OF THE SHEATH MATERIAL AS A MATHEMATICAL FLUID IS A VERY GOOD APPROXIMATION IN THIS CASE.

WE ARE ALSO IN THE PROCESS OF EXPANDING OUR REPERTOIRE OF COMPUTATIONAL TOOLS AT AEROSPACE BY INTEGRATING OTHER CODES INTO OUR APPROACH TO PROBLEMS. AMONG THESE IS SIN, A ONE-DIMENSIONAL HYDROCODE THAT HAS BEEN VERY USEFUL IN SCOPING PROBLEMS BEFORE USING MESA AND IN APPROXIMATING SIMPLE GEOMETRIES. WE HAVE RECENTLY OBTAINED, AND ARE IN THE PROCESS OF IMPLEMENTING, SCAP AND LESCA, TWO PROGRAMS FOR SHAPED CHARGE ANALYSIS DEVELOPED BY SANDIA.

THE NEXT MAJOR STEP IN OUR CAPABILITY WILL BE USING MESA-3D. IT IS RUNNING ON THE CRAY-2 AT PHILLIPS LABORATORY, AND WE ARE ABOUT TO BECOME USERS.

STATUS AND FUTURE DIRECTIONS

- OTHER SYSTEMS MODELED
  - PRESSURE CARTRIDGE
  - LINEAR SHAPED CHARGE PENETRATION
- PLANNING TO RUN 3D MESA AT PHILLIPS LAB
- INTEGRATING COMPLEMENTARY CODES
  - SIN
  - LESCA
  - SCAP