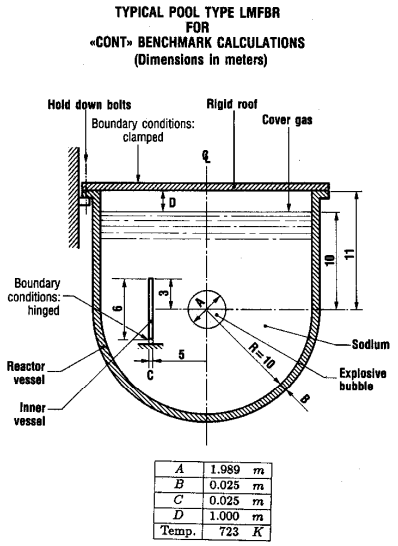
Exercise/Example 4 – CONT problem

Three fluids plus deformable structures

- Try out ALE solution with Lagrangian fluid/fluid interfaces (single-component fluid model)
- Try out ALE solution with ALE fluid/fluid interfaces (multi-phase multi-component fluid model)



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This is a well-known reactor safety benchmark problem from the 1970's/80s.

Geometric data:

Simplified sodium-cooled fast breeder reactor (axisymmetric) with internal shield. The roof is rigid.

Materials

The explosive bubble is made of a misture of molten fuel and fluid sodium (corium). The pool is filled by liquid sodium. An argon cover gas fills the region below the roof. The tank and inner shield are made of elasto-plastic steel.

Numerical Solution

CONT01

We use the standard single-component fluid material model. This means that the two fluid-fluid interfaces are treated as Lagrangian. Due to sliding of the sodium/argon interface along the tank, the FSA model may not be used alone to describe fluid-structure interactions (use is made of Lagrangian sliding locally). The input file is:

```
CONT - 01
*-------------------------------------------------------------------------
 ECHO
 !CONV win
*-----------------------------------------------------------Problem type
AXIS NONL ALE lagc
*-----------------------------------------------------------Dimensioning
DIME
   PT2L 293 PT3L 70 ZONE 3
   ED41 33 FLU1 267 pmat 1
   BLOQ 100
   FSSA 100
   FSSL 100
   UNIL 50
   LIAI 900
   NALE 1 NBLE 232
   MTPO 9 MTEL 8
   impa 1 psim 7
TERM
opti noecho
*-----------------------------------------------------------------Geometry
GEOM LIBR POIN 355 ED41 33 FLU1 266 pmat 1 TERM
 0.00000E+00 0.00000E+00 0.00000E+00-2.50000E-02 1.28440E+00
 8.28200E-02 1.28760E+00 5.80290E-02 2.54760E+00 3.29920E-01
 2.55400E+00 3.05750E-01 3.76850E+00 7.37220E-01 3.77790E+00
 7.14060E-01 4.92700E+00 1.29800E+00 4.93930E+00 1.27620E+00
 6.00390E+00 2.00290E+00 6.01890E+00 1.98290E+00 6.98130E+00
 2.84020E+00 6.99880E+00 2.82230E+00 7.84310E+00 3.79620E+00
```

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5.00000E+00 7.60000E+00 5.02500E+00 7.60000E+00 5.00000E+00
8.20000E+00 5.02500E+00 8.20000E+00 5.00000E+00 8.80000E+00
5.02500E+00 8.80000E+00 5.00000E+00 9.40000E+00 5.02500E+00
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9.58100E+00 9.47610E-01 9.68140E+00 9.76550E-01 9.78550E+00
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1.14990E+01 1.45770E+00 1.16580E+01 1.27950E+00 1.17990E+01
1.08770E+00 1.19210E+01 8.84300E-01 1.20230E+01 6.71570E-01
1.21030E+01 4.51710E-01 1.21610E+01 2.27060E-01 1.21960E+01
0.00000E+00 1.22080E+01 0.00000E+00 1.58450E+00 4.38710E+00
6.61290E+00 8.70160E+01 6.69730E+00 1.28720E+00 6.83650E+00
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7.55480E+00 2.67900E+00 7.88140E+00 2.92900E+00 8.24300E+00
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0.00000E+00 5.37680E+00 5.93760E-01 5.41500E+00 1.17770E+00
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7.13160E+00 3.96400E+00 7.62100E+00 4.00130E+00 8.09140E+00
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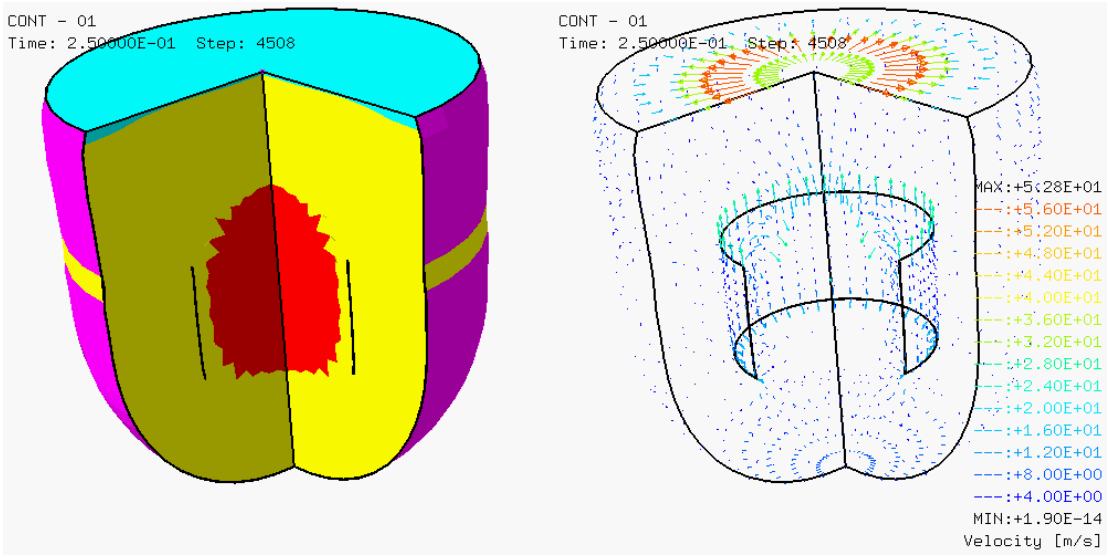
  299  328  329  300  300  329  330  301  301  330
  331  302  302  331  332  303  303  332  333  304
  304  333  334  305  305  334  335  306  306  335
  336  307  307  336  337  308  308  337  338  309
  309  338  339  310  310  339  340  311  311  340
  198   71  312  341  342  313  313  342  343  314
  314  343  344  315  315  344  345  316  316  345
  346  317  317  346  347  318  197  199  168  168
  219  222  180  180  342  341  348  349  343  342
  349  350  344  343  350  351  345  344  351  352
  346  345  352  353  347  346  353  354   71   72
  283  283   72  312  283  283
  355
* added pmat: element 300, node 355
opti echo
*-----------------------------------------------Geometric Complements
COMP EPAI 2.5E-2 LECT 1 PAS 1 23 24 PAS 1 33 TERM
     GROU 5 'vessel'  LECT 1 PAS 1 23 TERM
            'shield'  LECT 24 PAS 1 33 TERM
            'liqu'    LECT 34 35 64 PAS 1 291 298 PAS 1 299 TERM
            'bull'    LECT 36 PAS 1 63 TERM
            'gaz'     LECT 292 PAS 1 297 TERM
     COUL jaun LECT liqu TERM
          roug LECT bull TERM
          turq LECT gas  TERM
          rose LECT vessel shield TERM
*-------------------------------------------------------------Grid motion
GRIL LAGR LECT 1 PAS 1 48 49 PAS 1 70 74 PAS 1 102 319
          335 PAS 1 340 341 PAS 1 347 198 221 355 TERM
     EULE LECT 348 PAS 1 354 TERM
     ALE  LECT 34 PAS 1 299 TERM
     AUTO AUTR
*-------------------------------------------------------Material data
MATE VM23 RO 7800. YOUNG 1.6E11 NU 0.333 ELAS 1.05E8
          TRAC 2 1.05E8 .656256E-3 1.6105E10 1.00666
          LECT vessel TERM
     VM23 RO 7800. YOUNG 1.6E11 NU 0.333 ELAS 1.05E8
          TRAC 2 1.05E8 .656256E-3 1.6105E10 1.00666
          LECT shield TERM
     FLUT RO 832. EINT 98.68 GAMM 7.15D0 CL 0.5 CQ 2.56 PB 2.71E5
          PMIN 0. AHGF 0. ITER 2 ALF0 1. BET0 1. KINT 0 NUM 5
          LECT liqu TERM
     FLUT RO 2.4278E3 EINT 0. GAMM 0.75D0 CL 0.5 CQ 2.56 PB 0.
          PMIN 0. AHGF 0. ITER 2 ALF0 1. BET0 1. KINT 0 NUM 4
          LECT bull TERM
     FLUT RO .242777373 EINT 6.865E5 GAMM 1.6 CL 0.5 CQ 2.56 PB 0.
          PMIN 0. AHGF 0. ITER 2 ALF0 1. BET0 1. KINT 0 NUM 1
          LECT gas TERM
     mass 1.0 lect 300 term
*-----------------------------------------------------Boundary conditions
LIAIS freq 1 RENUM
 BLOQ 1 LECT 1 2 47 48 49 50 73 74 102 103 131 132 160 161 189 190
             231 232 260 261 289 290 318 319 347 348 354 TERM
      2 LECT 47 PAS 1 50 348 PAS 1 354 TERM
      3 LECT 1 2 47 48 TERM
*UNIL 2 -1 20.99 LECT 341 PAS 1 347 TERM
      12 lect 355 term
 impa ddl 2 cote -1
      proj lect 300 term
      cibl lect 341 pas 1 347 term
LINK DECO
  FSS ALE  NCOT 26
       LECT 1 3 1 320 319 0 0 0 0 1 0 TERM
```

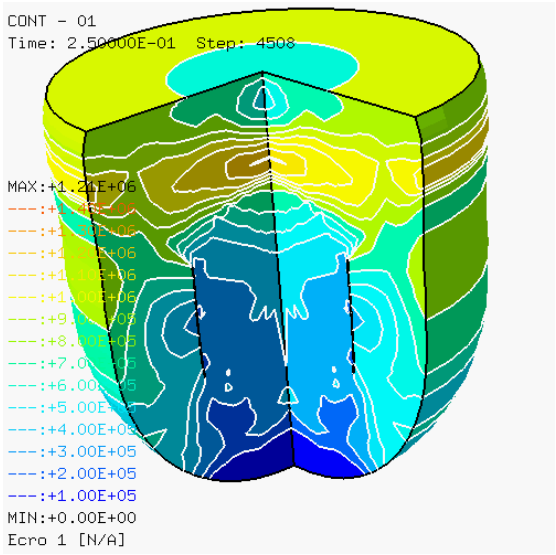
```
LECT 2 5 3 321 320 0 0 0 0 1 1 TERM
LECT 3 7 5 322 321 0 0 0 0 1 1 TERM
LECT 4 9 7 323 322 0 0 0 0 1 1 TERM
LECT 5 11 9 324 323 0 0 0 0 1 1 TERM
LECT 6 13 11 325 324 0 0 0 0 1 1 TERM
LECT 7 15 13 326 325 0 0 0 0 1 1 TERM
LECT 8 17 15 327 326 0 0 0 0 1 1 TERM
LECT 9 19 17 328 327 0 0 0 0 1 1 TERM
LECT 10 21 19 329 328 0 0 0 0 1 1 TERM
LECT 11 23 21 330 329 0 0 0 0 1 1 TERM
LECT 12 25 23 331 330 0 0 0 0 1 1 TERM
LECT 13 27 25 332 331 0 0 0 0 1 1 TERM
LECT 14 29 27 333 332 0 0 0 0 1 1 TERM
LECT 15 31 29 334 333 0 0 0 0 1 1 TERM
LECT 16 -33 31 -335 334 0 0 0 0 1 1 TERM
LECT 24 51 49 201 199 52 50 202 200 1 -1 TERM
LECT 25 53 51 203 201 54 52 204 202 1 1 TERM
LECT 26 55 53 205 203 56 54 206 204 1 1 TERM
LECT 27 57 55 207 205 58 56 208 206 1 1 TERM
LECT 28 59 57 209 207 60 58 210 208 1 1 TERM
LECT 29 61 59 211 209 62 60 212 210 1 1 TERM
LECT 30 63 61 213 211 64 62 214 212 1 1 TERM
LECT 31 65 63 215 213 66 64 216 214 1 1 TERM
LECT 32 67 65 217 215 68 66 218 216 1 1 TERM
LECT 33 69 67 219 217 70 68 220 218 -1 1 TERM
NPOI 28
LAGR NCT1 10
        LECT 277 -334 335 TERM
        LECT 278 335 336 TERM
        LECT 279 336 337 TERM
        LECT 280 337 338 TERM
        LECT 281 338 339 TERM
        LECT 282 339 340 TERM
        LECT 283 340 198 TERM
        LECT 34 198 221 TERM
        LECT 35 221 341 TERM
        LECT 292 341 348 TERM
    NPOI 11
    NCT2 8
        LECT 16 -31 33 TERM
        LECT 17 33 35 TERM
```

```
        LECT 18 35 37 TERM
        LECT 19 37 39 TERM
        LECT 20 39 41 TERM
        LECT 21 41 43 TERM
        LECT 22 43 45 TERM
        LECT 23 45 47 TERM
      NPOI 9
*-------------------------------------------------------------------Outputs
ECRITURE COOR DEPL VITE CONT ECRO TFRE 250.E-3
          POIN LECT 1 74 102 59 69 341 347 43 332 TERM
          ELEM LECT 36 63 292 297 34 262 1 21 TERM
    fich alic temp FREQ 1
          POIN LECT 1 74 102 59 69 341 347 43 332 TERM
          ELEM LECT 36 63 292 297 34 262 1 21 TERM
    FICH ALIC TFRE 2.5E-3
*-------------------------------------------------------------------Options
OPTI AMORT QUAD 2.56 NOTEST
     NOCR LECT 292 PAS 1 297 183 196 TERM
     cstab 0.45
     REZO GAM0 0.8
     log 1
*-----------------------------------------------Transient calculation
CALC TINI 0.0 DTMI 1E-9 TEND 250.E-3
*=============================================================POST-TREATMENT
SUIT
Post-treatment
ECHO
RESU ALIC TEMP GARD PSCR
SORT GRAP
AXTE 1000.0 'Time [ms]'
*-----------------------------------------------Curve definitions
COUR 1  'dy_1'   DEPL COMP 2 NOEU LECT 1    TERM
COUR 2  'dy_341'  DEPL COMP 2 NOEU LECT 341 TERM
*-------------------------------------------------------------------Plots
trac 1 2 axes 1.0 'DISPL. [M]' yzer
*-----------------------------------------------Results qualification
QUAL DEPL COMP 2 LECT   1 TERM REFE -6.27942E-2 TOLE 1.E-2
     DEPL COMP 2 LECT 341 TERM REFE  4.39215E-1 TOLE 1.E-2
*===================================================================
FIN
```

The final mesh (colors indicate materials in this case) and fluid velocities are:



The final fluid pressures:

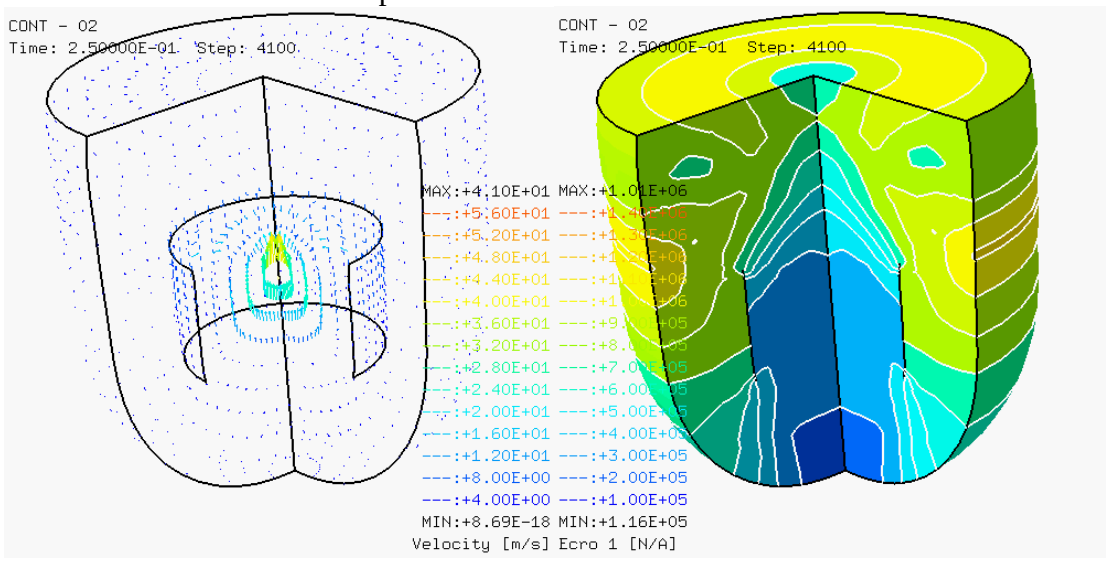


CONT02

This example uses the multi-phase multi-component fluid material model. This means that the two fluid-fluid interfaces may be treated as ALE and the FSA model may be used to describe fluid-structure interactions. The input file is:

```
CONT - 02
*-----------------------------------------------------------------------
 ECHO
CAST mesh
!CONV win
*-----------------------------------------------------------Problem type
AXIS NONL ALE
*-----------------------------------------------------------Dimensioning
DIME
   PT2L 278 PT3L 35 ZONE 3
   ED01 33 FL24 230 FL23 28
   NALE 18 NBLE 278
   MTPO 29
   MTEL 24
   ECRO 13128
TERM
*-------------------------------------------------------------Geometry
GEOM ED01 stru FL23 flui3 FL24 flui4 TERM
*-----------------------------------------------Geometric Complements
COMP EPAI 2.5E-2 LECT stru TERM
*---------------------------------------------------------Grid motion
GRIL LAGR LECT stru TERM
     ALE LECT flui TERM
     AUTO AUTR
*-------------------------------------------------------Material data
MATE VM23 RO 7800. YOUN 1.6E11 NU 0.333 ELAS 1.05E8
          TRAC 2 1.05E8 .656256E-3 1.6105E10 1.00066
          LECT vessel TERM
     VM23 RO 7800. YOUN 1.6E11 NU 0.333 ELAS 1.05E8
          TRAC 2 1.05E8 .656256E-3 1.6105E10 1.00066
          LECT shield TERM
     FLMP NLIQ 1 NGAS 2
     FLUT RO 832. EINT 98.68 GAMM 7.15D0 CL 0.5 CQ 2.56
          PB 2.71E5 PMIN 0. AHGF 0. ITER 2 ALF0 1.
          BET0 1. KINT 0 NUM 5
          LECT liqu TERM
     FLUT RO 2.4278E3 EINT 0. GAMM 0.75D0 CL 0.5 CQ 2.56
          PB 0. PMIN 0. AHGF 0. ITER 2 ALF0 1.
          BET0 1. KINT 0 NUM 4
          LECT bull TERM
     FLUT RO .242777373 EINT 6.865E5 GAMM 1.6 CL 0.5 CQ 2.56
          PB 0. PMIN 0. AHGF 0. ITER 2 ALF0 1.
          BET0 1. KINT 0 NUM 1
          LECT gas TERM
*-----------------------------------------------Boundary conditions
LINK COUP
     BLOQ 1 LECT p2p TERM
     BLOQ 123 LECT p4p TERM
     CONT SPLA NX 1 NY 0 LECT symax TERM
     CONT SPLA NX 0 NY 1 LECT top   TERM
     FSA  LECT fsan TERM
*-------------------------------------------------------------------Outputs
ECRI COOR DEPL VITE ACCE CONT ECRO TFRE 250.E-3
     FICH ALIC TEMP FREQ 1
          POIN LECT p0 TERM
     FICH ALIC TFRE 2.5E-3
*-----------------------------------------------------------------Options
OPTI NOTE
     log 1 csta 0.5
     REZO GAM0 0.8
     FLMP EPS1 1.E-5
*-----------------------------------------------Transient calculation
CALCUL TINI 0.0 TEND 250.E-3
*=============================================POST-TREATMENT
SUIT
Post-treatment
ECHO
RESU ALIC TEMP GARD PSCR
SORT GRAP
AXTE 1000.0 'Time [ms]'
*-----------------------------------------------Curve definitions
COUR 1  'dy_1'    DEPL COMP 2 NOEU LECT p0  TERM
*-------------------------------------------------------------------Plots
trac 1 axes 1.0 'DISPL. [M]' yzer
*-----------------------------------------------Results qualification
QUAL DEPL COMP 2 LECT  p0 TERM REFE -1.23718E-1 TOLE 1.E-2
*=====================================================================
FIN
```

The final fluid velocities and pressures:



The final bubble material mass fraction (giving an idea of the size and form of the bubble) and an intermediate time view of the liquid sodium mass fraction: