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SANDCMOT User Instructions

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Abstract

This report includes a formal code description of the SANDCMOT program that is used to analyse sodium boiling and clad motion phenomena during the initiation phase of loss-of-flow accidents within LMFBR's. The code input, a flow chart, a short characterization of the major subroutine's function as well as a list of main variables are presented. A detailed description of the relevant physics can be found in previous reports enumerated in the reference list.

SANDCMOT Benutzungsanleitung

Zusammenfassung

Dieser Bericht enthält eine formale Programmbeschreibung des SANDCMOT Programms, das zur Analyse der Natriumsiedephase und der Hüllrohrmaterialbewegung während eines Kühlmitteldurchsatzstörfalls in einem schnellen, natriumgekühlten Brutreaktor benutzt wird. Die Eingabedaten, ein Flußdiagramm, eine kurze Funktionsbeschreibung der wichtigsten Unterprogramme sowie eine Liste der wichtigsten Variablen werden zusammengestellt. Eine ausführliche Darstellung der zugrundegelegten Physik findet sich in früheren Berichten, die in der Referenzliste aufgeführt sind.

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I. INTRODUCTION

The SANDCMOT-code has grown out of two other programs. One of these is the SANDPIN-code developed at SANDIA NATIONAL LABORATORY /3/. This code provides the basic geometrical framework and also has a rather elaborated pin model including a fission gas , a pin mechanics and a thermodynamic model. In its original form it could not, however, take into account any relocation of molten fuel pin materials. Concerning the motion of molten cladding, this capability was provided by the CMOT-code that had been under development at KfK for several years /4,5/. Two basic flow regimes of the molten cladding are considered. It either may move along the surface of some fuel rods or as free drops within the voided coolant channel having no contact to any solid component. The two flow regimes are depicted in fig. 1. Their justification is based on experimental results that are summarized below. As the basic annular model geometry easily allows to represent several coolant channels the clad motion model was provided for every channel. Once the cladding temperature reaches the liquidus point plus a user supplied superheat its subsequent relocation is calculated for every channel. Thus, multichannel and related incoherency effects can be modeled. Interchannel molten clad mixing, however, is not considered.

The way to treat multipin bundles is shown in fig. 2 for the case of a seven pin bundle contained within a quartz tube. Essentially, a (symmetrical) pin bundle is represented by an annular ring geometry. The central pins are identical while the first annular ring of solid material represents the outer row of six pins. In between these massive rings the coolant channels are located. They are connected by radial cross flow channels that give rise to coolant diversion flows if one channel happens to be plugged. These flows are essential to assess multichannel incoherency effects. The annular radii are determined by requiring equal masses in both geometries. In order to correct for an error introduced when these radii are used for exchange area calculation among material components, a set of correction factors is supplied. They guarantee a correct calculation of exchange areas with the mass based radii.

The current clad motion model has been developed in accordance with results brought forth in the recent STAR experiments /6/. From the high speed motion pictures it appears that molten cladding does not wet the fuel substrate at moderate temperatures not too far exceeding the clad melting point (1700 K). As a result, molten clad moves in form of single waves and rivulets along the fuel rod surface. Also, these objects easily and frequently can get entrained and then continue flowing as single drops within the coolant channel. Both flow regimes have been included in the current clad motion model. Waves are represented simply by sphere caps that have a certain mass and contact angle to the fuel pin underneath. Currently, waves are assumed to be all similar and to be characterized by a unique mass value. This is a simplification because, experimentally, a spectrum of waves and drops is seen that has typical dimensions in the range 0.7 - 4 or 5 mm. It further is assumed that waves contacting hot fuel or cold cladding will have different contact angles. From a knowledge of the wave's volume and contact angle all relevant geometrical quantities like contact areas to the pin or to the coolant vapor phase easily can be deduced (see also fig. 5). The consideration of a wave substructure is a major improvement over the widely used film models because the actual flow regime obviously is more accurately simulated. Also the various interfacial exchange areas are better represented. This is apparent for the fuel to coolant contact area that is zero in the film flow case but is finite in any wave flow.

Another problem directly related to the wave substructure is the possibility of wave entrainment. In film flow models entrainment appears possible only at rather high vapor velocities of order 100 m/s due to the high surface tension of molten cladding. On the other hand, many waves are seen to get entrained and to flow as drops. If the waves finite contact angle to the pin is taken into account an entrainment criterion can be deduced that indeed predicts entrainment possible at vapor velocities of order 50 m/s in accordance with the STAR experimental results. To justify the current clad motion model the first two STAR experiments were recalculated. In both tests, clad and fuel motion essentially were seperated and allowed for an independent analysis. The results are reported in ref. /1/ and confirm the suitableness of the model.

As the molten clad interaction with the surrounding vapor flow is of special importance the CMOT code also solves the two-dimensional (r-z) vapor flow within the model annular geometry. An extension to two dimensions is necessary as radial cross flows are important in assessing certain incoherency effects. Finally, in order to make the code more versatile and independent of extensive boundary data specification a sodium boiling model was incorporated recently /2/. It generalizes the single phase treatment of the coolant to a two-phase situation. The sodium boiling model was developed and checked against the TREAT-R5 experiment. It was a seven pin test that simulated loss of flow conditions. A detailed description of the model and a comparison of calculated and measured results can be found in ref. /2/. In its present form now, the SANDCMOT code is suitable for initiation phase analysis of sodium boiling and clad motion scenarios up to fuel pin disintegration.

Turning to some technical aspects the SANDCMOT source deck is not written in a pure FORTRAN format but does include a variety of HISTORIAN PLUS /7/ directives. By these directives a compact and less redundant form of the source data file is obtained. To get an executable version the HISTORIAN PLUS preprocessor has to be run first that will create a complete FORTRAN77 source deck. This deck, in a second step, has to be compiled and linked. The necessary JCL is given below.

Due to the historical development of the SANDCMOT code by a synthesis of two other codes the input specification is twofold. The SANDPIN related input is read in by formatted statements. The CMOT related input covering the sodium boiling and clad motion input is read in by NAMELIST statements. From a systematic point of view, this situation is somewhat unsatisfactory. On the other hand, practically, this division does not lead to any real difficulties but actually helps to quickly distinguish between the two program parts.

The numerical solution strategy is such that the heat transfer and pin mechanics calculations are widely implicit and therefore independent of any stability requirements to the integration time step. Only accuracy reasonings will limit the corresponding time step, DT. It is provided by the SANDPIN input and may vary in the course of integration. There is another time step, CDT, related to the integration of the clad motion and sodium boiling equations. CDT is always smaller or at most equal to DT that is the greatest time step used. If CDT is smaller than DT some subcycling is necessary to match the final time level of the DT integration. This subcycling is organized in subroutine CHANDY and includes the subroutines FFDT, BUPDAT, GDYN, DRPDY, ECOOL, UPDAT, CMOT, PLENOU, COUTPT, CURVOU and XPFILE. These routines, therefore, may be called several times each DT integration step. The flow chart in fig. 4 clearly reflects this point. The DT integration essentially is performed in the subroutines TTEMPS, FISGAS and STRESS originating from the SANDPIN code.

As the computational mesh used for the sodium boiling phase or the preheating phase in the STAR experiments may be rather coarse, it is refined at the onset of clad motion to allow for a better resolution. To this purpose an input variable DZW(j) in NAMELIST NAMO exists where the desired axial mesh width can be specified. By JLI and JUI, it also can be specified which coarse mesh cells are to be subdivided. For cells below JLI or above JLU no mesh refinement is carried out. The code, upon execution of the subroutine INITIO, will create a fine mesh within the range of specified coarse mesh cells such that a certain number of small mesh nodes totally fits into one coarse mesh node. The resulting axial width of the fine mesh cells usually will be smaller but close to the desired value DZW(j).

Variables normally are located at mesh cell centers. However, due to the staggered grid technique used velocities and some related variables are defined at mesh cell boundaries. If for example v is an axial velocity, v(j) indicates the velocity at the bottom boundary of cell j. Radial velocities are often quoted with respect to some coolant channel k. UGR(k) for example is the radial coolant velocity between channel k and k+1. The computational grid layout together with the locations of some variables are shown in fig. 3.

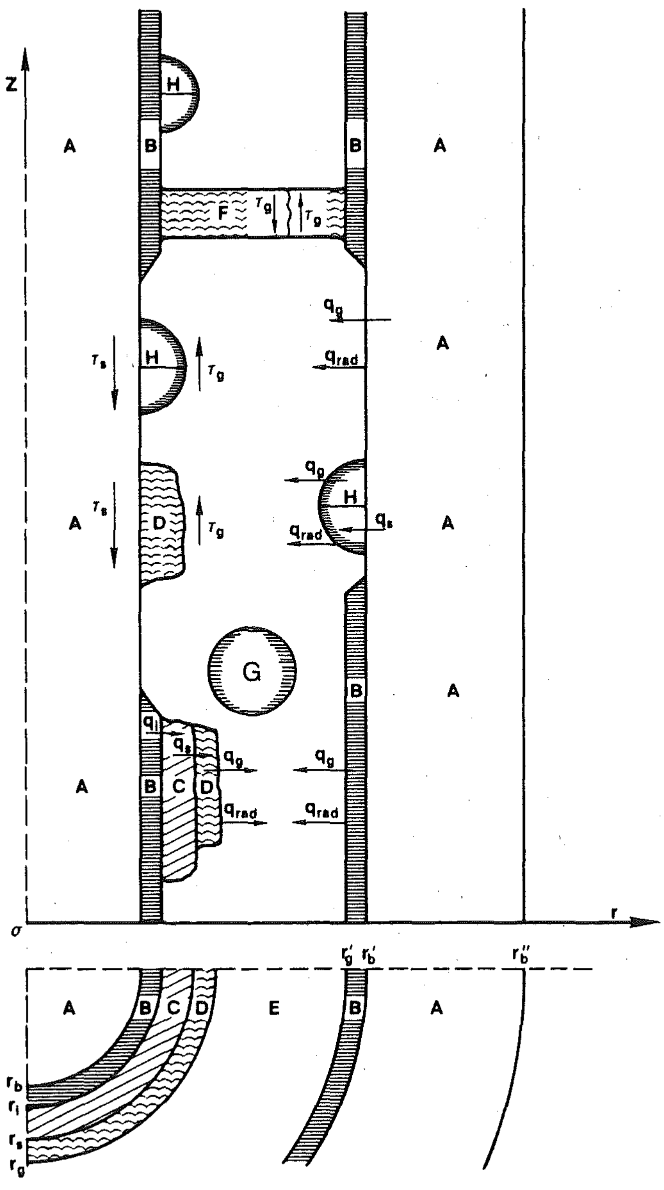

Fig. 1 : Molten clad flow regimes (A: fuel, B: intact cladding, C: resolidified cladding, D: molten cladding film, E: coolant channel, F: molten clad bridge, G: entrained drop, H: molten clad wave, q: heat flux, τ: shear stress)

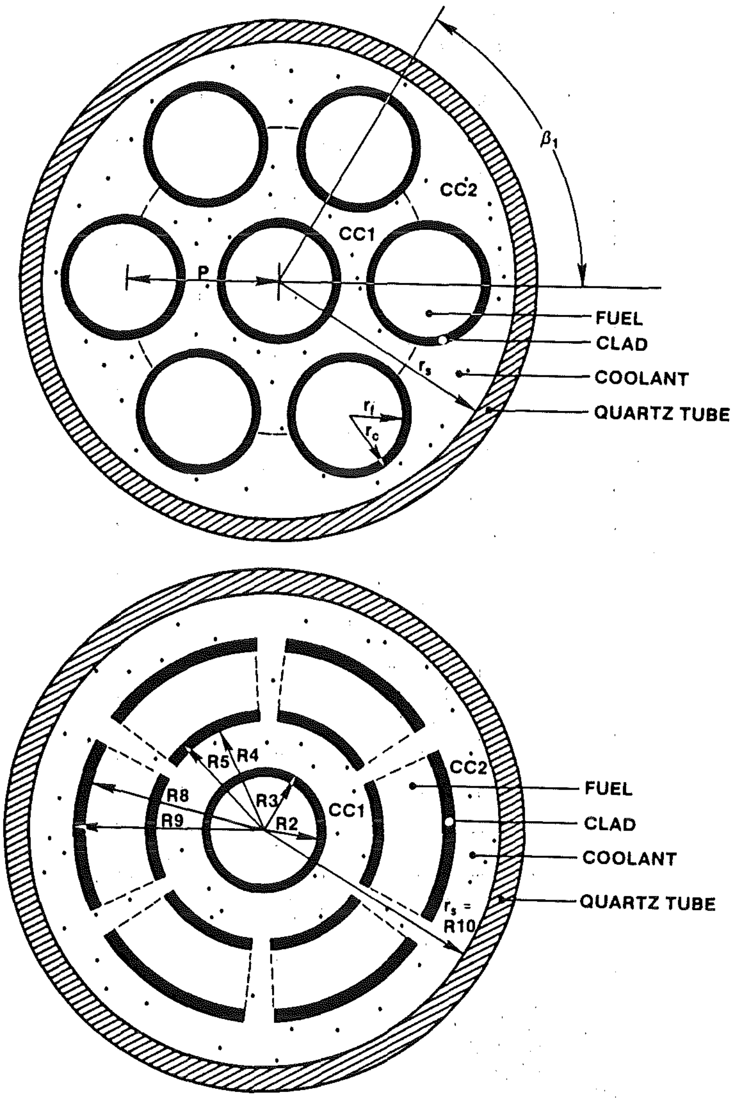

Fig. 2 : Multipin bundle and model geometry

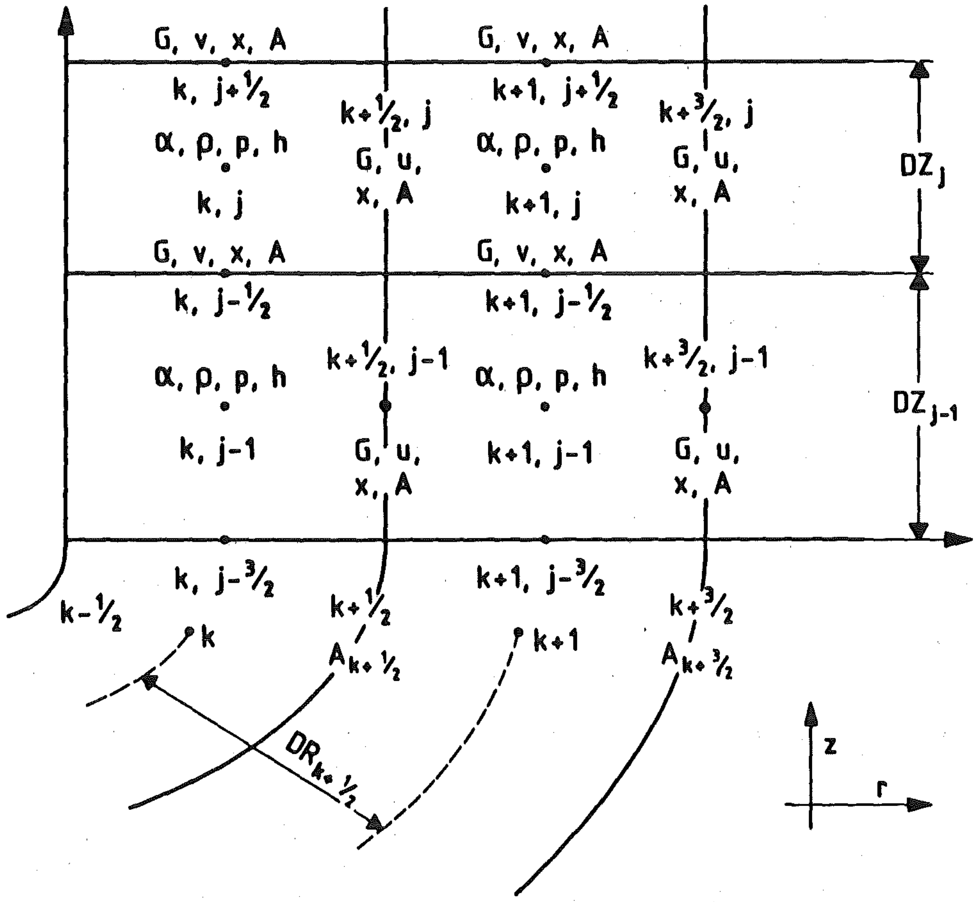

Fig. 3 : Computational grid

II. CODE INPUT

II.1 SANDPIN related input

```
C------------------------------------------------------------------------
C      II.1 SANDPIN DIRECTED INPUT                                      --
C           INPUT ACCOMODATION IN SUBROUTINES INPOT, INTLZ, CINIT
C
C           LOGICAL STRUCTURE OF INPUT DATA
C           1) GENERAL DIRECTIVE INPUT
C           2) SUBMODEL INPUT :
C              GENERAL
C              SUBMODEL IDENTIFICATION
C              GEOMETRY AND OTHER LOCAL INPUT
C              INITIAL CONDITIONS
C           3) AXIAL POWER INPUT
C           4) BOUNDARY CONDITIONS
C           5) TIME STEP CONTROL
C           6) ADDITIONAL MATERIAL PROPERTIES
C           7) FURTHER GAP AND HEAT TRANSFER INPUT
C------------------------------------------------------------------------
C
C              GENERAL DIRECTIVE INPUT
C
C  ----------------------------------------------------------------------
C  ZEROTH CARD : TITLE
C  ----------------------------------------------------------------------
C
C  FIRST CARD (6I6)
C  ----------------------------------------------------------------------
C
C  ITMPOP      TEMPORARY INPUT OPTION   0=>INITIAL TEMP DIST MAINTAINED
C                                       1=>FINITE DIFFERENCE HEAT TRANSFER
C                                          WITH EXPLICIT MELTING CORRECTION
C                                       2=>FINITE DIFFERENCE HEAT TRANSFER
C                                          WITH IMPLICIT MELTING CORRECTION
C  ITMPIN      INITIAL TEMP OPTION      0=>ALL INIT TEMPS SET TO  300 K
C                                       1=>TEMPS GIVEN BY INIT COOLANT TEMP
C                                       2=>TEMPS GIVEN BY BOUNDARY TEMP
C                                       3=>TEMPS READ IN BY ZONE
C  IGRIDO       GEOMETRY INPUT OPTION    0=>READ IN GEOMETRY AT 273.15K
C                                        1=>GEOMETRY AT INITIAL TEMPERATURE
C  NFGSTP      # OF FISSION-GAS TIME STEPS PER THERMAL/MECHANICS STEP
C                                       (IF NFGSTP=0 NO FG CALC. IS DONE)
C  NCOFLO      # OF COOLANT FLOW REGIONS (NCOFLO-1 INNER CHANNELS ARE
C              RADIALLY CONNECTED, CHANNEL NCOFLO IS SEPERATE)
C  IFLOPT      INDICATOR FOR COOLANT CHANNEL TREATMENT (=1 DIMENSIONS
C              ARE READ IN, =0 NO DATA ARE READ IN )
C  ----------------------------------------------------------------------
C
C  SECOND CARD 2(E12.5)
C  ----------------------------------------------------------------------
C
C  TIME       START TIME
```

```
C  TFIN       FINAL TIME
C  ----------------------------------------------------------------------
C
C  THIRD CARD E12.5
C  ----------------------------------------------------------------------
C
C  AOTEMP     IMPLICIT EXPLICIT OPTION FOR FINITE DIFFERENCE SCHEME
C             0. => FULLY EXPLICIT
C             .5 => CRANK NICHOLSON
C             1. => FULLY IMPLICIT
C
C    FISSION-GAS MODEL GLOBAL DATA
C    FOLLOWING DATA IS APPLICABLE THROUGHOUT PROBLEM
C
C INSERTED CARD N.1 -- - FORMAT(6E12.5)
C
C    DTGSMN              - MININMUM FISSION-GAS TIME STEP ALLOWED
C    FINTER              - FRACTION OF RETAINED GAS THAT'S INTERGRANULAR
C    CVL                 - COVERAGE LIMIT FOR LARGE INTER GRANULAR BUBBLES
C    GPRESS              - FINAL PLENUM PRESSURE AT WHICH PIN WAS IRRADIATED
C    TSSEQ               - SS TEMP ABOVE WHICH INTER GAS ASSUMES EQUILIBRIUM
C    PTRAN               - HYDROSTATIC PRESSURE OF SOLID/LIQUID FUEL,
C  ----------------------------------------------------------------------
C
C  COMMENT CARD FOR INPUT
C  ----------------------------------------------------------------------
C
C  FOURTH CARD (I6)
C  ----------------------------------------------------------------------
C
C  NSUBS      NUMBER OF AXIAL SUBMODELS
C  ENTER GEOMETRY DATA FOR AXIAL SUBMODELS NSUBS TIMES
C
C  COMMENT CARD FOR INPUT
C  -----------------
C  4.1  CARD (6I6)
C  -----------------
C
C  ISB       SUBMODEL NUMBER
C  ISBTYP    SUBMODEL TYPE INDICATOR
C               0 - NON-PIN REGION
C               1 - FISSILE REGION
C               2 - FERTILE (BLANKET) REGION
C               3 - FISSION-GAS PLENUM REGION
C               4 - STRUCTURE REGION
C  ILAFM      MECHANICS OPTION INDICATOR
C               0 - INPUT DIMENSIONS USED IN CALCULATION ALL TIME
C               1 - SIMPLE VOLUME AVERAGE THERMAL EXPANSION IN
C                   FUEL, CLADDING, AND STRUCTURE ZONES (BY ZONE)
C               2 - IF NO LIQUID - SAME AS 1
C                   WITH LIQUID  - LIQUID EXPANDS TO EQUILIBRIUM SIZE
C                                  SOLID MOVED OUT ACCORDINGLY
C  IGS       FISSION GAS OPTION 0=>NO .. 1=>YES
C               0 - NO FG CALCULATION PERFORMED
C               1 - FG CALCULATION FOR SOLID ONLY
C               2 - SOLID PLUS EQUILIBRIUM SWELLING FOR LIQUID
```

```
C               3 - SOLID PLUS CALCULATION OF HYDROSTATIC P IN LIQUID
C  NZN      NUMBER OF RADIAL ZONES IN THIS SUBMODEL
C  NZ       NUMBER OF AXIAL NODES  FOR THIS SUBMODEL
C  NZG      NUMBER OF AXIAL LOCATIONS FOR INPUTTING RADIAL DATA
C  ------------------
C  4.2  CARD 2(E12.5)
C  ------------------
C
C  ZMIN     LOWER AXIAL BOUNDARY FOR SUBMODEL
C  ZMAX     UPPER AXIAL BOUNDARY FOR SUBMODEL
C  ------------------
C  4.3  CARD NZN(I6)
C  ------------------
C
C  IZNTP1(I,J) I=1,NZN..J=1,NSUBS     HEAT TRANS FLAG FOR ZONE
C              1=>CONDUCTION
C              2=>CONVECTION                 => + UPWARD FLOW
C              3=>CONVECTION + RADIATION     => - DOWNWARD FLOW
C              4=>MOLTEN CENTER CONVECTION OUTER RING CONDUCTION
C  ------------------
C  4.4  CARD NZN(I6)
C  ------------------
C
C  IZNTP2(I,J) I=1,NZN..J=1,NSUBS     MECHANICS FLAG FOR ZONE
C              0=>NO DIMENSIONAL CHANGE CALCULATED (COOLANT)
C              1=>FUEL REGION
C              2=>CLADDING REGION
C              3=>STRUCTURE REGION
C  ------------------
C  4.5  CARD NZN(I6)
C  ------------------
C
C  NRG(I)      I=1,NZN              NUMBER OF RADIAL REGIONS IN ITH ZONE
C  ------------------
C  4.6  CARD NZN(I6)
C  ------------------
C
C  NTN(I)      I=1,NZN              NUMBER OF THERMAL NODES IN ITH ZONE
C  ------------------
C  4.7  CARD NRTT(I6)  NRTT=NRG(1)+NRG(2)+.....NRG(NZN)
C  ------------------
C
C  NSN(J)      J=1,NRTT             NUMBER OF STRESS NODES IN JTH REGION
C                                   (EXTRA REGIONS WILL BE CREATED IF
C                                    .GT.1 ; HOWEVER NO INPUT FOR
C                                    THESE NEW REGIONS IS REQUIRED)
C  ------------------
C  4.8  CARD NRTT(I6)
C  ------------------
C
C  IMTL(J)     J=1,NRTT               MATERIAL NUMBER IN THE J-TH REGION
C                                     1=>UO2
C                                     2=>MIXED OXIDE
C                                     3=>STAINLESS STEEL 316
C                                     4=>SODIUM
C                                     5=>SODIUM-POTASSIUM NAK
```

```
C                                       6=>HELIUM
C                                       7=>ALUMINUM
C                                       8=>ARGON
C                                       9=>NOT USED
C                                       10=>NOT USED
C                                       >10 RESERVED FOR EXTERNAL INPUT
C  ------------------
C  4.9  CARD NRTT(I6)
C  ------------------
C
C  IRCN(J)     J=1,NRTT                 RADIAL CONNECTION INFORMATION
C                                       0=> SOLID  CONDUCTION ACROSS BOUND
C              POSITIVE => GAP CONDUCTION MODEL
C                                       1=> GAP MODEL 1
C                                       2=> GAP MODEL 2
C              NEGATIVE => CONVECTIVE HEAT TRANSFER
C                                       -1=> FFTF CONVECTIVE HT COEF.
C                                       -2=> USER INPUTS CONVECTIVE HT COEF.
C  ------------------
C  4.10 CARD I10
C  ------------------
C
C  NCOFLO      NUMBER OF FLOW CHANNELS  0, 1, 2, ...
C  ------------------
C  4.11 CARD 5(E12.5)
C  ------------------
C
C  AFLOW(1,-)  FLOW AREA FOR UPWARD COOLANT FLOW IN THIS SUBMODEL
C  AFLOW(2,-)  FLOW AREA FOR DOWNWARD COOLANT FLOW IN THIS SUBMODEL
C  HDIAM(1,-)  HYDRAULIC DIAMETER  UPWARD     HDIAM=4*AFLOW/WETTED_PERIMETER
C  HDIAM(2,-)  HYDRAULIC DIAMETER  DOWNWARD   HDIAM=4*AFLOW/WETTED_PERIMETER
C  RGRD(N1)    INNER GRID RADIUS, GRID ASSUMED TO BE A RING INSIDE THE CHANNEL,
C              IF NO GRID IS PRESENT SET TO ZERO
C  RGRD(N2))   OUTER GRID RADIUS,
C              MASS OF GRID = PI*(RGRD(N2)^2-RGRD(N1)^2)
C  TBOUND      EXTERNAL BOUNDARY TEMPERATURE (K)
C              NOTE : IT IS OK TO HAVE ONLY ONE FLOW REGION OR EVEN NONE
C  ------------------
C  NZG SETS OF INPUT DATA FOR EACH SUBMODEL
C  REPEAT THE NEXT (INDENTED) CARDS NZG TIMES
C  ------------------
C      E12.5
C      ZLOC           AXIAL LOCATION FOR FOLLOWING INPUT DATA
C      ------------------
C      NRTT(E12.5)
C      RXI,RXO        INNER AND OUTER RADII FOR EACH REGION
C      SCORI,SCORO    CORRECTION FACTORS APPLIED TO ANNULAR GEOMETRY RADIA
C                     TO CORRECT SURFACE AREAS TO PIN BUNDLE STANDARDS
C      ------------------
C      NRTT(E12.5)
C      CRI,CRO    INNER AND OUTER CRACK CIRCUMFERENCE OF RADIAL CRACKS
C      ------------------
C      NRTT(E12.5)
C      CZI,CZO    INNER AND OUTER FRACTION OF SUBMODEL HEIGHT WHICH IS
C                 AXIALLY CRACKED
C      ------------------
```

```
C      NRTT(E12.5)
C      PORR        FRACTIONAL (TOTAL) POROSITY IN EACH REGION
C                  (ENTER PRESSURE IN ATMOSPHERES IF MATERIAL IS A GAS)
C ----------------------------------------------------------------------------
C      SKIP TO RADIAL POWER PROFILE INPUT IF IGS=0
C
C      BEGINING OF FISSION GAS INPUT
C ----------------------------------------------------------------------------
C
C      GASCON      TOTAL GAS CONCENTRATION AT THIS AXIAL LOCATION (ATOMS/
C      SMEAR       SMEAR DENSITY - USED TO GET CORRECT AVERAGE POROSITY
C      ------------------
C      NRTT(E12.5)
C      CGINTRA     RADIAL SHAPE OF INTRAGRANULAR GAS DISTRIBUTION
C      ------------------
C      NRTT(E12.5)
C      RINTRA      INITIAL INTRAGRANULAR BUBBLE RADIUS
C      ------------------
C      NRTT(E12.5)
C      RINTER      INITIAL INTERGRANULAR BUBBLE RADIUS
C      ------------------
C      NRTT(E12.5)
C      FATOMS      INITIAL FRACTION OF RESOLVED INTRAGRANULAR GAS
C      ------------------
C      NRTT(E12.5)
C      FGBO        FRACTION OF GRAIN-BOUNDARY POROSITY THAT'S INTERCONNECTED
C      ------------------
C      NRTT(E12.5)
C      DGRN        FUEL GRAIN DIAMETER
C      ------------------
C      NRTT(E12.5)
C      TSS         STEADY-STATE IRRADIATION TEMPTERATURE
C
C   END OF FISSION GAS INPUT
C----------------------------------------------------------------------
C
C   RADIAL POWER PROFILE INPUT
C----------------------------------------------------------------------
C
C  NZN(E12.5)
C  PFRAC(I,ISB)       POWER FRACTION  I=1,NZN...ISB=SUBMODEL NUMBER
C                     FRACTION OF THE ISB-TH SUBMODEL POWER IN THE I-TH ZONE
C                     (NORMALIZED TO 1. WITHIN EACH SUBMODEL)
C  ------------------
C  NZN(I6)
C  NSHP(I,ISB)        NUMBER OF INPUT TERMS DETERMINING RADIAL POWER SHAPE
C                     I=1,NZN...ISB=SUBMODEL NUMBER
C                     0=> FLAT POWER PROFILE IN I-TH ZONE
C                     >0  => TABULAR INPUT DATA
C                     <0  => POLYNOMIAL INPUT DATA
C
C     NZN SETS OF DATA TO INPUT FOR THE ISB-TH SUBMODEL
C----------------------------------------------------------------------
C
C  NSHP(I6)
C  SHP(I)             SHAPE DATA I=1,NSHP (OMIT IT NSHP(I)-TH RADIAL ZONE
```

```
C
C  ENTER INITIAL TEMPERATURE DISTRIBUTION ACCORDING TO ZONE IF ITMPIN=3
C  ------------------
C
C  NZN(E12.5)
C  TMPI(I)            TEMPERATURE OF I=TH ZONE I=1,NZN
C  ------------------------------------------------------------------------
C
C                     END OF AXIAL SUBMODEL DATA INPUT
C
C  ------------------------------------------------------------------------
C
C  AXIAL POWER INPUT          POWER(J)=PBAR(J)*CPBAR**C.F.*MW(TYME)
C                             POWER MUST BE DEFINED OVER THE ENTIRE AXIAL DOMAIN
C
C  ------------------------------------------------------------------------
C
C  COMMENT CARD FOR INPUT
C  -----------------
C  2(I6),2E12.5
C  NPBAR             NUMBER OF DATA POINTS FOR AXIAL DATA INPUT
C  IDUM              DUMMY VARIABLE (NOT USED)
C  CPBAR             CONSTANT TO MULTIPLY POWER VALUES BY
C  CZ                CONSTANT TO MULTIPLY AXIAL POSITION OF POWER INPUT BY
C  -----------------
C  NPBAR(E12.5)
C  PBARX(I)          AXIAL POWER AT I-TH AXIAL LOCATION
C  -----------------
C  NPBAR(E12.5)
C  ZX(I)             AXIAL LOCATION  FOR I-TH INPUT VALUE
C  ------------------------------------------------------------------------
C
C  INPUT DATA FOR TIME DEPENDENT BOUNDARY CONDITIONS
C  ------------------------------------------------------------------------
C  INPUT COMMENT CARD
C  -----------------
C  E12.5,I6
C  FLOW1             ABSOLUTE MASS FLOW RATE ( KG/SEC )
C  NFLOW             NUMBER OF RELATIVE FLOW RATES TO INPUT
C  -----------------
C  11(E12.5)
C  RELFLW(I)         RELATIVE FLOW RATE I=1,NFLOW
C  -----------------
C  11(E12.5)
C  TIMFLW(I)         TIMES FOR RELATIVE FLOW RATES  I=1,NFLOW
C------------------
C  PR1               ABSOLUTE PRESSURE (ATM)
C  NPRINL            NUMBER OF INLET PRESSURE POINTS TO INPUT
C  11(E12.5)
C  PRINLT(I)         INLET PRESSURE I=1,NPRINL
C  11(E12.5)
C  TPRINL(I)         TIMES FOR INLET PRESSURE INPUT  I=1,NPRINL
C  -----------------
C  PR1               ABSOLUTE PRESSURE (ATM)
C  NPROUT            NUMBER OF OUTLET PRESSURE POINTS TO INPUT
C  11(E12.5)
```

```
C  PROUTL(I)        OUTLET PRESSURE I=1,NPROUT
C  11(E12.5)
C  TPROUT(I)        TIMES FOR OUTLET PRESSURE INPUT  I=1,NPROUT
C  ----------------
C  PR1              ABSOLUTE PRESSURE DROP (ATM)
C  NPRES            NUMBER OF PRESSURE DROP POINTS TO INPUT, IF GREATER
C                   THAN ZERO THE PRESSURE DROP OPTION IS CHOSEN
C  11(E12.5)
C  PRDRP(I)         PRESSURE DROP ACROSS BUNDLE I=1,NPRES
C  11(E12.5)
C  TPRDRP(I)        TIMES FOR PRESSURE DROP INPUT  I=1,NPRES
C  E12.5,I6
C  TCIN1            CONSTANT MULTIPLIER TO INCREASE COOLANT INLET TEMPERATURES
C  NTCIN            NUMBER OF VALUES TO INPUT FOR COOLANT TEMPERATURES
C  11(E12.5)
C  RELTCI(I)        TEMPERATURE OF COOLANT INLET AT THE I-TH TIME INTERVAL
C  TIMTCI(I)        TIME VALUES FOR INLET COOLANT TEMPERATURES I=1,NTCIN
C  ----------------------------------------------------------------------------
C
C    TIME DEPENDENT POWER DATA
C
C  ----------------------------------------------------------------------------
C
C    FORMAT FOR POWER INPUT IS DEPENDENT ON IPOWER OPTION CHOSEN (1. CARD)
C    -- CARD  1 ALWAYS NEEDED
C    -- CARDS 2 NEEDED FOR IPOWER =1,2,3,4 ONLY
C
C    POWER INPUT OPTIONS ARE DEFINED AS
C       IPOWER = 0      CONSTANT POWER FOR ALL TIME
C                       POWER = CFAC
C       IPOWER = 1      TWO CONSTANT POWER SECTIONS
C                       POWER = CFAC*POWR(1)                       T<TPOW
C                       POWER = CFAC*POWR(2)                       T>TPOW
C       IPOWER = 2      CONSTANT FOLLOWED BY RAMP
C                       POWER = CFAC*POWR(1)                       T<TPOW
C                       POWER = CFAC*(POWR(1)+T*POWR(2))           T>TPOW
C       IPOWER = 3      CONSTANT FOLLOWED BY EXPONENTIAL
C                       POWER = CFAC*POWR(1)                       T<TPOW
C                       POWER = CFAC*POWR(1)*EXP((T-TPOW)/POWR(2)) T>TPOW
C       IPOWER = 4      CONSTANT FOLLOWED BY TWO EXPONENTIALS
C                       POWER = CFAC*POWR(1)                       T<TPW1
C                       POWER = CFAC*POWR(1)*EXP((T-TPW1)/POWR(2)) T<TPW2
C                       POWER = CFAC*PWR2*EXP((T-TPW2)/POWR(3))    T>TPW2
C                              where PWR2=POWR(1)*EXP(TPW2-TPW1)/POWR(2))
C       IPOWER = 5      POWER = CFAC*(VALUE INTERPOLATED FROM POWER
C                                    VS TIME DATA READ BELOW)
C       IPOWER = 6      POWER = CFAC*(VALUE INTERPOLATED FROM POWER
C                                    VS TIME DATA READ FROM TAPE9)
C       IPOWER = 7      POWER = CFAC*(VALUE AS OBTAINED FROM INTERPOLATED
C                                    ENERGY VS TIME DATA READ FROM TAPE9)
C  ----------------------------------------------------------------------------
C
C ---CARD  N.1-- - FORMAT(2I6,E12.5)                   -- ALWAYS NEEDED --
C
C    IPOWER              - POWER INPUT OPTION (SEE DESCRIPTION ABOVE)
C    NPOW                - # OF DATA PAIRS TO BE READ FOR IPOWER = 4,5,6
```

```
C                            (LEAVE BLANK FOR IPOWER = 1,2,3)
C    CFAC              - CONSTANT MULTIPLIER FOR ALL POWER DATA
C                            USED TO CONVERT ALL POWER DATA TO J/KG
C                            -----COUPLING FACTOR-----
C ---CARD  N.2-- - FORMAT(3E12.5)                   -- IPOWER = 1,2,3 --
C
C    POWR(1)           - CONSTANT POWER UNTIL TIME TPOW
C    TPOW              - TIME AT WHICH CONSTANT POWER POWR(1) ENDS
C    POWR(2)           - POWER CHARACTERIZATION AFTER TIME TPOW
C                            IPOWER = 1  => CONSTANT POWER
C                            IPOWER = 2  => SLOPE OF POWER RAMP
C                            IPOWER = 3  => EXPONENTIAL TIME CONSTANT
C ---CARDS N.2-- - FORMAT(6E12.5)                   -- IPOWER =5, ONLY --
C
C    POWR(I),TPOW(I)   - NPOW PAIRS OF POWER VS TIME DATA (3 PAIRS/CARD)
C
C
C  ---------------------------------------------------------------------
C  TIME ITERATION AND OUTPUT CONTROL
C  ---------------------------------------------------------------------
C  I6
C  NDT              NUMBER OF INTERVALS FOR TIME INPUT CONTROL
C                   REPEAT NEXT CARD NDT TIMES
C  2(E12.5),I6
C  TYME(I)          END TIME FOR THIS CONTROL INTERVAL
C  DTYME(I)         TIME STEP USED FOR HEAT TRANSFER IN THIS CONTROL INTERVAL
C  NTYME(I)         ITERATION FOR PRINTING OUTPUT (10=> EVERY 10-TH TIME STEP)
C  ---------------------------------------------------------------------
C
C  MATERIAL PROPERTY INPUT
C
C  MATERIAL 1-10 ARE RESERVED FOR INTERNAL MATERIALS
C  MATERIALS 11-99 ARE RESERVED FOR EXTERNAL INPUT
C  EXTERNAL MATERIAL INPUT CAN ONLY USED CONSTANT PROPERTIES IN THIS VERSION
C  ---------------------------------------------------------------------
C
C       1  = UO2
C       2  = (UO2+PUO2) MIXED OXIDE
C       3  = CLAD 316 SS 20% CW
C       4  = SODIUM
C       5  = NAK
C       6  = HELIUM ( 5 PSIA)
C       7  = ALUMINUM 6061-T6
C       8  = NOT USED
C       9  = NOT USED
C       10 = NOT USED
C  ---------------------------------------------------------------------
C  COMMENT CARD FOR MATERIAL DATA INPUT
C  I6
C  NPROPS       = NUMBER OF MATERIALS FOR WHICH EXTERNAL INPUT IS REQUIRE
C                 (EXTERNAL INPUT REQUIRED FOR MATERIALS 1 AND 2 - IF USE
C                 PLUS ANY USER SUPPLIED MATERIALS)
C  I6
C  IM           = MATERIAL NUMBER (EQUALS 1 - IF USED)
C  2E12.5
C  XBUM1        = BURNUP FOR MATERIAL 1
```

```
C  XU5M1        = U-235 ENRICHMENT FRACTION
C  I6
C  IM           = MATERIAL NUMBER FOR SECOND MATERIAL (EQUALS 2 - IF USED)
C  3E12.5
C  XBUM2        = BURNUP OF MIXED OXIDE
C  XU5M2        = U-235 ENRICHMENT IN MIXED OXIDE
C  XPUM2        = PU FRACTION
C  ------------
C  USER SUPPLIED MATERIALS  REPEAT NEXT 3 CARDS
C  FOR EACH USER SUPPLIED MATERIAL
C  ------------
C  I6
C  IM           = MATERIAL NUMBER FOR USER SUPPLIED MATERIAL
C  4E12.5
C  TMLT1        = SOLIDUS TEMPERATURE
C  TMLT2        = LIQUIDUS TEMPERATURE
C  HFUSE        = HEAT OF FUSION
C  EMMIS        = EMISSIVITIES
C  5E12.5
C  ACCOM(I)     = ACCOMODATION COEFFICIENT (I=1,5) USE ONLY FOR GAP MATERIAL
C  6E12.5
C  XPVAL(I)     = PROPERTY VALUES (CONSTANT VALUES ONLY)
C                 1 - SOLID THERMAL CONDUCTIVITY
C                 2 - LIQUID THERMAL CONDUCTIVITY
C                 3 - SOLID SPECIFIC HEAT(HEAT CAPACITY)
C                 4 - LIQUID SPECIFIC HEAT
C                 5 - SOLID DENSITY
C                 6 - LIQUID DENSITY
C  ------------
C  COMMENT CARD FOR GAP INPUT DATA
C  ------------
C  I6
C  NGAPS        = NUMBER OF GAP MODELS FOR INPUTING DATA
C  7I6
C  IGAP         = GAP MODEL NUMBER
C  IGCON        = GAS CONDUCTIVITY FLAG
C                 0 - READ IN MOLE FRACTIONS  FOR FMOLE VARIABLE BELOW
C                     GAS CONDUCTIVITIES WILL BE CALCULATED INTERNALLY
C                 >=1 GAS CONDUCTIVITIES TO BE READ IN AS A POLYNOMIAL
C                     IN TEMPERATURE WITH IGCON = NUMBER OF TERMS
C  IGRAD        = RADIATION HEAT TRANSFER TO BE CALCULATED THROUGH THE GAP
C                 0 => YES .... OTHER => NO
C  IGPRS        = SOLID/SOLID INTERFACE PRESSURE EFFECT ON GAP CONDUCTANCE
C                 0 => YES .... OTHER => NO
C  IPGAS        = GAP GAS PRESSURE FLAG
C                 0 - GAS PRESSURE IS CALCULATED INTERNALLY AND USED IN JUMP
C                     DISTANCE CALCULATION
C                 1 - GAS PRESSURE IS BASED ON GAP GAS PRESSURE INPUT ON NEXT
C                     CARD
C  MATI         = MATERIAL NUMBER ON LEFT SIDE OF GAP
C  MATO         = MATERIAL NUMBER ON RIGHT SIDE OF GAP
C  6E12.5/E12.5
C  RUFI         = LEFT SURFACE ROUGHNESS
C  RUFO         = RIGHT SURFACE ROUGHNESS
C  GASPRS       = INITIAL GAP GAS TEMPERATURE (NOT USED FOR IPGAS=0)
C  HGMAX        = MAXIMUM SOLID/SOLID COEFFICIENT ALLOWED
```

```
C  HMLT1         = GAP CONDUCTANCE FOR INNER SURFACE MOLTEN
C  HMLT2         = GAP CONDUCTANCE FOR OUTER SURFACE MOLTEN
C  HMLT3         = GAP CONDUCTANCE FOR BOTH SURFACES MOLTEN
C  5E12.5
C  FMOLE(I)      = MOLE FRACTION FOR THE FOLLOWING GASES (IGCON = 0)
C                  1 - HELIUM
C                  2 - XENON
C                  3 - KRYPTON
C                  4 - NITROGEN
C                  5 - ARGON
C                  IF IGCON >= 1 FMOLE(1-IGCON)
C  -----------
C  COMMENT CARD FOR CONVECTIVE HEAT TRANSFER
C  -----------
C  6(I6)
C  NHCOF(N)      = NUMBER OF HEAT TRANSFER CORRELATION IN CHANNEL N
C                = 1: FFTF
C                = 2: DITTUS-BOELTER
C                = 3: LYON
C                > 10: GENERAL FORM GIVEN BY HCOF
C  IF NHCOF>10  SPECIFY COEFFICIENTS IN GENERAL NUSSELT NUMBER RELATION
C  E12.5
C  HCO           = COEFFICIENTS IN GENERAL NUSSELT NUMBER REALTION
C  ----------------------------------------------------------------------------
C
C    CLADDING MELTOFF DATA
C    NOTE THAT THIS DATA IS ONLY NEEDED IF THE UPDATE SET CMLT IS DEFINED
C  ----------------------------------------------------------------------------
C
C    (2I6,2E12.5)
C    NCSUB               - SUBMODEL # IN WHICH REMOVAL OCCURS
C    IZNC                - ZONE # CORRESPONDING TO CLADDING
C    TIMELT              - TIME AT WHICH CLADDING REMOVAL OCCURS
C    CCF                 - COUPLING FACTOR MULTIPLIER SUCH THAT
C                          CFAC(NEW)=CFAC(OLD)*CCF
C  ----------------------------------------------------------------------------
C
C    THIS DATA IS NEEDED ONLY IF THE UPDATE SET ELECT IS DEFINED
C  ----------------------------------------------------------------------------
C
C   (2I6,E12.5)
C   ISIN           = SUBMODEL NUMBER TO BE USED FOR INPUT FLOW OUTPUT
C   ISEX           = SUBMODEL NUMBER TO BE USED FOR OUTLET FLOW OUTPUT
C   TELEC          = END TIME FOR ELECTRICAL HEATING INPUT
C                    (UP TO THIS TIME, SELECT THE REACTOR POWER AND
C                    THE COUPLING FACTOR TO GIVE THE CORRECT
C                    ELECTRICAL HEATING  J/KG/SEC)
C
C  ----------------------------------------------------------------------------
C  ----------------------------------------------------------------------------
C  END OF SANDPIN INPUT DESCRIPTION
C  ----------------------------------------------------------------------------
C  ----------------------------------------------------------------------------
```

As an example, the SANDPIN input for the TREAT-R5 test calculations is reproduced hereafter.

```
TREAT-R5 POST TEST CALCULATION, 7-PIN BUNDLE, 20% ENR. INNER PIN, 14% OUTER PINS
    2     3      0      0      3     1
        0.0        13.0                                                  TIMO,TFIN
        1.0                                                              AOTEMP
        0.1         .25          .30          .28E7         1700.
START OF GEOMETRY INPUT
    4                                                                    # OF AXIAL SUBMODELS
FIRST AXIAL SUB-MODEL (SS LOWER REFLECTOR)
    1     4     1     0     10     4     1                               10 RADIAL ZONES
        0.0       .1651                                                  AXIAL EXTENSIONS
    1     1     3     1     1     1     3     1     3     1              HEAT TRANSFER FLAG
    3     2     0     2     3     2     0     0     0     0              MECHANICS FLAG
    1     1     1     1     1     1     1     1     1     1              # OF RADIAL REGIONS
    5     3     1     3     5     3     1     5     1     4              # THERMAL NODES
    1     1     1     1     1     1     1     1     1     1              # STRESS NODES
    3     3     4     3     3     3     4     3     6    14              4-SODIUM, 6-HELIUM, 14-MOLYBDAN
    1    -1    -1     1     1    -1    -1    -1    -1    -2              RADIAL CONNECTION FLAG
  7.498E-5    7.730E-5    2.17E-4          AFLOW
  4.515E-3    2.367E-3    5.61E-3          HDIAM
        1.0         1.0         1.0        HWPERIMETER
        0.0   9.5740E-3         0.0        INNER GRID RADIUS
        0.0   9.6700E-3         0.0        OUTER GRID RADIUS
      300.0                                TBOUND
      1.200
        0.0      .00247      .00254     .002921     .002921     .005692     .005692     .006152     .006222     .008679  RADIA
    .008749     .009142     .009142      .01040      .01040      .01091      .01091     0.01372     0.01372     0.01524  RADIA
        1.0         1.0         1.0         1.0         1.0      1.3450      1.3450      1.0820      1.0400      0.9618  CORF
     0.9811       1.080       1.080       1.050       1.050      1.0460      1.0460         1.0         1.0         1.0  CORRF
        0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0
        0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0
        0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0
        0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0  CRACKS
        .00         0.0         5.0         0.0         0.0         0.0         5.0         0.0         1.0         0.0  POROS.
       1.00         .00         0.0         0.0        1.00         0.0         0.0         0.0         0.0         0.0  PFRAC
    0     0     0     0     0     0     0     0     0     0                NSHAPE
       594.        594.        594.        594.        594.        594.        594.        594.        300.        300.  TINIT
SECOND AXIAL SUB-MODEL (NUCLEAR HEATED FUEL PIN SECTION)
    2     1     1     0     10    22     1
     0.1651      1.0795
    1     1     3     1     1     1     3     1     3     1
    1     2     0     2     1     2     0     0     0     0              MECHANICS FLAG
    1     1     1     1     1     1     1     1     1     1
    5     3     1     3     5     3     1     5     1     4
    1     1     1     1     1     1     1     1     1     1
    1     3     4     3     1     3     4     3     6    14              4-SODIUM, 6-HELIUM, 14-MOLYBDAN
    1    -1    -1     1     1    -1    -1    -1    -1    -2              (CONNECT)
  7.498E-5    7.730E-5    2.17E-4          AFLOW
  4.515E-3    2.367E-3    5.61E-3          HDIAM
        1.0         1.0         1.0        HWPERIMETER
        0.0   9.5740E-3         0.0        INNER GRID RADIUS
        0.0   9.6700E-3         0.0        OUTER GRID RADIUS
      300.0                                TBOUND
      1.200
        0.0      .00247      .00254     .002921     .002921     .005692     .005692     .006152     .006222     .008679  RADIA
```

— 22 —

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 .008749   .009142   .009142    .01040    .01040    .01091    .01091   0.01372   0.01372   0.01524 RADIA
     1.0       1.0       1.0       1.0       1.0    1.3450    1.3450    1.0820    1.0400    0.9618 CORF
  0.9811     1.080     1.080     1.050     1.050    1.0460    1.0460       1.0       1.0       1.0 CORRF
     0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
     0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
     0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
     0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0 CRACKS
     .10       0.0       5.0       0.0       0.1       0.0       5.0       0.0       1.0       0.0 POROS.
    5.34       .00       0.0       0.0      4.75       0.0       0.0       0.0       0.0       0.0 PFRAC
  -3    0    0    0   -3    0    0    0    0    0    NSHAPE
     1.0      0.00 1.96274E04                         RADIAL PROFILE FOR 20% ENRICHED CENTER PIN IN 7-PIN BUNDLE
     1.0  -0.22895  0.016790                          RADIAL PROFILE OUTER RING (PARABOLA)
    594.      594.      594.      594.      594.      594.      594.      594.      300.      300. TINIT
THIRD AXIAL SUB-MODEL (UPPER BLANKET + INCONEL)
   3    2    1    0   10    4    1
  1.0795    1.2446
   1    1    3    1    1    1    3    1    3    1
   3    2    0    2    3    2    0    0    0    0   MECHANICS FLAG
   1    1    1    1    1    1    1    1    1    1
   5    3    1    3    5    3    1    5    1    4
   1    1    1    1    1    1    1    1    1    1
   3    3    4    3    3    3    4    3    6   14   4-SODIUM, 6-HELIUM, 14-MOLYBDAN
   1   -1   -1    1    1   -1   -1   -1   -1   -2   (CONNECT)
7.498E-5  7.730E-5   2.17E-4   AFLOW
4.515E-3  2.367E-3   5.61E-3   HDIAM
     1.0       1.0       1.0   HWPERIMETER
     0.0 9.5740E-3       0.0   INNER GRID RADIUS
     0.0 9.6700E-3       0.0   OUTER GRID RADIUS
   300.0                       TBOUND
   1.200
     0.0    .00247    .00254   .002921   .002921   .005692   .005692   .006152   .006222   .008679 RADIA
 .008749   .009142   .009142    .01040    .01040    .01091    .01091   0.01372   0.01372   0.01524 RADIA
     1.0       1.0       1.0       1.0       1.0    1.3450    1.3450    1.0820    1.0400    0.9618 CORF
  0.9811     1.080     1.080     1.050     1.050    1.0460    1.0460       1.0       1.0       1.0 CORRF
     0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
     0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
     0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
     0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0 CRACKS
     0.0       0.0       5.0       0.0       0.0       0.0       5.0       0.0       1.0       0.0 POROS.
    5.34       .00       0.0       0.0      4.75       0.0       0.0       0.0       0.0       0.0 PFRAC
   0    0    0    0    0    0    0    0    0    0    NSHAPE
    594.      594.      594.      594.      594.      594.      594.      594.      300.      300. TINIT
FOURTH AXIAL SUB-MODEL (UPPER PLENUM - HELIUM , CALC. FROM 0.5 IN3 GAS VOLUME)
   4    3    1    0   10   12    1
  1.2446    2.4376
   1    1    3    1    1    1    3    1    3    1
   0    2    0    2    0    2    0    0    0    0   MECHANICS FLAG
   1    1    1    1    1    1    1    1    1    1
   5    3    1    3    5    3    1    5    1    4
   1    1    1    1    1    1    1    1    1    1
   6    3    4    3    6    3    4    3    6   14   4-SODIUM, 6-HELIUM, 14-MOLYBDAN
   1   -1   -1    1    1   -1   -1   -1   -1   -2   (CONNECT)
7.498E-5  7.730E-5   2.17E-4   AFLOW
4.515E-3  2.367E-3   5.61E-3   HDIAM
     1.0       1.0       1.0   HWPERIMETER
     0.0 9.5740E-3       0.0   INNER GRID RADIUS
```

```
   0.0     9.6700E-3       0.0        OUTER GRID RADIUS
 300.0                                TBOUND
   1.200
   0.0       .00247       .00254      .002921      .002921      .005692      .005692      .006152      .006222      .008679  RADIA
 .008749     .009142      .009142     .01040       .01040       .01091       .01091       0.01372      0.01372      0.01524  RADIA
   1.0         1.0          1.0         1.0          1.0        1.3450       1.3450       1.0820       1.0400       0.9618   CORF
 0.9811      1.080        1.080       1.050        1.050        1.0460       1.0460         1.0          1.0          1.0    CORRF
   0.0         0.0          0.0         0.0          0.0          0.0          0.0          0.0          0.0          0.0
   0.0         0.0          0.0         0.0          0.0          0.0          0.0          0.0          0.0          0.0
   0.0         0.0          0.0         0.0          0.0          0.0          0.0          0.0          0.0          0.0
   0.0         0.0          0.0         0.0          0.0          0.0          0.0          0.0          0.0          0.0    CRACKS
   2.0         0.0          5.0         0.0          2.0          0.0          5.0          0.0          1.0          0.0    POROS.
   5.34        .00          0.0         0.0          4.75         0.0          0.0          0.0          0.0          0.0    PFRAC
0      0    0      0    0      0    0      0    0      0       NSHAPE
   594.        594.         594.        594.         594.         594.         594.         594.         300.         300.   TINIT
AXIAL POWER INPUT
 24     0      1.0      1.0
   0.0         0.0         .7316       .7858        .8346        .87756       .91443       .94495       .9689        .98614
 .99652        1.00       .99652       .98614       .96890       .94495       .91443       .87756       .8346        .78585
 .73164      .73160         0.0          0.0
   0.0        .1652        .1720        .2220        .2720        .3220        .3720        .4220        .4720        .5220
 .5720        .6220        .6720        .7220        .7720        .8220       0.8720       0.9220       0.9720       1.0220
 1.0720      1.0792       1.0796       2.4376
TIME DEPENDENT INPUT ... FLOW RATE...INLET PRESSSURE...PRESSURE DROP...TEMP...POWER
 5.1373E-4    11                                                |||||||||| FLOW RATE IS M**3/SEC
   2.1         2.1          2.1         1.0          0.6         0.50         0.00         0.00         -1.0          0.0
   0.0
   0.0         1.0          7.95        10.0         11.0         13.7         14.5         17.8         18.0         19.35
  28.0
   1.0E0      10                                                |||||||||| INLET PRESSURE IN ATM
   8.369       8.097        4.66        3.266        1.565       1.2248       1.1568         0.68        0.408       0.2722
   0.0         7.95         8.5         9.0          10.0         10.8         12.0         14.0         18.0         26.0
   1.0E0      2                                                 |||||||||| RETURN FLOW CHANNEL PRESSURE DROP
 -15.1       -15.9
   0.0        33.0
   1.E0       9                                                 |||||||||| PRESSURE DROP IN ATM, CALC. VIA FLOW RATE, DPHYD.
 -1.0817     -1.0817      -0.700       -0.38       -0.2667     -0.24632       -0.200       -0.200       -0.200
   0.0         7.95         9.0         10.0         11.0         13.7         14.5         19.0         33.0
 600.00       2                                                 ||||||||||  INLET TEMPERATURES
   1.0        1.030
   0.0        15.0
7      0    5763.688                                            |||||||| COUPLING FACTOR FOR 20% UO2 OUTER RING 14%
9
   0.10       0.020     6
   3.50       0.050    10
   5.20       0.005   100
   5.70       0.010    10
   7.95       0.050    10
  13.75       0.020    20
  19.00        .001    25
  22.00        .010     5
  28.00        .001   100
3     12     26      33
MATERIAL PROPERTY INPUT      |||| MAT(11)=ARGON, MAT(12)=HELIUM
5
1
```

```
      0.0         .400
  11                                                               IIIIIIIII THERMO PROPERTIES FOR ARGON 0.35 ATM
      0.0          1.0         0.0         0.0
      0.0          0.0         0.0         0.0         0.0
   1.77E-2      1.77E-2        521.        521.        .624        .624
  12                                                               IIIIIIII THERMO PROPERTIES FOR HELIUM 0.35 ATM
      0.0          1.0         0.0         0.0
      0.0          0.0         0.0         0.0         0.0
   .14184       .14184         5238.       5238.       .624        .624
  13                                                               IIIIIIIII THERMO PROPERTIES FOR FUSED QUARTZ
    1708.        1709.         0.0         .01
      0.0          0.0         0.0         0.0
     1.88         2.59         1047.       1047.       2550.       2550.
  14                                                               IIIIIIIII THERMO PROPERTIES FOR MOLYBDAN
    2890.        2892.         1000.       .01
      0.0          0.0         0.0         0.0
    110.0        110.0         251.0       251.0       10220.      10220.
GAP INPUT DATA
   2
   1     2    0     1      1     1     3
   8.25E-6    8.25E-6       1.22E5      5.0E07      1.7E04      1.7E04      0.1E00
 1.033E02   1.677E-1                                                             GAP GAS CONDUCTIVITY POLYNOMIAL
   2     0    0     1      1     1     3
   8.25E-6    8.25E-6       1.22E5      1.7E04      1.7E04      1.7E04      0.1E00
      1.0          0.0         0.0         0.0         0.0
CONVECTION HEAT TRANSFER DATA
   1     1    2
   3     3        50.00       1.0101
   1     4          0.0          0.0
PLENUM DATA
   594.26         1.E01
```

II.2 CMOT related input

```
C--------------------------------------------------------------------------
C      II.2 CMOT REALTED INPUT BY NAMELIST OPTION                         --
C           INPUT ACCOMODATION IN MAIN
C
C  -----------------------------------------------------------------------
C &REST            (GENERAL INFORAMTION)
C
C   KREST          = 0, NO RESTART, INPUT DATA FOR SANDPIN ARE ALSO READ
C                  = 1, RESTART, NO SANDPIN BUT ALL NAMELIST INPUT IS READ
C   NRFR           = FILE FOR RESTART INPUT (21)
C   NRFW           = FILE TO OUTPUT RESTART DATA (FOR USE IN NEXT RESTART)
C   ISTPM          = MAXIMUM STEP NUMBER
C   ISTPI          = INCREMENT OF STEP NUMBER TO INITIATE RESTART OUTPUT
C   NPLT           = DUMMY
C
C &SAND            (CHANGE SOME SANDPIN INPUT IN CASE OF RESTART)
C
C   NDT            = NUMBER OF INTERVALS FOR TIME INPUT CONTROL
C   TYME(I)        = END TIME FOR CONTROL TIME INTERVAL I
C   DTYME(I)       = TIME STEP USED FOR HEAT TRANSFER IN THIS INTERVAL
C   NTYME(I)       = EVERY NTYME-TH TIME STEP OUTPUT ON UNIT 6 IS DESIRED
C   TFIN           = FINAL TIME TO STOP CALCULATIONS
C   TFINCL         = NO CLAD MOTION CALCULATIONS BEYOND T = TFINCL
C   NHCOF(N)       = COOLANT HEAT TRANSFER CORRELATION IN CHANNEL N
C
C &NAM0
C
C   JLI            = MESH REFINEMENT FOR CLAD MOTION CALCULATIONS ONLY FOR
C   JLU            = COARSE MESH J VALUES JLI ≤ J ≤
C   DZW(J)         = DESIRED AXIAL MESH HEIGHT OF FINE MESH IN CELL J
C   IMATM          = MATERIAL NUMBER OF CLADDING TO BE USED IN CM
C   NCC            = DUMMY
C
C &NAM1
C
C   RENC1          = CRITICAL REYNOLDSNUMBER FOR FILM/WAVE FLOW (1600)
C   FRICB          = FACTOR IN FF CORRELATION (0.316)
C   FRICE          = EXPONENT IN FF CORRELATION (-0.25)
C   RENCR          = CRITICAL REYNOLDSNUMBER FOR COOLANT FLOW (2300)
C   FRICB1         = FACTOR IN FF CORRELATION (0.46)
C   FRICE1         = EXPONENT IN FF CORRELATION (-0.2)
C                  : LATTER CORRELATION VALID FOR RE_cool > 1.E4
C   XNYFR          = REFERENCE VISCOSITY IN CLAD MOTION FF CORRELATION
C                    DUE TO GROLMES (5.0857E-5 M^2/S)
C   NFRICO         = SELECT FF CORRELATION FOR CM (SEE SUBR. FRICFA) :
C                    1 : WALLIS R.
C                    2 : NIKURADSE R.
C                    3 : MOLTEN DROP R.
C                    5 : GROLMES R.
C                    6 : HENSTOCK R.
C                    7 : FEIND R.
C                    9 : NO ROUGHNESS AT ALL
```

```
C   FRFMAX        = MAXIMUM FRICTION FACTOR (5.0)
C   PRX           = AMBIENT INLET PRESSURE (1.5 ATM)
C   PLENA         = INERTIAL LENGTH OF INLET SLUG
C   PLENZ         = INERTIAL LENGTH OF EXIT SLUG
C   DHIN          = DIAMETER OF INLET/EXIT PIPE SECTION
C   AINL          = CROSS SECTIONAL AREA OF INLET/EXIT PIPE
C   FRFIN         = COEFFICIENT IN INLET PIPE FF R. (FRFIN/RE)
C   FRFOU         = COEFFICIENT IN EXIT PIPE FF R. (FRFOU/RE)
C   FORIFI        = COEFFICIENT INLET PIPE FF (FORIFI/RE^0.25)
C   FORIFO        = COEFFICIENT EXIT PIPE FF (FORIFO/RE^0.25)
C   PBARO         = BAROMETRIC PRESSURE (ATM)
C   DPLOS         = ADDITIONAL CONSTANT INLET PRESSURE (ATM)
C   IPLEN         = CONDITIONALLY USED IN SUBROUTINE PLEN
C   ACMIN         = MINIMUM OF COOLANT CHANNEL CROSS SECTIONAL AREA
C   NPROPT        = OPTION TO USE PRESSURE OR FLOW RATE BOUNDARIES
C                   (HAS TO BE REVISED IN GDYN)
C   JORIFI        = CONDITIONALLY USED TO LOCATE IRREVERSIBLE PRESSURE
C                   LOSSES AT BUNDLE INLET (SEE GDYN, DP1)
C   IGEOM         = GEOMETRY INDICATOR FOR SELECTION OF APPROPRIATE
C                   FRICTION FACTOR RELATION (SEE FRICF)
C   MITER         = DUMMY
C   PRGRD         = DUMMY
C   VOIDB         = DUMMY
C   PMAS          = DUMMY
C
C &NAM2
C
C   DR(N)         = DISTANCE BETWEEN SUCCESSIVE CHANNELS N,N+1
C   ACONC(N)      = EXCHANGE AREA BETWEEN SUCCESSIVE CHANNELS N,N+1
C   DOHR          = HYDRAULIC DIAMETER OF CROSS FLOW CHANNELS
C   FRFR          = TO ENHANCE RADIAL FF IN CROSS FLOW CHANNELS
C   FORIF         = NOT USED CURRENTLY
C   SGRD          = GRID CONTRIBUTION TO SURFACE FRICTION
C   SLIPM         = MAXIMUM SLIP RATIO (30.)
C
C &NAM3
C
C   CDTMAX        = MAXIMUM TIME STEP
C   CDTMIN        = MINIMUM TIME STEP
C   CDTBL         = TIME STEP IF SOMEWHERE α =1 (SINGLE VAPOR)
C   RELX          = RELAXATION FACTOR IN ITERATIVE SOLUTION OF 5-POINT EQS.
C   A0            = COEFFICIENT IN DONOR CELL EXPRESSION
C   B0            = COEFFICIENT IN DONOR CELL EXPRESSION
C                   (USED MAINLY IN CLAD MOTION CALCULATIONS)
C   FZIP          = DUMMY
C
C &WETT
C
C   TETREF        = DUMMY
C   TETCF         = ANGLE MOLTEN CLADDING WAVE ON FUEL (RAD)
C   TETCC         = ANGLE MOLTEN CLADDING WAVE ON CLAD (RAD)
C   DROPD         = MOLTEN CLADDING DROP DIAMETER
C
C &ENTR
C
C   PENTR         = SELECT ENTRAINMENT MECHANISM FOR CM (SEE ENTR)
```

```
C                         0 : NO ENTRAINMENT
C                         1 : FILM FLOW, SURFACE WAVE ENTR.
C                         2 : WAVE/RIVULET ENTR.
C    WECR             = CRITICAL WEBER NUMBER FOR FILM ENTRAINMENT (13.0)
C    TAURES           = RESIDENCE TIME OF DROPS IN COOLANT CHANNEL, DEPOSITION
C    ADROP            = DROP CROSS SECTIONAL AREA
C    CENTR            = FACTOR IN ENTRAINMENT CRITERION (SEE SUBR. ENTR)
C    EFRAC            = FACTOR TO ENHANCE ENTRAINMENT RATE
C    DNU1-DNU3        = COEFFICIENTS OF GENERAL NUSSELT NUMBER CORRELATION
C                       FOR DROP HEAT TRANSFER (SEE SUBR. ECOOL)
C    ADPMIN           = MINIMUM TOTAL DROP VOLUME/UNIT LENGTH
C    FUSURF           = DUMMY
C    DRPFRC           = DUMMY
C    FENTRE           = DUMMY
C    FENTRB           = DUMMY
C
C &THEM
C
C    DTSUP            = INCREASE ABOVE SATURATION TEMPERATURE TO INITIATE
C                       COOLANT BOILING (5.0 K)
C    SHEAT            = INCREASE ABOVE CLAD LIQUIDUS TEMPERATURE TO INITIATE
C                       CLAD MOTION (0.0 K)
C    HDROP            = COEFFICIENT IN HEAT TRANSFER RELATION TO EXPRESS
C                       COOLING BY IMPINGING DROPS (SEE HCOEF)
C    GAMR             = COEFFICIENT TO ENHANCE RADIAL HEAT MIXING (SEE ECOOL)
C    VMAX             = CURRENTLY NOT USED
C    DHDP             = USED TO SUPPRESS PRESSURE WORK TERM IN ENTHALPY EQ.
C    Y1-Y5            = USED FOR CODE TESTING (0.0,15.0,1.2E5,17.,0.0)
C    PLENR            = AMPLITUDE OF SINUSLIKE VARYING INLET PRESSURE COMPONENT
C    CPC              = USED TO SMOOTH 2-PHASE-SINGLE PHASE TRANSITION (ECOOL)
C    CVC              = DUMMY
C    XNU1-XNU5        = DUMMY
C    RDROP            = DUMMY
C    PSINGL           = DUMMY
C    GBX              = DUMMY
C    XKG              = DUMMY
C    ZGAP             = DUMMY
C
C &PLOT
C
C    TPLOT            = TIME TO START CLAD MOTION PLOT OUTPUT ON UNIT 12
C    DTPL             = PLOT OUTPUT TIME INTERVAL
C    TCURV            = TIME TO START SELECTED CURVE OUTPUT ON UNIT 16
C    DTCURV           = CORRESPONDING TIME INTERVAL
C    TWRIT            = TIME TO START OUTPUT ON UNIT 6
C    DTWRIT           = CORRESPONDING TIME INTERVAL
C    JLPR             = LOWEST AXIAL NODE TO BE USED IN UNIT 6 OUTPUT
C    JUPR             = UPPEST AXIAL NODE TO BE USED IN UNIT 6 OUTPUT
C    NXX              = DUMMY
C
C &DEBG
C
C    IDBP             = CURRENTLY NOT USED
C    IDBT             = CURRENTLY NOT USED
C    IDUGR            = CURRENTLY NOT USED
C    IDB4             = CURRENTLY NOT USED
```

```
C   IDB5          = CURRENTLY NOT USED
C
C -----------------------------------------------------------------------
C -----------------------------------------------------------------------
C  END OF CMOT INPUT DESCRIPTION
C -----------------------------------------------------------------------
C -----------------------------------------------------------------------
```

The CMOT related input as used for the TREAT-R5 analysis is reproduced hereafter.

```
***TREAT-R5 RECALCULATION WITH SANDCMOT  11/85                          ***
&REST
KREST=0,NRFR=21,NRFW=22,NPLT=20,ISTPM=8888,ISTPI=100,                 &END
&SAND
TFIN=16.95,DTYME(7)=1.E-3,NTYME(7)=100,                                &END
&NAMO
JLI=8,JUI=32,DZW=8*1.0,24*0.02,12*1.03,IMATM=3,                        &END
&NAM1
RENC1=1600.,FRICB=0.316,FRICE=-0.25,RENCR=2300.,
FRICB1=0.046,FRICE1=-0.2,XNYFR=5.0857E-05,VOIDB=1.0E-3,
NFRICO=3,FRFMAX=5.,PLENA=5.5,PLENZ=4.5,
DHIN=3.81E-2,AINL=1.1395E-3,FRFIN=5.E6,FRFOU=5.1E6,
FORIFI=1.0E4,FORIFO=4.0E4,PRGRD=100.,DPLOS=0.00,PBARO=1.0,             &END
PRX=1.5,PMAS=8.E-1,IPLEN=1,ACMIN=1.E-8,                                &END
&NAM2
DR=5.3783E-3,1.0E5,1.E05, ACONC=1.376E-2,0.0,0.0,
FRFR=1.,DOHR=2.E-3,FORIF=1.0,SGRD=0.0,SLIPM=30.,                       &END
&NAM3
FZIP=.0,A0=.5,B0=.0,CDTMIN=5.00E-4,CDTMAX=2.E-2,RELX=1.0,
CDTBL=2.E-4,                                                           &END
&WETT
TETCF=1.574,TETCC=1.0466,DROPD=2.0E-3,                                 &END
&ENTR
PENTR=2.0,WECR=13.0,TAURES=0.7E-3,DRPFRC=0.2,
ADROP=1.169E-6,ADPMIN=1.0E-10,DNU1=0.,DNU2=0.5,DNU3=0.33,
FENTRB=0.271,FENTRE=0.217,FUSURF=1.,EFRAC=1.,CENTR=1.0,                &END
&THEM
ZGAP=1.0E0,VMAX=1.00,SHEAT=1.00,PLENR=5.E4,Y1=0.00,
Y2=15.,Y3=1.2E5,Y4=17.0000,HDROP=0.025E0,CPC=0.000,CVC=1.00,
XNU1=0.,XNU2=.023,XNU3=.8,XNU4=.33,XNU5=.0,DTSUP=5.0,
RDROP=1.2E-3,GAMR=1.0,DHDP=0.0,                                        &END
&PLOT
DTPL=1.E-2,TPLOT=70.0,NXX=0,JLPR=1,JUPR=45,DTWRIT=0.1101,
DTCURV=5.0E-2,TCURV=0.0,TWRIT=0.44873,                                 &END
&DEBG
IDBP=0,IDBT=0,IDUGR=2                                                  &END
***END OF BOILING AND CLAD MOTION INPUT                                ***
```

III. FLOW CHART AND SUBROUTINES

The following figure shows the flow chart of the SANDCMOT code.

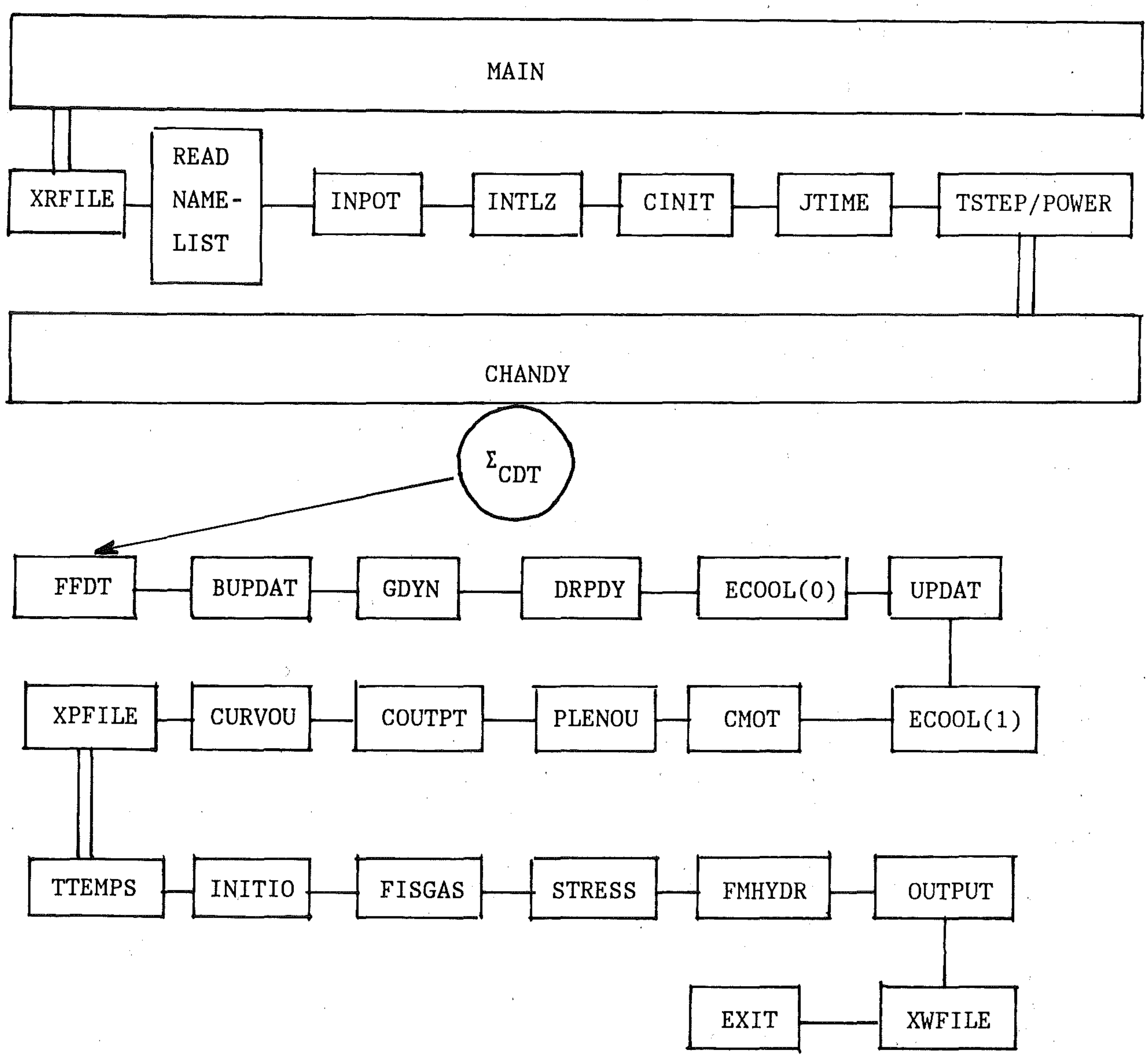

Fig. 4 : Flow chart of SANDCMOT

The various subroutines fulfill the following functions :

MAIN

reads the input, initializes several variables and organizes the program calls.

XRFILE

reads the COMMON-blocks from a restart file. It is only called when by the input quantity KREST it is indicated that a former calculation is to be continued.

INPOT

reads the SANDPIN input, defines the geometry and initializes most of the variables.

INTLZ

completes the initialization of variables, especially those needed for the fission gas calculations.

CINIT

initializes the variables needed for the clad motion calculations. It has an entry point INITIO that carries out the mesh refinement used for the clad motion calculations. Many indices are also redefined for the new mesh.

JTIME

calculates the CPU-time in 1/100 s that is left according to the maximum CPU-time specified in the job-JCL.

note : JTIME is an assembler program

TSTEP

calculates the thermodynamic time step DT from input data.

POWER

calculates the power to be deposited within the fuel pins.

CHANDY

organizes the various steps for the solution of the clad motion and coolant dynamics. Especially, it uses an iteration if the dynamics time step CDT is smaller than the heat transfer time step DT.

FFDT

calculates the clad motion and coolant dynamics time step CDT.

BUPDAT

calculates the new molten or solified clad distribution. BUPDAT calls the subroutine ENTR that determines the entrainment and drop deposition rates.

GDYN

solves the basic equations of the coolant flow including momentum and energy exchange with the molten cladding drop flow. It calls two other subroutines, FRICD AND DRPDY, that calculate the drop friction factors or solve preliminarily the momentum and energy equations of the drop flow. GDYN determines the pressure distribution within the coolant channels that is used in UPDAT to finally update all the other variables of the coolant and drop flow.

DRPDY

solves parts of the momentum and energy equation of the drop flow to be used as a good first estimate in GDYN. Final updating is done in UPDAT and ECOOL(1).

ECOOL(0)

solves the radial heat transfer equation in the cladding region of the fuel pins to derive the coolant energy source term. In a second step, the coolant enthalpy equation is solved including heat convection and diffusion (Patankar formalism). Also, temperatures are derived and a first estimate of the new void fractions.

UPDAT

updates coolant and macroscopic drop densities, mass flow rates and velocities. ECOOL(1) is called to derive the final coolant enthalpies and temperatures as well as void fractions and qualities. Also, it is checked if the boiling criterion of the coolant has been reached and two-phase flow is initialized, eventually. Vapor and liquid velocities and corresponding mass flow rates are calculated.

ECOOL(1)

solves the coolant enthalpy equation using advanced time level quantities wherever this is possible (like new velocities). Final coolant and drop temperatures are derived. Also void fractions and qualities are updated.

CMOT

solves the momentum and energy equations of the molten cladding flow. This is done for both sides of a coolant channel.

PLENOU

calculates the exit plenum temperature TOUT.

COUTPT

organizes the output of clad motion and coolant dynamics results on unit 6.

CURVOU

write selected data on unit 16 that are used mainly to plot coolant flow results.

XPFILE

writes data on unit 12 that are used to create clad motion graphics.

TTEMPS

calculates the final temperature distribution within all the fuel pins. The coolant energy source term serves as a boundary condition to the pins. This routine is essentially taken from SANDPIN.

INITIO

is called only one time at the beginning of clad motion to carry out the mesh refinement and to reinitialize corresponding variables.

FISGAS

does the fission gas calculations. This routine is taken from SANDPIN.

STRESS

calculates the mechanical behavior of the fuel pins. This routine is taken from SANDPIN.

FMHYDRO

calculates the static pressure within a fuel melt.

OUTPOT

organizes the output of the fuel pin and fission gas models on unit 6. This routine essentially is as in SANDPIN.

XWFILE

writes all COMMON-block variables on the external unit NRFW. From there, they are read in at the beginning of a restart run.

EXIT

routine that terminates the calculation.

IV. VARIABLES

In total there are 34 named COMMON blocks. From the great number of COMMON-variables only those used most frequently are summarized below. The indices are such that an index j usually denotes the axial location either with respect to the coarse or fine mesh. Radially, there are successive annular rings that build up a pin or a cluster of pins. These rings are subdivided into zones labeled by an index nz. Zones may be further subdivided into regions labeled by an index nr and these in turn may contain a certain number of basic cells characterized by an index i. Zones may be, for example, fuel, cladding or coolant zones, regions eventually the restructered, columnar or unrestructered parts of some fuel pellet. Each region, finally, may contain several cells (nodes) where the temperature points are defined. Also, an index n specifies a certain coolant channel. When the inner or outer boundary of an annular coolant channel is meant an index ni is used. The outer boundary then corresponds to ni = 2n, the inner one to ni = 2n-1. Furthermore, an index sm indicates a certain axial submodel, that may contain several axial coarse mesh nodes with identical axial node height DH.

COMMON	variable	Dim.	Meaning
CNSTNT	PI	-	$\pi = 3.1415926$
	PI4	-	$4\pi = 12.5663706$
	PI43	-	$4/3\pi = 4.188790205$
	BOLTZ	W/m^2K^4	Stefan-Boltzmann constant (5.67E-8)
	RGAS	J/kg-moleK	gas constant (8.314E3)
	RR	J/g-moleK	gas constant (8.314)
	BK	J/molec.K	Boltzmann constant (1.38E-23)
	VDWB	m^3/molec.	Van-der Waals constant (8.50E-29)
	GB	m/s^2	gravitational acceleration (9.80665)
	PCONV	Pa/atm	conversion factor (1.0133E5)
OUTCOM	TITLE(20)	-	general purpose field (see SANDPIN input)

INTG00	IREAD	-	unit to read SANDPIN input (5)
	IWRITE	-	unit to write output (6)
	IPLOT	-	temperature plot output (11)
	JMAX	-	axial j-index maximum
	ISTEP	-	number of global calculation steps
	IPRINT	-	variable that triggers print-out
	ITMPOP	-	input option (see 1st. card)
	ITMPIN	-	input option (see 1st. card)
	IGRIDO	-	input option (see 1st. card)
	IFLOPT	-	input option(see 1st. card)
	NCOFLO	-	number of coolant channels
	ISIN	-	submodel ISIN is used for inlet flow output
	ISEX	-	submodel ISEX is used for outlet flow output
	IPOWER	-	power input option (see power input)
INTG01	ISBTYP(sm)	-	type indicator of a certain submodel sm
	ILAFM(sm)	-	mechanics option indicator of submodel sm
	IGAS(sm)	-	fission gas option of submodel sm
	NZONE(sm)	-	number of radial zones in submodel sm
	NRT(sm)	-	total number of radial regions in submodel sm
	ISUB(j)	-	submodel type of axial mesh node j
	IFLOW(n,j)	-	radial i-index corresponding to coolant cell (n,j)
	NR(nz,sm)	-	number of regions in zone nz of submodel sm
	IZNTP1(nz,sm)	-	zone type heat transfer flag
	IZNTP2(nz,sm)	-	zone type mechanics flag
	IRCON(nr,sm)	-	gives the physical connection to next region
	IMAT(nr,sm)	-	material number of region nr in submodel sm
	NNODES(nr,j)	-	number of nodes in region nr of axial node j
	NSLOC(nr,j)	-	stores the radial node index i of the leftmost node in region nr
	NZCH(n,j)	-	zone number of coolant cell (n,j)
	NIRC(n,j)	-	region number of coolant cell (n,j)
	IMATCH(n)	-	material number of coolant in channel n
REAL00	TIME	s	current time of DT integration
	TFIN	s	final time to stop any calculation

	DT	s	time step (heat transfer, mechanics calc.)
	DTOLD	s	DT of previous time step
	RELPOW	MW	relative reactor power
	ENERGY	MJ	integral reactor energy
	TNAIN	K	coolant (sodium) inlet temperature at bottom of computational array
	TNAINP	K	old time level TNAIN
	TOUT	K	coolant exit temperature at top of of computational array
	TOUTP	K	old time level TOUT
	AOTEMP	-	implicit/explicit integration scheme
	TELEC	s	pin clad is heated electrically up to TELEC
	PELEC	W/kg	electrical power density deposited in pin clad
	PLENM	kg	upper gas plenum mass (used in STAR analysis)
REAL06	PFRAC(nz,sm)	-	power fraction in zone nz of submodel sm
REAL01	DH(j)	m	axial width of node j (time dependent)
	H(j)	m	axial height of node center
	PGAS(j)	atm	gap gas pressure (see SANDPIN input)
	PBAR(j)	-	axial power distribution (see SANDPIN input)
	PB(j)	atm	gap pressure
	PSTRN(j)	atm	gap pressure
REAL02	HO(j)	m	original axial position of node center, input
	DHO(j)	m	input axial node height (see SANDPIN input)
REAL03	RO(i,j)	m	input radia of annular geometry
	DRCRKO(i,j)	m	input radial crack width
	DZCRKO(i,j)	m	input axial crack width
REAL04	R(i,j)	m	transient radia of annular geometry
	GCORF(i,j)	-	geometry correction factor, area/mass correction
	DRCRK(i,j)	m	transient radial crack width
	DZCRK(i,j)	m	transient axial crack width
	TF(i,j)	K	transient temperature at node (i,j)
	FMASS(i,j)	kg	mass of node (i,j)

	POR(i,j)	-	porosity of node (i,j), or coolant pressure
	PSHAPR(i,j)	-	radial power shape, in arbitrary units
REAL05	TP(i,j)	K	old time level TF (nodal temperature)
	RP(i,j)	m	old time level R (radia of annular geometry)
	DRCRKP(i,j)	m	old time level DRCRCK
	DZCRKP(i,j)	m	old time level DZCRCK
CLDMLT	-	-	variables related to clad removal option, cladding is simply replaced by a pseudo material. To be used for clad motion calculation off.
INTGAS	NFGSTP	-	input, number of fission gas time steps / DT
GSCNST	-	-	constants related to SANDPIN fission gas model
REAL07	-	-	variables related to SANDPIN fission gas model
REAL08	-	-	variables related to SANDPIN fission gas model
REAL09	-	-	variables related to SANDPIN fission gas model
ITIMDP	NDT	-	number of intervals for time input control
	NPOW	-	number of data pairs for IPOWER = 4,5,6
	NFLOW	-	number of relative flow rates to input
	NPRES	-	number of pressure drop data to input
	NPRINL	-	number of inlet pressure data to input
	NPROUT	-	number of outlet pressure data to input
	NTCIN	-	number of coolant inlet temperature data to input
	NTYME(ndt)	-	unit=6 output for every NTYME-th iteration
TIMDEP	TYME(ndt)	s	time point of time control interval ndt
	DTYME(ndt)	s	thermal/mechanics integration time step DT
	RELFLW(ip)	-	input, relative flow rates
	TIMFLW(ip)	s	corresponding time points
	RELTCI(ip)	-	input, relative coolant inlet temperatures
	TIMTCI(ip)	s	corresponding time points

	PRDRP(ip)	-	input, relative axial pressure drop across bundle
	TPRDRP(ip)	s	corresponding time points
	PRINLT(ip)	-	input, relative bundle inlet pressure
	TPRINL(ip)	s	corresponding time points
	PROUTL(ip)	-	input, relative bundle exit pressure
	TPROUT(ip)	s	corresponding time points
	CFAC	J/kgMW	coupling factor, J's per kg per MW reactor power
	CFF	-	change of coupling factor due to clad removal
DATMAT	TMLT1(m)	K	solidus melting point of material m
	TMLT2(m)	K	liquidus melting point of material m
	HFUSE(m)	J/kg	latent heat of fusion of material m
	EMMIS(m)	-	emissivity of material m
	ACCOM	-	accomodation coefficients used in gap model
	IMPNT	-	pointer field to locate data in DATM field
	DATM	-	general purpose material data field
COFCOM	HCOF	-	coefficients of general heat transfer relation
IGAPCM	IGCON	-	gap gas conductivity flag (see SANDPIN input)
	IGPRS	-	solid/solid interface pressure effect on gap conductance
	IGRAD	-	radiation heat transfer across gap
	IPGAS	-	gap gas pressure flag
	MATI	-	material number on left side of gap
	MATO	-	material number on right side of gap
GAPCOM	RUFI	m	left surface roughness of gap
	RUFO	m	right surface roughness of gap
	AMIX	-	mixture accomodation coefficient
	HGMAX	W/m^2K	maximum gap conductance
	HMLT1	W/m^2K	gap conductance for inner surface molten
	HMLT2	W/m^2K	gap conductance for outer surface molten
	HMLT3	W/m^2K	gap conductance for both surfaces molten
	GASPRS	atm	initial gap gas pressure
	WEIGHT	g	molecular weight
	FMOLE	-	mole fractions of gap gases

	COEF	-	coefficients of gap gas conductivity (see subroutine HGAP)
ENTRAN	PENTR	-	molten clad entrainment option (see subr. ENTR)
	WECR	-	critical Weber number (see subr. ENTR)
	DROPD	m	molten clad drop diameter
	TAURES	s	drop residence time within coolant channel
	VDROP	m^3	drop volume
	VDMIN	m^3	minimum drop volume allowed in one cell
	DELTCF	m	height of molten clad drop resting on fuel
	DELTCC	m	height of molten clad drop on solid cladding (see fig. 5)
	CENTR	-	entrainment enhancement coefficient (ENTR)
	DNU1-DNU3	-	coefficients of general drop Nusselt number
	E(ni,j)	m^2/s	entrainment rate
	D(ni,j)	m^2/s	drop deposition rate
	AD(n,j)	m^2	drop volume per length
	ADP(n,j)	m^2	drop volume per length (old time level)
	UD(n,j)	m/s	axial drop velocity
	AUD(n,j)	m^3/s	drop volume flux
	FRD(n,j)	-	drop drag coefficient
	CHOM(n,j)	kg/m^3	homogeneous gas/drop density
	VOID(n,j)	-	α, void fraction
	VOIDP(n,j)	-	void fraction previous time step
	QAL(n,j)	-	x, vapor quality
	QALP(n,j)	-	vapor quality previous time step
	UV(n,j)	m/s	axial vapor velocity
	UL(n,j)	m/s	axial liquid velocity
	WV(n,j)	kg/m^2s	axial vapor mass flux
	WL(n,j)	kg/m^2s	axial liquid mass flux
	SLIP(n,j)	-	slip ratio
	RGRD(ni,j)	m	inner/outer grid radius of annular grid ring within coolant channel n
	TGRD(n,j)	K	temperature of grid material
	FGRD(n,j)	-	friction factor of grid surfaces
	SGRD	-	fraction of grid surfaces that contribute to any frictional momentum or heat exchange

ENTRNW	EFRAC	-	factor to enhance entrainment rate (ENTR)
	EV(ni,j)	m/s	interfacial axial velocity of entrained clad
WETTAB	TETCF	rad	contact angle molten clad drop on fuel
	TETCC	rad	contact angle drop on solid clad (see fig. 5)
	ADRF1	m^2	contact area molten clad drop on fuel
	ADRC1	m^2	contact area molten clad drop on solid clad
	ADRF2	m^2	projected area of drop on fuel on z-axis
	ADRC2	m^2	projected area of drop on solid clad on z-axis
ICMIPT	JLI	-	input, lower axial boundary of fine mesh
	JUI	-	input, upper axial boundary of fine mesh
	JLOW	-	lower axial boundary of fine mesh
	JUP	-	upper axial boundary of fine mesh
	JGM	-	maximum of fine mesh j-index (=JMAX before start of clad motion)
	JGM1	-	= JGM+1
	NFRICO	-	friction factor relation (see subr. FRICF)
	IMATM	-	molten clad material number (:3 for steel)
	NC1	-	NCOFLO-1
	NNC(j)	-	number of fine mesh nodes in coarse node j
	ICLM(n)	-	indicator for clad motion in channel n
	NHCOF(n)	-	number of heat transfer correlation used in channel n (see subr. HCOEF)
	JCB(ni,j)	-	indicates the state of a node : -1: original, 0: cladding just molten, 1: molten clad on fuel, 2: molten/refrozen clad on intact clad
	IFUEL(n,j)	-	i-index of radial node adjacent to fuel boundary
ICMBAL	ISTPI	-	step number increment for restart dump on f. 22
	NCYC(n)	-	number of clad motion cycles in channel n
RCMIPT	DHF	kg/m^3	density of molten cladding (constant)
	FRICB	-	coefficient in friction factor relation
	FRICE	-	exponent of Reynoldsnumber

	FRICB1	-	coefficient of friction factor relation
	FRICE1	-	exponent of Reynoldsnumber
	FRFMAX	-	upper limit to friction factor value
	XNYFR	-	reference viscosity, Grolmes friction f. relation
	RENCR	-	critical Reynoldsnumber of coolant flow
	SLIPM	-	maximum slip ratio
	DZW(j)	m	desired axial mesh height of fine mesh
RCMBLA	CDT	s	integration time step of sodium boiling and clad motion dynamics
	CDTO	s	old time level CDT
	CMSTRT	s	time of first clad motion event
	CTIME	s	current time of CDT/DT iteration
	CDTMIN	s	smallest CDT that is allowed
	CDTMAX	s	greatest CDT that is allowed
	CDTBL	s	maximum CDT if there is a single phase vapor bubble
	DHMIN	m	minimum coolant channel hydraulic diameter
	DFMIN	m	minimum clad film thickness (1.E-5 m)
	ACMIN	m^2	minimum volume of molten clad per unit of length
	FBOT	m^3	flow of molten clad out of bottom cell
	FTOP	m^3	flow of molten clad out of top cell
	CMASS(ni)	kg	initial mass of clad available on boundary ni
	CMASM	kg	total mass of molten clad
	RFC(ni,j)	m	radius of fuel/clad interphase
	RCS(ni,j)	m	radius solid/molten clad interphase
	RCG(ni,j)	m	radius coolant channel boundary
	RCO(n,j)	m	radius 'line of zero shear stress of coolant flow'
	CCORF(ni,j)	-	geometry correction factor for RCG
	A(ni,j)	m^2	volume of molten clad per unit of length
	AS(ni,j)	m^2	volume of resolidified clad per unit of length
	ACI(ni,j)	m^2	volume of intact clad per unit of length
	AT(ni,j)	m^2	total volume of clad per unit of length
	AR(ni,j)	m^2	old time level A
	ACMX(ni,j)	m^2	maximum volume available for molten clad/length
	DF(ni,j)	m	molten clad film thickness
	U(ni,j)	m/s	molten clad velocity
	UP(ni,j)	m/s	old time level U

	AU(ni,j)	m^3/s	volume flux of molten clad
	AUP(ni,j)	m^3/s	old time level AU
	XNDROP(ni,j)	-	number of molten clad waves on fuel pin/length
	DOH(n,j)	m	coolant channel hydraulic diameter
	TLG(n,j)	N/m	field to save interfacial shear stress
	DZ(j)	m	axial height of mesh cell j
THERMO	SHEAT	K	temperature exceeding the clad melting point to indicate full movability
	TSF	K	clad solidus temperature
	TLF	K	clad liquidus temperature
	TMOV	K	TLF+SHEAT
	HSF	J/kg	latent heat of fusion
	CPS	J/KgK	solid clad heat capacity
	CPL	J/KgK	liquid clad heat capacity
	CLF	W/mK	liquid clad heat conductivity
	DTSUP	K	superheat necessary for coolant boiling inception
	TBOIL	s	time of first coolant boiling event
	DELTMX	K	convergence criterion of temperature iteration
	GAMR	-	factor to enhance radial energy exchange between the coolant channels
	BAC, FOR	-	weighting factors in explicit/implicit finite difference schemes
	HDROP	-	factor in drop Nusselt number relation (HCOEF)
	TBOUND	K	external boundary temperature (see SANDPIN input)
	TCC(j,n)	K	coolant temperature
	TCP(j,n)	K	old time level TCC
	TL(ni,j)	K	molten clad or fuel pin surface temperature
	TLP(ni,j)	K	old time level TL
	TS(ni,j)	K	temperature of resolidified clad (if no such clad is present TS=TL)
	TSP(ni,j)	K	old time level TS
	TDROP(n,j)	K	drop temperature field
	TDROPP(n,j)	K	old time level TDROP
	QFLUX(ni,j)	Ws/mK	heat flux supplied as boundary condition to the pin temperature calculation)
	SQFLX(ni,j)	W/mK	sum of heat fluxes from each CDT cycle

	TFF(i,j)	K	fine mesh temperature field
	TFP(i,j)	K	old time level TFF
TAUWAL	RENC1	-	critical molten clad film Reynoldsnumber
	PLENR	-	temporaryly used for TREAT-R5 recalculation
	PBARO	atm	barometric pressure
	DHIN	m	hydraulic diameter of piping system
	AINL	m^2	cross sectional area of piping system
	PLENA	m	length of inlet pipe section
	PLENZ	m	length of exit pipe section
	FRFIN	-	coefficients in friction factor relations
	FRFOU	-	used for the piping system
	FORIFI	-	
	FORIFO	-	
RCMRST	TFINCL	s	no clad motion beyond time = TFINCL
	TREVRS	s	time of first coolant flow reversal
	DOHR	m	hydraulic diameter of radial cross flow channels
	RELX	-	relaxation parameter (see subr. SOLV2D)
	A0, B0	-	coefficients in donor cell differencing
	AC(j,n)	m^2	coolant channel cross section
	DHG(j,n)	kg/m^3	coolant density
	DHGP(j,n)	kg/m^3	old time level DHG
	PR(j,n)	Pa	coolant pressure
	UG(j,n)	m/s	coolant velocity
	UGV(j,n)	m/s	weighted coolant velocity (αUV+(1-α)Ul)
	UGUD(j,n)	m/s	gas/drop homogeneous mixture velocity
	CFLOW(j,n)	kg/m^2s	coolant axial mass flux
	DR(n)	m	radial distance between two coolant channels
	ACONC(n)	m	exchange area between two neighboring cool. ch.
	UGR(j,n)	m/s	radial coolant velocity
	WCROS(j,n)	kg/m^2s	radial coolant mass flux
	FRF(j,ni)	-	friction factor of coolant channel boundaries
	PRINL(n)	Pa	pressure at pin bundle inlet
IPLOTM	IPLCM	-	unit for clad motion plot output (12)
	ICURV	-	unit for selected curve output (16)

	JLPR	-	lowest node to appear in unit 6 output
	JUPR	-	highest node to appear in unit 6 output
PLOTMO	DTPL	s	time increment for CM-plot output
	DTCURV	s	time increment for selected curve output
	DTWRIT	s	time increment for additional unit 6 output
	TPLOT	s	time point to initiate next plot output
	TCURV	s	time point to initiate next curve output
	TWRIT	s	time point to initiate next unit 6 output

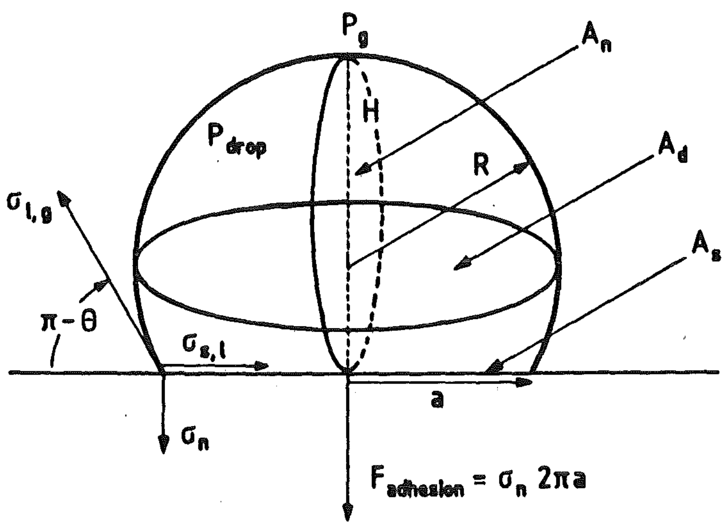

Fig. 5 : Molten clad drop geometry

V. PLOT PROGRAMS

Two plot programs are available. One of these can be used for representation of clad motion results as this is illustrated in fig. 6. The plots are created by use of the DISSPLA software package /8/. The corresponding plotprogram source is saved under 'TS0908.SANDTP.DATA(CPLOTFOR)'.

In order to represent additional information concerning mainly the coolant boiling phase, selected curves are saved on unit 16 and may be displayed by use of the PLOTEASY program /9/. The corresponding JCL together with the PLOTEASY input are listed in Appendix A.1. Plot examples are contained in the sample output description in Appendix A.2.

VI. JCL

In order to obtain a compilable FORTRAN version of the SANDCMOT source deck the HISTORIAN PLUS preprocessor has to be run first /7/. This program is a general maintenance program that reduces redundant programming and allows the user to keep a relatively compact source deck with several options. HISTORIAN executes the various directive statements, deletes or inserts lines or whole program blocks and thereby produces a FORTRAN program ready for compilation. The job-JCL for the HISTORIAN step as well as for the COMPILE and LINK step is given below. For compilation of the function JTIME the assembler compiler ASC is invoqued. The complete load-module is saved as a member SPCMS in the load module library 'TS0908.LIBT.LOAD' that is created in the same run:

```
//INR908HL JOB (0908,101,P6N1D),HENKEL,NOTIFY=INR908,MSGCLASS=H,
//          REGION=1848K,TIME=(0,30)
//*----------------------------------------------------------------
//****RUN HISTORIAN
//*----------------------------------------------------------------
// EXEC FHG,NAME=HISTX
```

```
/*MAIN LINES=50
//STEPLIB DD DSN=ADI707.HISTOR.LOAD,DISP=SHR
//*-      SANDCMOT SOURCE DECK                   -------------------------
//G.FT10F001 DD DSN=TS0908.SPCMS.DATA,DISP=SHR
//*-----------------------------------------------------------------------
//G.FT22F001 DD DSN=&SAND,DISP=(,PASS),
// SPACE=(4080,(200,80),RLSE),UNIT=SYSDA,
// DCB=(LRECL=80,RECFM=FB,BLKSIZE=3840)
//G.FT25F001 DD DSN=&SAND,DISP=(,PASS),
// SPACE=(TRK,(200,80),RLSE),UNIT=SYSDA,
// DCB=(LRECL=80,RECFM=FB,BLKSIZE=3840)
//G.FT23F001 DD DISP=(,PASS),DSN=&SPCMS,
// SPACE=(TRK,(100,30,10),RLSE),UNIT=SYSDA,
// DCB=(BLKSIZE=240,LRECL=80,RECFM=FB)
//G.FT27F001 DD DISP=(,PASS),
// SPACE=(4080,(500,30),RLSE),UNIT=SYSDA
//G.SYSIN DD *
HISTORIAN(N,T,6,8)
*READ 10
*/ DEFINE DIRECTIVES
*IDENT,DEF
*DEFINE CHDY,PIN,PLOT,ELEC
/*
//*-----------------------------------------------------------------------
//****ASSEMBLER COMPILE STEP
//*-----------------------------------------------------------------------
// EXEC ASC
//A.SYSPRINT DD DUMMY
//A.SYSIN DD DSN=TS0908.SAND.DATA(JTIME),DISP=SHR
//*-----------------------------------------------------------------------
//****COMPILE/LINK STEP
//*-----------------------------------------------------------------------
// EXEC F7CL,PARM.C='SOURCE,NOMAP,OPT(3),XOPT(NOAMOVE)'
//C.SYSIN DD DSN=&SPCMS,DISP=(OLD,DELETE)
//L.SYSLMOD DD DISP=SHR,DSN=TS0908.LIBT.LOAD,
//  UNIT=DISK,VOL=SER=TS0000,SPACE=(TRK,(25,10,5),RLSE),
//  DCB=(RECFM=U,BLKSIZE=19069)
//L.SYSIN DD *
 ENTRY MAIN
 NAME SPCM(R)
/*
//
```

G.FT10F001	:	HISTORIAN PLUS input source file ('TS0908.SPCMS.DATA').
G.FT22F001	:	temporary working file.
G.FT25F001	:	temporary working file.
G.FT27F001	:	temporary working file.
G.FT23F001	:	output of the HISTORIAN step, a compilable version of the input source file.
G.SYSIN	:	operational input to the HISTORIAN step, definition of directives.
A.SYSIN	:	the assembler input file to be compiled.
C.SYSIN	:	input file to the FORTRAN77 compile/link step (output of HISTORIAN step). The executable program is saved under
L.SYSLMOD	:	'TS0908.LIBT.LOAD' receives the LOAD module member SPCM.
L.SYSIN	:	input to the LINKAGE EDITOR.

The possibilities of the HISTORIAN PLUS program and the meaning of the various directives and parameters are described in ref. /6/.

Once an executable version of the SANDCMOT program has been created it can be run with the following JCL:

```
//INR908RN JOB (0908,101,P6N1D),HENKEL,NOTIFY=INR908,MSGCLASS=H,
//         REGION=2548K,TIME=(3,00)
//*MAIN LINES=200
//*-----------------------------------------------------------------------
//*****TREAT-R5 TEST CALCULATIONS
//*-----------------------------------------------------------------------
// EXEC F7G,NAME=SPCM
//G.STEPLIB DD DSN=TSO908.LIBT.LOAD,DISP=SHR
//*-----------------------------------------------------------------------
//*****INPUT GO-STEP
//*-----------------------------------------------------------------------
//G.FT05F001 DD DSN=TSO908.SANDIN.DATA(TRTR54),DISP=SHR
//G.FT09F001 DD DSN=TSO908.SANDIN.DATA(TRTPWR),DISP=SHR
//*****PLOT-FILE FOR TEMPERATURES ETC.
//G.FT11F001 DD DSN=INR908.TRT.PLT1,DISP=(,CATLG),
//  SPACE=(TRK,(20,5),RLSE),DCB=(RECFM=VBS,BLKSIZE=3188,BUFNO=1)
//*****PLOT-FILE FOR CLAD MOTION PICTURES
//G.FT12F001 DD UNIT=DISK,VOL=SER=BAT000,
//  DSN=INR908.TRT.PLC1,DISP=(,CATLG),
//  SPACE=(TRK,(20,5),RLSE),DCB=(RECFM=VBS,BLKSIZE=3188,BUFNO=1)
//*****FISSION GAS OUTPUT
//G.FT13F001 DD UNIT=DISK,VOL=SER=BAT000,
//  DSN=INR908.TRT.FG1,DISP=(,CATLG),
//  SPACE=(TRK,(20,5),RLSE),DCB=(RECFM=VBS,BLKSIZE=3188,BUFNO=1)
//*****OUTPUT OF SELECTED CURVES
//G.FT16F001 DD UNIT=DISK,VOL=SER=BAT000,
//  DSN=INR908.TRT.CRVA1,DISP=(,CATLG),
//  SPACE=(TRK,(20,5),RLSE),DCB=(RECFM=VBS,BLKSIZE=3188,BUFNO=1)
//*****READ RESTART FILE
//G.FT21F001 DD DSN=INR908.TRT.R0,DISP=SHR
//*****WRITE RESTART FILE
//G.FT22F001 DD DSN=INR908.TRT.R1,DISP=(,CATLG),
//  VOL=SER=BAT000,UNIT=DISK,
//  SPACE=(TRK,(20,5),RLSE),DCB=(RECFM=VBS,BLKSIZE=3188,BUFNO=1)
//*
//*-----------------------------------------------------------------------
//* NAMELIST INPUT                                                      --
//*-----------------------------------------------------------------------
//G.FT07F001 DD *
 &REST
 KREST=1,NRFR=21,NRFW=22,NPLT=20,ISTPM=8888,ISTPI=100,               &END
 .....
 a.s.o. , see example CMOT related input
/*
//
```

G.FT05F001 : SANDPIN related input (geometry, heat transfer and mechanics flags, initial and boundary conditions).

G.FT07F001 : NAMELIST input (coolant boiling and clad motion).
G.FT09F001 : power trace.
G.FT11F001 : plot output for pin temperatures.
G.FT12F001 : plot output for clad motion pictures.
G.FT13F001 : plot output for fission gas results.
G.FT16F001 : plot output for coolant boiling results.
G.FT21F001 : in case of restart, restart input file.
G.FT22F001 : restart file created from current run.

VII. REFERENCES

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4. G. Angerer, 'Modelltheoretische Untersuchungen des Abschmelz- und Wiedererstarrungsvorgangs von Brennstabhüllen während Störfällen in schnellen natriumgekühlten Reaktoren', KfK 2662, (1978)

5. P. Henkel, 'Analyse von Phänomenen der Hüllrohrbewegung; Anwendung des CMOT-II-Codes auf Hüllenschmelzexperimente', KfK 3847 (1985)

6. S.A. Wright, G. Schumacher, P.R. Henkel, 'In-Pile Observations of Fuel and Clad Relocation During LMFBR Core Disruptive Accidents in the STAR Experiments', Nucl. Techn. Vol.71, No.1, 187 (1985)

7. OPCODE, Inc., Reference manual HISTORIAN PLUS RELEASE 4.1 (1985)

8. DISSPLA software package, Integrated Software Systems Corporation, 10505 Sorrento Valley Rd, San Diego, Cal., (1981)

9. C. Broeders, PLODAT program description, internal report (1978)

VIII. APPENDIX

A.1 PLOT JCL

```
//INR908P2 JOB (0908,101,P6N1D),HENKEL,REGION=2048K,TIME=(0,30),
// MSGLEVEL=(1,1),MSGCLASS=H,NOTIFY=INR908
//*MAIN LINES=40
// EXEC PGM=IEFBR14
//DDN DD DSN=&&VSSCR,UNIT=SYSDA,SPACE=(TRK,50),DISP=(,PASS),
// DCB=(RECFM=F,LRECL=2000,BLKSIZE=2000)
// EXEC F7CLG,PARM.C='OPTIMIZE(3),LANGLVL(77)',
// IMSL=SP,PARM.L='SIZE(500K,100K)'
//C.SYSPRINT DD SYSOUT=*
//C.SYSIN DD *
      PROGRAM PLOTCRV
      ......
      see 'TS0908.JOB.CNTL(PLOTCRV)'
      ......
C*
      STOP
      END
//L.SYSPRINT DD SYSOUT=*
//L.SYSIN DD *
 ENTRY CPLOT
/*
//G.FT01F001 DD DISP=SHR,DSN=INR908.STAR1.CRV1
//             DD DISP=SHR,DSN=INR908.STAR1.CRV2
//             DD DISP=SHR,DSN=INR908.STAR1.CRV3
//             DD DISP=SHR,DSN=INR908.STAR1.CRV4
//             DD DISP=SHR,DSN=INR908.STAR1.CRV5
//G.FT20F001 DD DISP=SHR,DSN=INR908.STAR1.PLT1
//*
//* PLOTEASY STEP
//PLOTEASY EXEC PLOTEASY,
// PREPAR=PLODAT,PLOT=PLVERS,PLOTID=S,JOBID=908P
//***FOR TEXTRONIX ONLY PREPAR=PLODAT,PLOT=PLGDDM,PLOTID=S,JOBID=310D
//G.FT20F001 DD DISP=SHR,DSN=INR908.STAR1.PLT1
//G.SYSIN DD *
NAMELIST INPUT FOR MODULE PLODAT/PLOTEASY
 &INPUT NAME='FLOWRATE',KENN1=1,KENN2=1,NFI=20,PGRID=T,MAXPUN=2000,
 NLGX=1,NLGY=105,DROP=T, NTEXTX='     TIME (S)',NTEXTY='      F(KG/S)',
 FIXPLO=T,XMIN=0.001,XMAX=22.0,YMIN=-0.60,YMAX=1.6E0,X1=0.67,Y1=0.92,
 NKURVE=2,NT=206,NTXN=1,PRXAY=T,NTXT1='CALC. INLET C1    ',
 PRTEXT=F,SX=13.,SY=9., INDZ=14,
 NTEXT='COOLANT INLET FLOW RATES IN CHANNELS  1,2         ',           &END
 &INPUT KENN2=2,NT=208,NTXT1='CALC. INLET C2    ',                     &END

 &INPUT NAME='FLOWRATE',KENN1=1,KENN2=3,NFI=20,PGRID=T,MAXPUN=2000,
 NLGX=1,NLGY=105,DROP=T, NTEXTX='     TIME (S)',NTEXTY='       F(KG/S)',
 FIXPLO=T,XMIN=0.001,XMAX=22.0,YMIN=-0.60,YMAX=1.6E0,X1=0.62,Y1=0.92,
 NKURVE=3,NT=206,NTXN=1,PRXAY=T,NTXT1='CALC. INLET        ',
 PRTEXT=F,SX=13.,SY=9., INDZ=14,
 NTEXT='COOLANT INLET/EXIT FLOW RATES IN CHANNEL 1,2         ',        &END
 &INPUT KENN2=4,NT=208,NTXT1='CALC. EXIT+0.2     ',                    &END
 &INPUT KENN2=5,NT=202,NTXT1='EXP. INLET         ',                    &END
```

```
&INPUT NAME='FLOWRATE',KENN1=1,KENN2=7,NFI=20,PGRID=T,MAXPUN=2000,
NLGX=3,NLGY=105,DROP=T, NTEXTX='    TIME (S)',NTEXTY=' VOID B.(CM)',
FIXPLO=T,XMIN=13.00,XMAX=18.0,YMIN=0.002,YMAX=5.0E2,X1=0.65,Y1=0.92,
NKURVE=4,NT=202,NTXN=1,PRXAY=T,NTXT1='  SANDCMOT          ',
PRTEXT=F,SX=13.,SY=9., INDZ=14,NPG=1,NPA=80,NP=1,PSYMB=T,
NTEXT='DEVELOPMENT OF VOID BOUNDARIES IN C1 & C2      ',          &END
&INPUT KENN2=8,NT=202,NTXN=0,                                        &END
&INPUT KENN2=11,NT=207,NTXT1='  EXPERIMENT        ',NTXN=1,          &END
&INPUT KENN2=12,NT=207,NTXN=0,                                       &END

&INPUT NAME='FLOWRATE',KENN1=1,KENN2=21,NFI=20,PGRID=T,MAXPUN=2000,
NLGX=1,NLGY=105,DROP=T, NTEXTX='AXIAL H.(CM)',NTEXTY='     VOID (-)',
FIXPLO=T,XMIN=0.001,XMAX=400.,YMIN=-0.001,YMAX=2.0E0,X1=0.61,Y1=0.92,
NKURVE=6,NT=216,NTXN=1,PRXAY=T,NTXT1='TIME 14.0 S, C1  ',
PRTEXT=F,SX=13.,SY=9., INDZ=14,
NTEXT='VOID DEVELOPMENT IN 7-PIN BUNDLE                ',           &END
&INPUT KENN1=2,KENN2=21,NT=204,NTXT1='TIME 14.5 S, C1 ',            &END
&INPUT KENN1=3,KENN2=21,NT=208,NTXT1='TIME 15.0 S, C1 ',            &END
&INPUT KENN1=4,KENN2=21,NT=214,NTXT1='TIME 15.5 S, C1 ',            &END
&INPUT KENN1=5,KENN2=21,NT=218,NTXT1='TIME 16.0 S, C1 ',            &END
&INPUT KENN1=6,KENN2=21,NT=202,NTXT1='TIME 16.5 S, C1 ',            &END

/*
//P.PLOTTAPE DD DUMMY
//P.PLOTPARM DD *
 &PLOT XMAX=60., &END
//VERSATEC  EXEC SVPLOT,SPACE=100
```

A.2 SAMPLE OUTPUT

Sample output as printed on unit 6 is provided below for the STAR2 and TREAT-R5 experiments. From the SANDPIN related output, fuel pin and structure temperature distributions are available. Also given are the nodal temperatures and radii for selected axial nodes. Further, average temperatures are printed in a table for the fuel, clad and structure materials as well as for the coolant. This is done for every axial coarse mesh node. The corresponding output is created in subroutine OUTPOT.

Clad motion results are summarized in another table including the outer clad radius (RAD-GAS), thickness of the molten clad, its velocity and temperature. Additionally, the number of molten clad drops in a coolant channel, the hydraulic diameter, the gas velocity and the pressure are reported. In the first two columns, the fine and coarse mesh indices are specified. Such output is provided for every channel from subroutine COUTPT.

Concerning the sodium boiling output, a similar list is put together for each coolant channel. It includes the coarse mesh index J, hydraulic diameter DOH, coolant density RHO, temperature TCC, pressure P, void fraction VOID, flow quality, liquid and vapor phase velocities UF, UV, axial coolant flow rate CFLOW, mixture velocity UG, mixture enthalpy XHM, slip ratio SLIP and radial cross flow rates WCROS. For the last variable, alternatively, friction factors, FRF, may be printed out.

Additional to the printed output, plots can be created from the respective plot files. In fig. 6, the STAR2 clad motion history is shown. The z-axis lies in horizontal direction while the radial axis points upwards. Simply shaded areas indicate fuel, the vertical bars circumscribe the fissile section. Doubly shaded areas are solid cladding, either as fabricated initially or resolidified, black areas indicate molten clad. These areas also appear within the coolant channel characterized by dots and represent entrained drops. The arrows above are a measure for the gas velocities. It should be noted that the molten clad is always depicted as mass equivalent annular rings and thus has a film flow appearance. This is also the reason why the drop fractions sometimes appear to be rather small because the drop mass is homogenized along an annular ring.

For the TREAT-R5 experiment, the calculated void profile development in both channels is shown in fig. 7. These plots are created by help of the PLOTEASY program /9/.

RADIAL NODES AT AXIAL NODE 6

1.0232E-10	2.5274E-04	7.5821E-04	1.2637E-03	1.7692E-03	2.2746E-03	2.5274E-03	2.6212E-03	2.6867E-03	2.8178E-03
2.9489E-03	3.0144E-03	4.3450E-03	5.9453E-03	6.0106E-03	6.1411E-03	6.2716E-03	6.3369E-03	6.3369E-03	6.5501E-03
6.9765E-03	7.4029E-03	7.8293E-03	8.2557E-03	8.4689E-03	8.6322E-03	8.6912E-03	8.8092E-03	8.9272E-03	8.9862E-03
9.7955E-03	1.0860E-02	1.1028E-02	1.1365E-02	1.1702E-02	1.1870E-02	5.9935E-02	1.0800E-01	1.0858E-01	1.0972E-01
1.1030E-01									

RADIAL TEMPERATURES AT AXIAL NODE 6

2.3617E+03	2.3617E+03	2.3432E+03	2.2900E+03	2.1884E+03	2.0442E+03	1.9898E+03	1.9898E+03	1.9898E+03	1.9898E+03
1.9898E+03	1.9898E+03	5.2320E+02	1.6430E+03	1.6431E+03	1.6435E+03	1.6443E+03	1.6449E+03	1.6657E+03	1.7010E+03
1.7486E+03	1.7787E+03	1.7867E+03	1.7654E+03	1.7270E+03	1.5966E+03	1.5959E+03	1.5949E+03	1.5941E+03	1.5938E+03
4.3704E+02	3.5309E+02	3.5172E+02	3.4994E+02	3.4911E+02	3.4914E+02	6.5909E+02	3.0019E+02	3.0018E+02	3.0016E+02
3.0016E+02									

RADIAL NODES AT AXIAL NODE 9

1.0212E-10	2.5225E-04	7.5674E-04	1.2612E-03	1.7657E-03	2.2702E-03	2.5225E-03	2.6212E-03	2.6867E-03	2.8178E-03
2.9489E-03	3.0144E-03	4.3450E-03	5.9356E-03	6.0008E-03	6.1311E-03	6.2614E-03	6.3266E-03	6.3266E-03	6.5394E-03
6.9652E-03	7.3910E-03	7.8167E-03	8.2425E-03	8.4554E-03	8.6126E-03	8.6715E-03	8.7892E-03	8.9070E-03	8.9659E-03
9.7955E-03	1.0860E-02	1.1028E-02	1.1365E-02	1.1702E-02	1.1870E-02	5.9935E-02	1.0800E-01	1.0858E-01	1.0972E-01
1.1030E-01									

RADIAL TEMPERATURES AT AXIAL NODE 9

2.2000E+03	2.2000E+03	2.1875E+03	2.1503E+03	2.0789E+03	1.9603E+03	1.8617E+03	1.7154E+03	1.7135E+03	1.7112E+03
1.7101E+03	1.7097E+03	7.5781E+02	1.5823E+03	1.5819E+03	1.5816E+03	1.5818E+03	1.5822E+03	1.5952E+03	1.6168E+03
1.6503E+03	1.6726E+03	1.6779E+03	1.6589E+03	1.6262E+03	1.5089E+03	1.5083E+03	1.5074E+03	1.5067E+03	1.5064E+03
5.5910E+02	3.8227E+02	3.7963E+02	3.7620E+02	3.7455E+02	3.7458E+02	6.5925E+02	3.0020E+02	3.0018E+02	3.0017E+02
3.0017E+02									

R A D I A L   R E G I O N   T E M P E R A T U R E   S U M M A R Y   TIME = 74.99E+00

AXIAL NODE	SUB MODEL	DATA BY RADIAL REGION									
16	6	9.961E+02	9.960E+02	9.079E+02	9.038E+02	9.003E+02	8.873E+02	6.105E+02	4.018E+02	7.213E+02	3.002E+02
15	6	9.769E+02	9.768E+02	9.043E+02	8.997E+02	8.966E+02	8.838E+02	6.094E+02	4.028E+02	7.163E+02	3.002E+02
14	5	9.039E+02	9.042E+02	9.015E+02	9.593E+02	9.557E+02	9.277E+02	6.084E+02	4.034E+02	7.147E+02	3.002E+02
13	5	9.030E+02	9.032E+02	8.995E+02	9.586E+02	9.551E+02	9.272E+02	6.069E+02	4.018E+02	7.131E+02	3.002E+02
12	4	1.010E+03	9.976E+02	8.974E+02	9.786E+02	9.757E+02	9.442E+02	6.053E+02	4.002E+02	7.058E+02	3.002E+02
11	4	1.009E+03	9.933E+02	8.558E+02	9.752E+02	9.742E+02	9.416E+02	5.859E+02	3.931E+02	6.593E+02	3.002E+02
10	4	1.031E+03	1.154E+03	8.364E+02	1.046E+03	9.776E+02	9.386E+02	5.791E+02	3.848E+02	6.593E+02	3.002E+02
9	3	2.068E+03	1.712E+03	7.578E+02	1.582E+03	1.657E+03	1.507E+03	5.591E+02	3.767E+02	6.592E+02	3.002E+02
8	3	2.121E+03	1.718E+03	6.821E+02	1.595E+03	1.700E+03	1.546E+03	5.227E+02	3.684E+02	6.592E+02	3.002E+02
7	3	2.135E+03	1.812E+03	5.985E+02	1.626E+03	1.726E+03	1.568E+03	4.819E+02	3.593E+02	6.592E+02	3.002E+02
6	3	2.182E+03	1.990E+03	5.232E+02	1.644E+03	1.758E+03	1.595E+03	4.370E+02	3.502E+02	6.591E+02	3.002E+02
5	3	2.269E+03	2.087E+03	4.445E+02	1.696E+03	1.819E+03	1.648E+03	3.876E+02	3.406E+02	6.590E+02	3.002E+02
4	2	9.785E+02	9.408E+02	3.751E+02	9.350E+02	9.492E+02	9.120E+02	3.435E+02	3.279E+02	6.579E+02	3.002E+02
3	2	9.725E+02	9.356E+02	3.654E+02	9.316E+02	9.460E+02	9.099E+02	3.382E+02	3.225E+02	6.574E+02	3.002E+02
2	1	8.029E+02	7.872E+02	3.363E+02	7.833E+02	7.984E+02	7.828E+02	3.219E+02	3.136E+02	6.569E+02	3.002E+02
1	1	8.013E+02	7.854E+02	3.194E+02	7.819E+02	7.974E+02	7.818E+02	3.123E+02	3.103E+02	6.564E+02	3.002E+02

Table 1 : SANDPIN temperature output

CLAD MOTION OUTPUT TIME = 75.0140 ACTUAL DT = 0.0010 FINE MESH MIN. DZ = 0.009

CHANNEL 1

JF	J	RAD-GAS	LEFT SIDE L-THICK	LEFT SIDE CLAD VEL	TEMP	RIGHT SIDE L-THICK	RIGHT SIDE CLAD VEL	COOLANT NUMBER	CHANNEL DATA DIAM	CHANNEL DATA H-DIAM	GAS VEL	GAS PRES
38	11	2.96E-03	0.00E+00	0.00E+00	9.93E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.41E-03	9.69E+01	7.03E+04
37	11	2.96E-03	0.00E+00	0.00E+00	9.93E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.41E-03	9.63E+01	7.04E+04
36	10	2.97E-03	0.00E+00	0.00E+00	9.89E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.41E-03	9.56E+01	7.05E+04
35	10	2.97E-03	0.00E+00	0.00E+00	9.89E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.41E-03	9.50E+01	7.06E+04
34	10	2.97E-03	0.00E+00	0.00E+00	9.89E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.41E-03	9.44E+01	7.08E+04
33	10	2.97E-03	0.00E+00	0.00E+00	9.89E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.41E-03	9.38E+01	7.09E+04
32	10	2.97E-03	0.00E+00	0.00E+00	9.89E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.41E-03	9.32E+01	7.10E+04
31	10	2.97E-03	0.00E+00	0.00E+00	9.89E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.41E-03	9.25E+01	7.11E+04
30	10	2.97E-03	0.00E+00	0.00E+00	9.89E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.41E-03	9.21E+01	7.12E+04
29	10	3.47E-03	0.00E+00	0.00E+00	1.50E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.08E-03	1.17E+02	7.11E+04
28	10	3.67E-03	1.85E-05	1.80E-03	1.71E+03	2.64E-06	0.00E+00	9.40E-01	0.00E+00	3.57E-03	1.43E+02	7.09E+04
27	10	3.36E-03	1.42E-04	1.07E+00	1.71E+03	5.26E-05	0.00E+00	6.49E+00	0.00E+00	4.32E-03	1.18E+02	7.20E+04
26	9	3.21E-03	1.97E-04	1.23E+00	1.72E+03	2.82E-05	0.00E+00	8.33E+00	0.00E+00	4.99E-03	8.68E+01	7.29E+04
25	9	3.21E-03	1.98E-04	2.33E+00	1.72E+03	0.00E+00	0.00E+00	8.37E+00	0.00E+00	5.06E-03	8.20E+01	7.34E+04
24	9	3.15E-03	1.31E-04	1.69E+00	1.72E+03	0.00E+00	0.00E+00	5.49E+00	0.00E+00	5.23E-03	7.82E+01	7.37E+04
23	9	3.13E-03	1.11E-04	1.93E+00	1.72E+03	0.00E+00	0.00E+00	4.61E+00	0.00E+00	5.27E-03	7.56E+01	7.40E+04
22	8	3.12E-03	1.06E-04	2.94E+00	1.72E+03	0.00E+00	0.00E+00	4.41E+00	0.00E+00	5.29E-03	7.30E+01	7.42E+04
21	8	3.08E-03	6.72E-05	2.07E+00	1.72E+03	0.00E+00	0.00E+00	2.78E+00	0.00E+00	5.36E-03	7.04E+01	7.44E+04
20	8	3.08E-03	6.52E-05	7.27E-01	1.73E+03	0.00E+00	0.00E+00	2.69E+00	0.00E+00	5.36E-03	6.89E+01	7.46E+04
19	8	3.16E-03	1.47E-04	7.70E-01	1.74E+03	0.00E+00	0.00E+00	6.16E+00	0.00E+00	5.21E-03	6.51E+01	7.48E+04
18	7	2.75E-03	2.24E-04	9.10E-01	1.77E+03	7.49E-05	0.00E+00	7.99E+00	0.00E+00	5.84E-03	5.86E+01	7.53E+04
17	7	2.53E-03	0.00E+00	0.00E+00	1.90E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.38E-03	5.47E+01	7.55E+04
16	7	2.53E-03	0.00E+00	0.00E+00	1.94E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.36E-03	5.30E+01	7.56E+04
15	7	2.53E-03	0.00E+00	0.00E+00	1.94E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.38E-03	5.12E+01	7.57E+04
14	6	2.53E-03	0.00E+00	0.00E+00	1.98E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.38E-03	4.95E+01	7.58E+04
13	6	2.53E-03	0.00E+00	0.00E+00	2.00E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.38E-03	4.78E+01	7.59E+04
12	6	2.53E-03	0.00E+00	0.00E+00	2.01E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.38E-03	4.60E+01	7.60E+04
11	6	2.53E-03	0.00E+00	0.00E+00	2.01E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.38E-03	4.42E+01	7.61E+04

CHANNEL 2

JF	J	RAD-GAS	LEFT SIDE L-THICK	LEFT SIDE CLAD VEL	TEMP	RIGHT SIDE L-THICK	RIGHT SIDE CLAD VEL	COOLANT NUMBER	CHANNEL DATA DIAM	CHANNEL DATA H-DIAM	GAS VEL	GAS PRES
38	11	8.85E-03	0.00E+00	0.00E+00	9.41E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.13E-03	7.39E+01	7.13E+04
37	11	8.85E-03	0.00E+00	0.00E+00	9.41E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.13E-03	7.37E+01	7.14E+04

Table 2 : SANDCMOT clad motion output

F L O W   C H A N N E L   O U T P U T, TIME = 16.5112, DT = 1.00000E-03, CDT = 2.000000E-04

C H A N N E L 1, AC(J=1) = 7.61961E-05 , PR(INLET) = 1.20135E+05

J	DOH	RHO	TCC	PR	VOID	QUALITY	UF	UV	CFLOW	UG	XHM	SLIP	FRF/WCROS
42	4.59E-03	7.58E+02	1.08E+03	1.35E+05	0.0	0.0	2.42E-01	0.0	1.41E-02	2.42E-01	1.13E+06	1.00E+00	5.17E-05
41	4.59E-03	7.52E+02	1.11E+03	1.37E+05	0.0	0.0	2.45E-01	0.0	1.42E-02	2.45E-01	1.16E+06	1.00E+00	6.61E-06
40	4.60E-03	7.35E+02	1.17E+03	1.37E+05	0.0	4.23E-04	8.07E-01	1.12E+00	2.76E-02	8.06E-01	1.24E+06	1.39E+00	-1.58E-05
39	4.60E-03	2.21E+02	1.19E+03	1.36E+05	8.02E-01	1.69E-02	1.54E+00	8.90E+00	1.32E-02	1.56E+00	1.65E+06	5.79E+00	-9.37E-05
38	4.60E-03	1.08E+02	1.21E+03	1.56E+05	9.00E-01	5.77E-02	4.70E-01	4.84E+00	2.39E-03	4.96E-01	1.95E+06	1.03E+01	-4.99E-05
37	4.60E-03	7.88E+01	1.20E+03	1.52E+05	9.31E-01	1.75E-01	1.44E+00	2.55E+01	4.43E-03	1.73E+00	2.51E+06	1.77E+01	3.90E-03
36	4.60E-03	2.30E+01	1.21E+03	1.63E+05	9.80E-01	5.77E-01	3.84E+00	1.15E+02	6.47E-03	8.75E+00	3.84E+06	3.00E+01	3.58E-03
35	4.60E-03	4.53E+00	1.21E+03	1.63E+05	9.95E-01	8.78E-01	3.42E+00	1.02E+02	3.99E-03	2.26E+01	4.35E+06	3.00E+01	-1.33E-03
34	4.60E-03	4.58E-01	1.25E+03	1.71E+05	1.00E+00	1.00E+00	0.0	4.53E+01	1.49E-03	4.31E+01	5.23E+06	1.00E+00	2.95E-05
33	4.60E-03	3.87E-01	1.23E+03	1.73E+05	1.00E+00	1.00E+00	0.0	4.47E+01	1.35E-03	3.84E+01	5.25E+06	1.00E+00	2.69E-05
32	4.61E-03	3.88E-01	1.25E+03	1.75E+05	1.00E+00	1.00E+00	0.0	3.76E+01	1.14E-03	3.21E+01	5.27E+06	1.00E+00	1.83E-05
31	4.60E-03	3.90E-01	1.24E+03	1.76E+05	1.00E+00	1.00E+00	0.0	3.06E+01	9.31E-04	2.61E+01	5.28E+06	1.00E+00	9.53E-06
30	4.60E-03	3.87E-01	1.23E+03	1.77E+05	1.00E+00	1.00E+00	0.0	2.88E+01	8.59E-04	2.41E+01	5.29E+06	1.00E+00	3.27E-07
29	4.60E-03	3.78E-01	1.23E+03	1.77E+05	1.00E+00	1.00E+00	0.0	2.77E+01	7.97E-04	2.23E+01	5.29E+06	1.00E+00	-2.32E-06
28	4.60E-03	3.61E-01	1.23E+03	1.77E+05	1.00E+00	1.00E+00	0.0	2.76E+01	7.45E-04	2.09E+01	5.29E+06	1.00E+00	-5.47E-06
27	4.60E-03	3.32E-01	1.23E+03	1.77E+05	1.00E+00	1.00E+00	0.0	2.81E+01	6.93E-04	1.92E+01	5.29E+06	1.00E+00	-8.88E-06
26	4.66E-03	2.93E-01	1.70E+03	1.77E+05	1.00E+00	1.00E+00	0.0	2.28E+01	5.33E-04	1.45E+01	5.30E+06	1.00E+00	-1.08E-05
25	4.66E-03	2.93E-01	1.69E+03	1.77E+05	1.00E+00	1.00E+00	0.0	1.81E+01	4.23E-04	1.15E+01	5.29E+06	1.00E+00	-1.54E-05
24	4.66E-03	2.93E-01	1.66E+03	1.77E+05	1.00E+00	1.00E+00	0.0	1.42E+01	3.32E-04	9.03E+00	5.29E+06	1.00E+00	-1.54E-05
23	4.66E-03	2.94E-01	1.69E+03	1.77E+05	1.00E+00	1.00E+00	0.0	9.85E+00	2.32E-04	6.29E+00	5.29E+06	1.00E+00	-1.21E-05
22	4.66E-03	2.95E-01	1.70E+03	1.76E+05	1.00E+00	1.00E+00	0.0	5.75E+00	1.35E-04	3.66E+00	5.29E+06	1.00E+00	-1.01E-05
21	4.66E-03	2.93E-01	1.68E+03	1.76E+05	1.00E+00	1.00E+00	0.0	-2.38E+00	-5.57E-05	-1.51E+00	5.29E+06	1.00E+00	-1.23E-05
20	4.66E-03	2.93E-01	1.69E+03	1.75E+05	1.00E+00	1.00E+00	0.0	-9.38E+00	-2.21E-04	-5.97E+00	5.29E+06	1.00E+00	-1.86E-05
19	4.66E-03	2.96E-01	1.66E+03	1.74E+05	1.00E+00	1.00E+00	0.0	-1.48E+01	-3.52E-04	-9.54E+00	5.29E+06	1.00E+00	-3.07E-05
18	4.66E-03	3.01E-01	1.64E+03	1.73E+05	1.00E+00	1.00E+00	0.0	-2.00E+01	-4.85E-04	-1.31E+01	5.29E+06	1.00E+00	-4.50E-05
17	4.66E-03	3.06E-01	1.68E+03	1.72E+05	1.00E+00	1.00E+00	0.0	-2.00E+01	-4.99E-04	-1.35E+01	5.29E+06	1.00E+00	-5.92E-05
16	4.66E-03	3.18E-01	1.67E+03	1.72E+05	1.00E+00	1.00E+00	0.0	-1.18E+01	-3.01E-04	-8.18E+00	5.29E+06	1.00E+00	-7.23E-05
15	4.65E-03	3.23E-01	1.70E+03	1.72E+05	1.00E+00	1.00E+00	0.0	-3.97E+00	-1.03E-04	-2.80E+00	5.29E+06	1.00E+00	-7.73E-05
14	4.64E-03	3.28E-01	1.61E+03	1.73E+05	1.00E+00	1.00E+00	0.0	3.91E+00	1.03E-04	2.82E+00	5.27E+06	1.00E+00	-7.25E-05
13	4.63E-03	3.38E-01	1.55E+03	1.74E+05	1.00E+00	1.00E+00	0.0	8.04E+00	2.13E-04	5.83E+00	5.26E+06	1.00E+00	-5.54E-05
12	4.63E-03	3.33E-01	1.51E+03	1.77E+05	1.00E+00	1.00E+00	0.0	-1.22E-01	-3.28E-06	-8.94E-02	5.25E+06	1.00E+00	-3.26E-05
11	4.62E-03	3.51E-01	1.49E+03	1.78E+05	1.00E+00	1.00E+00	0.0	-6.04E+00	-1.94E-04	-5.27E+00	5.23E+06	1.00E+00	-1.44E-05
10	4.61E-03	4.66E-01	1.46E+03	1.79E+05	1.00E+00	8.74E-01	-1.59E+00	-4.76E+01	-1.96E-03	-9.90E+00	5.23E+06	3.00E+01	-2.64E-06
9	4.61E-03	8.68E+00	1.22E+03	1.79E+05	9.94E-01	6.02E-01	-1.29E+00	-3.86E+01	-2.27E-03	-3.08E+00	5.36E+06	3.00E+01	-1.47E-04
8	4.61E-03	2.74E+01	1.22E+03	1.79E+05	9.81E-01	2.10E-01	-1.12E+00	-2.04E+01	-3.32E-03	-1.39E+00	5.07E+06	1.82E+01	-3.90E-04
7	4.61E-03	7.61E+01	1.22E+03	1.78E+05	9.36E-01	3.03E-02	-1.56E+00	-1.11E+01	-1.11E-02	-1.61E+00	3.05E+06	7.09E+00	-2.34E-03
6	4.60E-03	2.01E+02	1.22E+03	1.69E+05	8.20E-01	4.84E-03	-2.81E+00	-8.57E+00	-4.27E-02	-2.82E+00	1.82E+06	3.05E+00	-1.29E-02
5	4.60E-03	3.69E+02	1.21E+03	1.59E+05	6.46E-01	2.61E-04	-1.62E+00	-2.05E+00	-6.25E-02	-1.61E+00	1.66E+06	1.27E+00	1.72E-05
4	4.58E-03	7.44E+02	1.13E+03	1.57E+05	0.0	0.0	-8.28E-01	0.0	-4.90E-02	-8.29E-01	1.19E+06	1.00E+00	3.37E-06
3	4.56E-03	7.93E+02	9.38E+02	1.58E+05	0.0	0.0	-7.90E-01	0.0	-4.88E-02	-7.90E-01	9.43E+05	1.00E+00	4.16E-06
2	4.56E-03	8.22E+02	8.18E+02	1.59E+05	0.0	0.0	-7.68E-01	0.0	-4.87E-02	-7.68E-01	7.92E+05	1.00E+00	3.93E-06
1	4.55E-03	8.41E+02	7.39E+02	1.60E+05	0.0	0.0	-9.56E-02	0.0	-4.82E-02	-9.56E-02	6.92E+05	1.00E+00	3.79E-06

Table 3 : SANDCMOT sodium boiling output

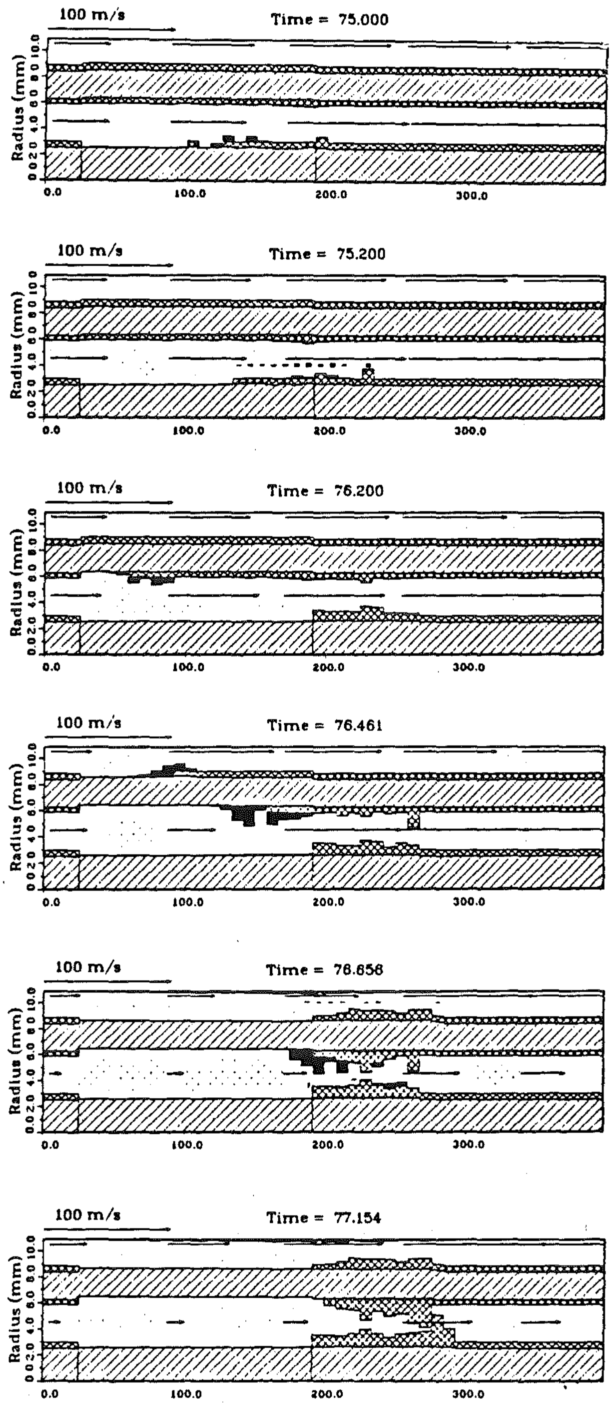
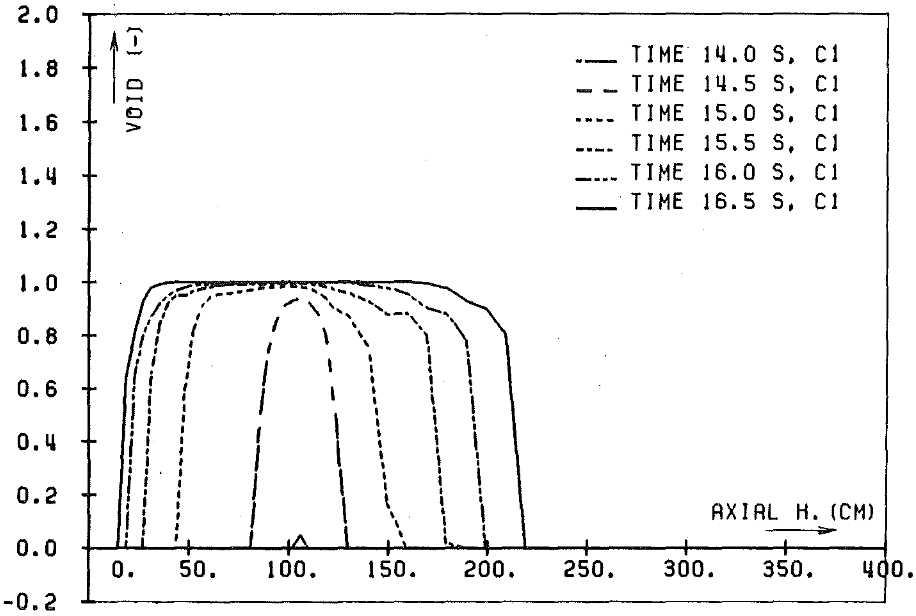


Fig. 6 : Clad motion history in STAR2



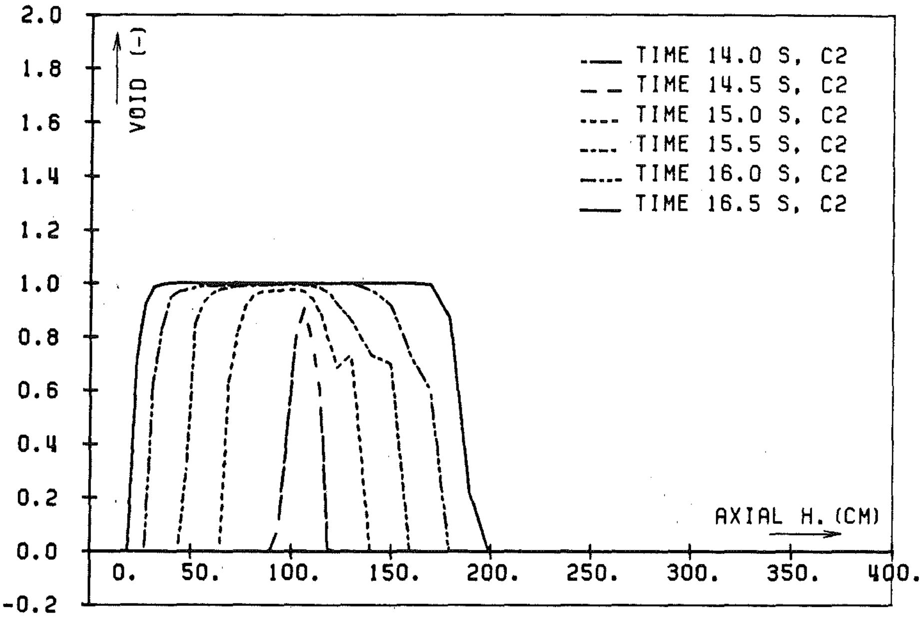


Fig. 7 : Void profile development in TREAT-R5 (according to SANDCMOT)
C1 : inner channel, C2: outer channel.