RELAP5-3D

Lecture 14

Modeling a PWR Core

Spiritual Thought

“As we focus our lives on the truths we know about God’s plan of salvation and the Atonement of Jesus Christ, we can echo the expression that everything will be all right in the end—and if it’s not all right, it’s not the end.”

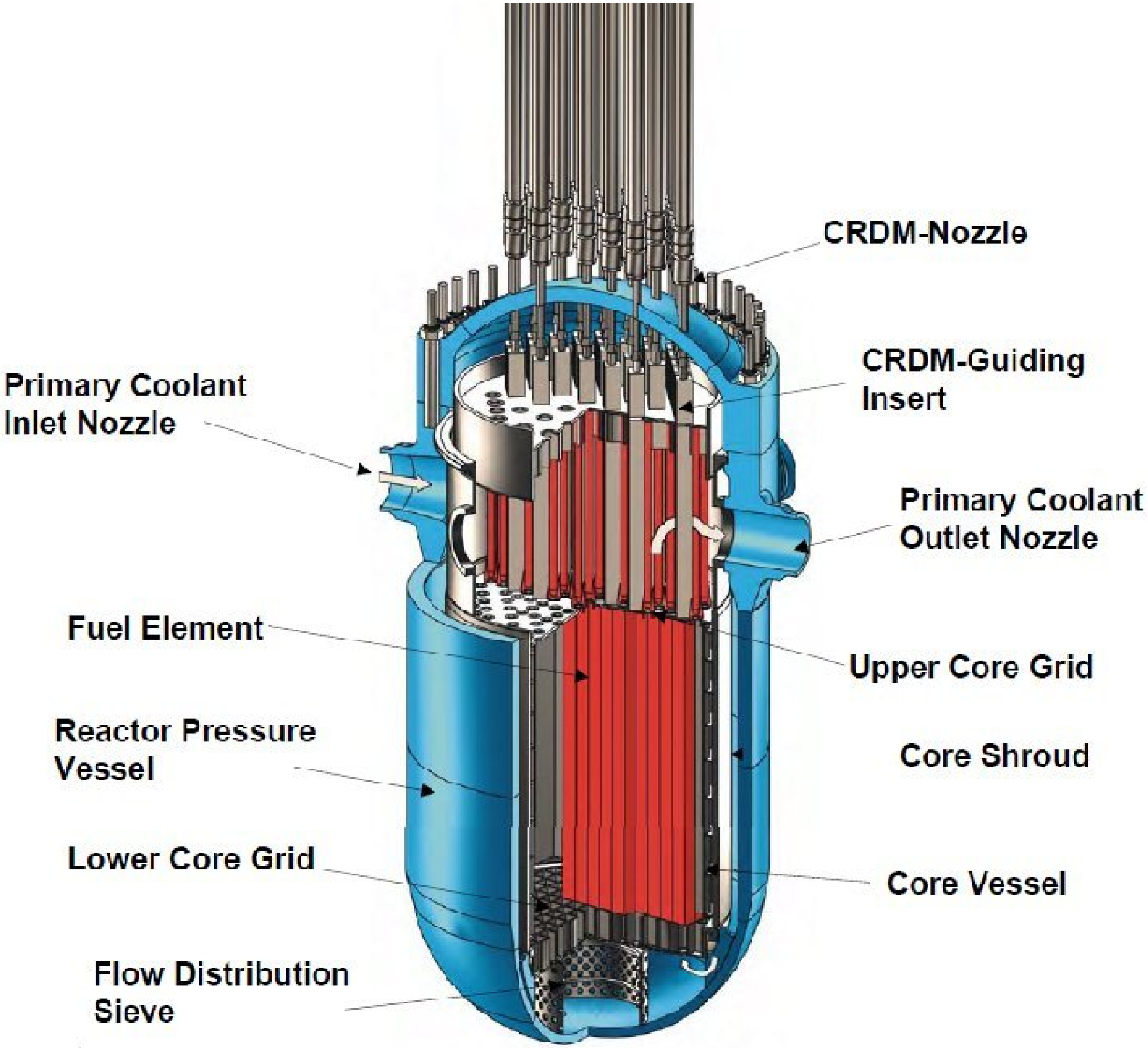
Morgan Young

BYU

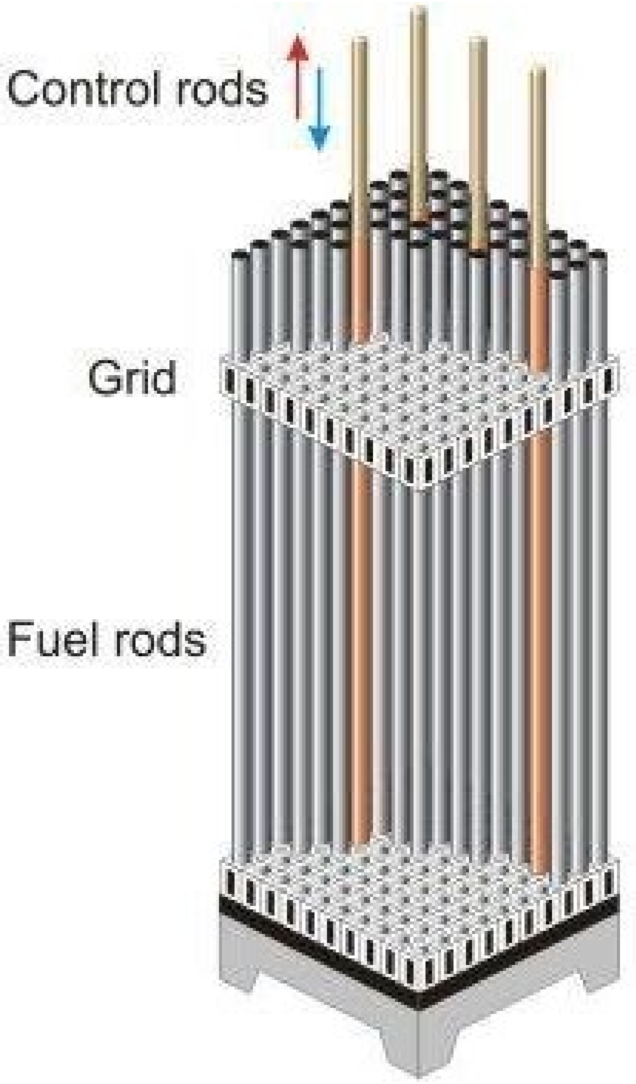
Objectives

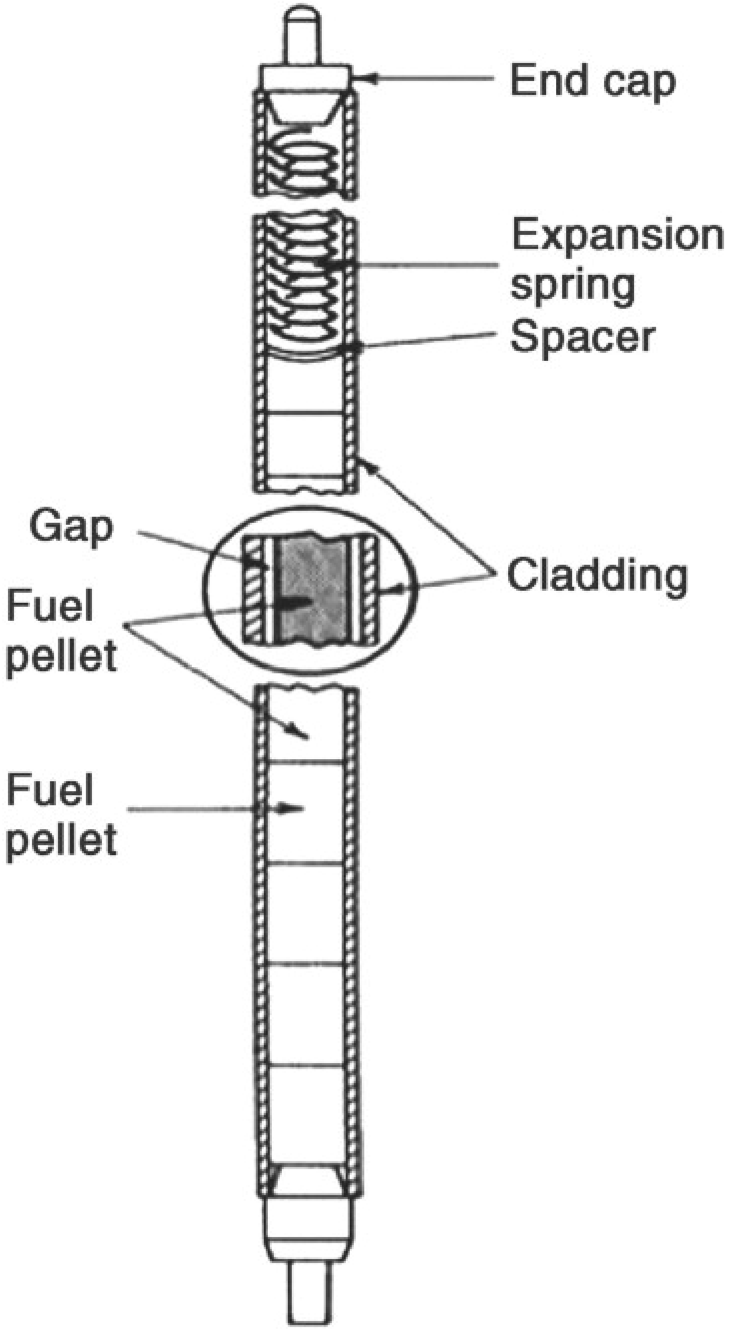
- Learn about the structure of a PWR core
- Learn about how a PWR core is modeled in RELAP

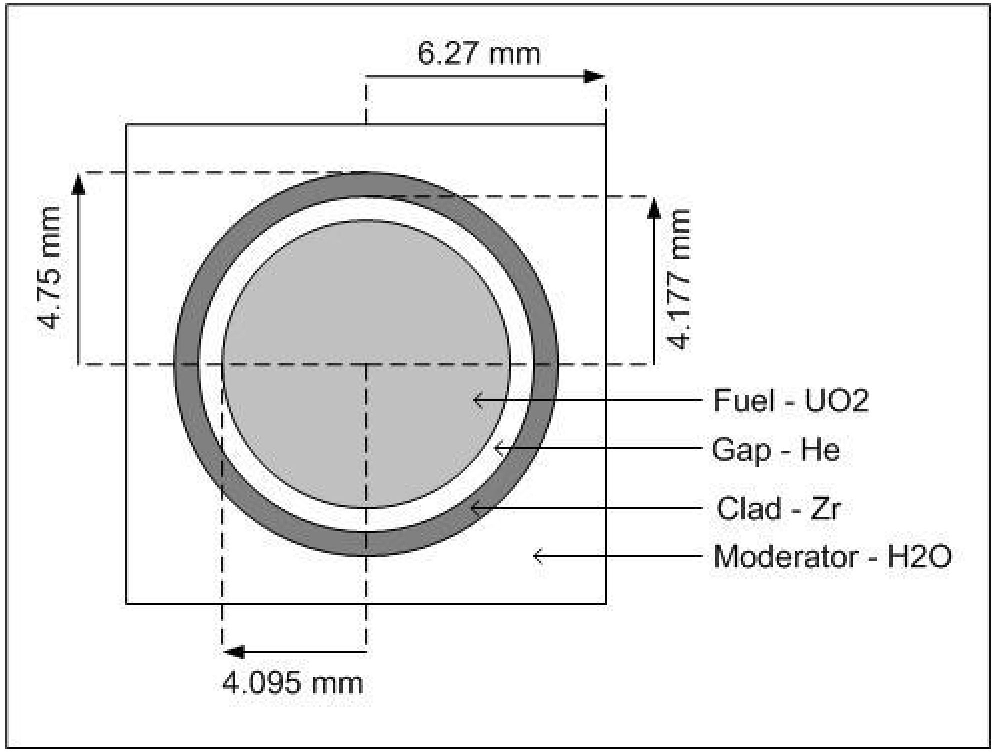
PWR Core


CRDM-Nozzle
CRDM-Guiding Insert
Primary Coolant Inlet Nozzle
Primary Coolant Outlet Nozzle
Fuel Element
Upper Core Grid
Reactor Pressure Vessel
Core Shroud
Lower Core Grid
Core Vessel
Flow Distribution Sieve

Fuel Rod


Control rods
Grid
Fuel rods


End cap
Expansion spring
Spacer
Gap
Fuel pellet
Cladding
Fuel pellet


6.27 mm
4.75 mm
4.177 mm
Fuel - UO2
Gap - He
Clad - Zr
Moderator - H2O
4.095 mm

BYU

Problem Statement

- Develop a simple model of a reactor core. The core contains 150 fuel assemblies, with a total power of 900 MW. 100 of the assemblies have 10% above average power, and 50 of the assemblies have 20% below average power. For the 100 higher powered assemblies, which are arranged in a 10 x 10 array, 3% of the power is deposited directly into the coolant (instead of into the fuel). For the 50 assemblies located around the higher-powered assemblies, all of the power is generated in the fuel. The fuel assemblies are generally arranged in a 13 x 13 array of fuel rods

Problem Statement (2)

- There is a flow area reduction of 10% at the core outlet
- The inlet and outlet plenums have flow areas of $4m^2$ and heights of 1.0m.
- The liquid velocity through the inlet plenum is 1.5 m/s; it's liquid temperature is 550 K. The source pressure is 15.0 Mpa, and the pressure above the core outlet plenum is 14.2 Mpa.

BYU

Problem Statement (3)

- Fuel Pin Data
  - Length = 3.6 m
  - Pellet O.D. = 7.6 mm
  - Cladding I.D. = 7.8 mm
  - Cladding O.D. = 9.0 mm
  - Axial Power Profile = flat (uniform)

BYU

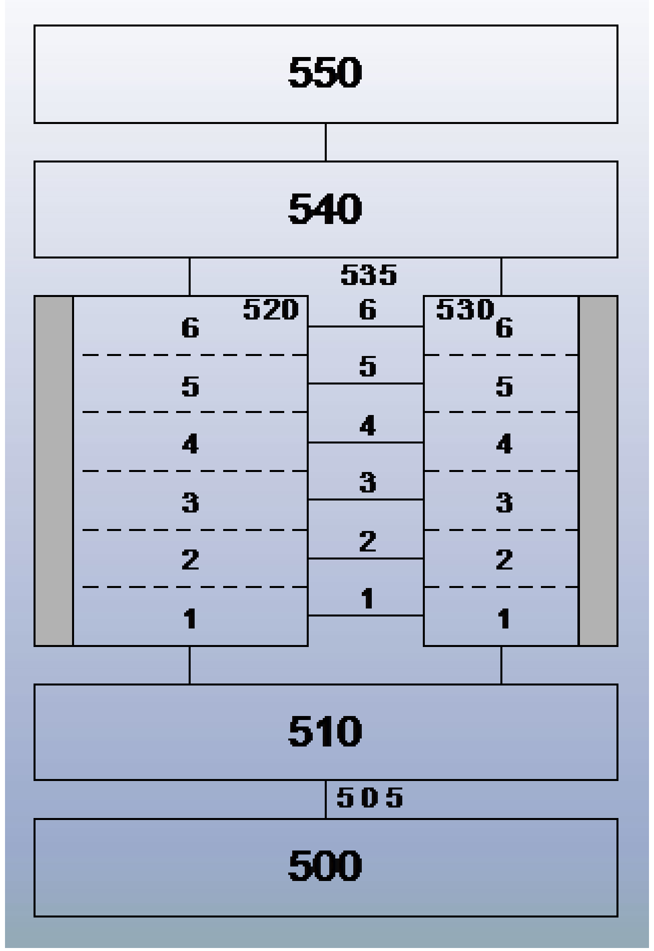
Problem Statement (4)

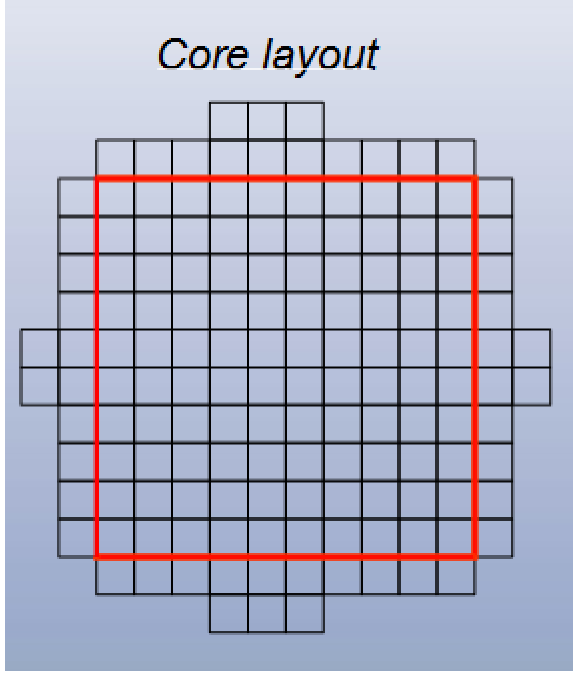
- Flow Area = $0.014 m^2$
- Hydraulic Diameter = 0.0132 m
- Fuel Rod Pitch = 11.7 mm
- Number of grid spacers = 7
- Flow Area at Grid Spacers = $0.01 m^2$
- Loss Coefficient at Grid Spacers = 1.0
- Inlet Loss Coefficients: $K_f = 0.5$, $K_r = 0.7$
- Outlet Loss Coefficients: $K_f = K_r = 1.3$

BYU

Nodalization Diagram

- 500 – Source
- 505 – Inlet
- 510 – Lower Plenum
- 520 – 100 Assemblies
- 530 – 50 Assemblies
- 535 – Multiple Junction
- 540 – Upper Plenum
- 550 – Sink





BYU

Goal

- Using reactor kinetics, determine the steady state conditions in the core.

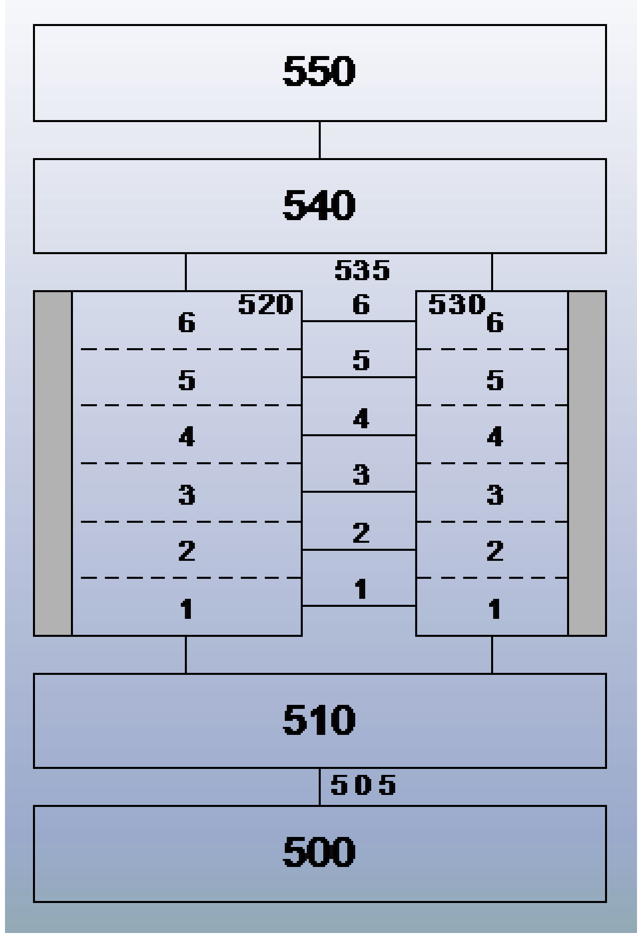
Start Easy, Control Cards

```
*******************************************************************************
*                                                                             *
*                        Miscellaneous Control Cards                          *
*                                                                             *
*******************************************************************************
*
*       Type      Option
100     new       stdy-st
*       Inp-Chk/Run
101     run
*       Input-Units     Output-Units
102     si              si
*       CPUrem1    CPUrem2    CPUalloted
105     5.0        6.0        5000.0
*       Ref-Vol         Elev     Fluid    Name
120     500010000       0.0      h2o      'Primary'
*
*******************************************************************************
*                                                                             *
*                            Time Step Control Cards                          *
*                                                                             *
*******************************************************************************
*
*       TimeEnd   MinStep   MaxStep   Ssdtt    MinorEditFreq   MajEditFreq   ResrtFreq
201     300.      1.0e-6    0.2       00007    1               300           300
*
```

BYU

Hydrodynamic Components

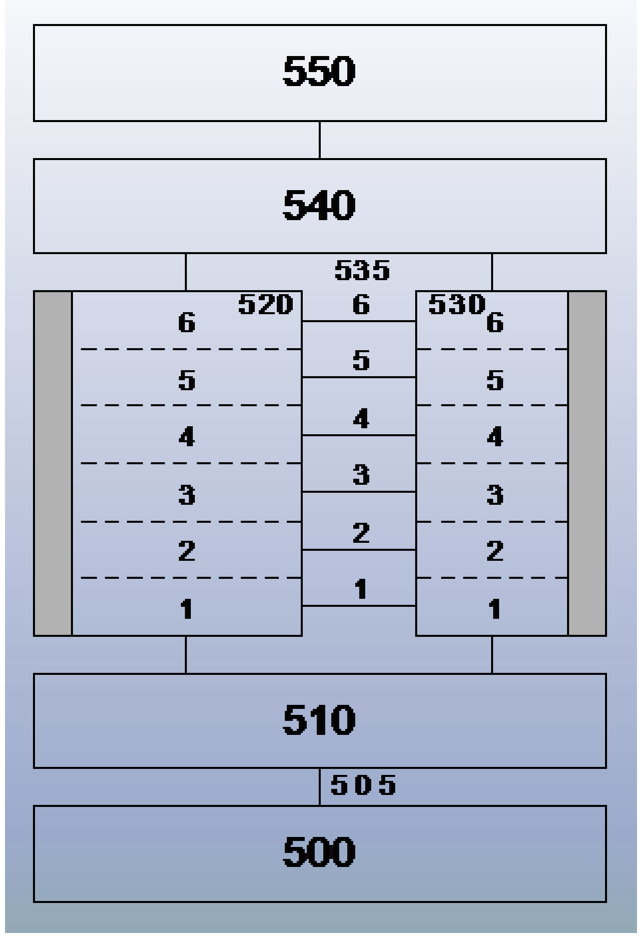
```
*********************************
*  Time Dependent Volume - 500  *
*********************************
*          Name     Type
5000000    source     tmdpvol
*          Area     Length    Volume
5000101    4.0      1.0       0.0
*          AzimAng    InclAng    ElevationChange
5000102    0.0        90.0       1.0
*          Roughness  HydraulicDiam  Tlpvbfe
5000103    0.0         0.0           0000000
*          Ebt        TripNum    SearchVar
5000200    003        0          time
*          SearchVar       Initial-Conditions
5000201    0.0             15.0e6     550.0
*
```



BYU

Hydrodynamic Components

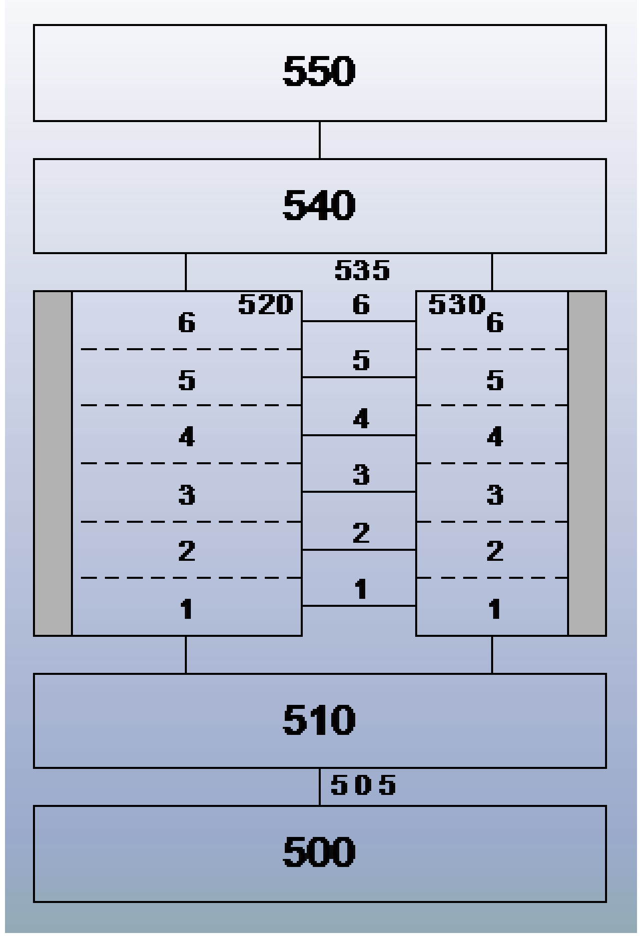
```
**********************************
*  Time Dependent Junction - 505  *
**********************************
*          Name    Type
5050000    jun1    tmdpjun
*          From          To           Area    Jefvcahs
5050101    500010000     510000000    0.0     00000000
*          Vel/Mfr    TripNum    SearchVar
5050200    0          0          time
*          SearchVar    Liquid    Vapor    Interface
5050201    0.0          1.5       0.0      0.0
*
```



BYU

Hydrodynamic Components

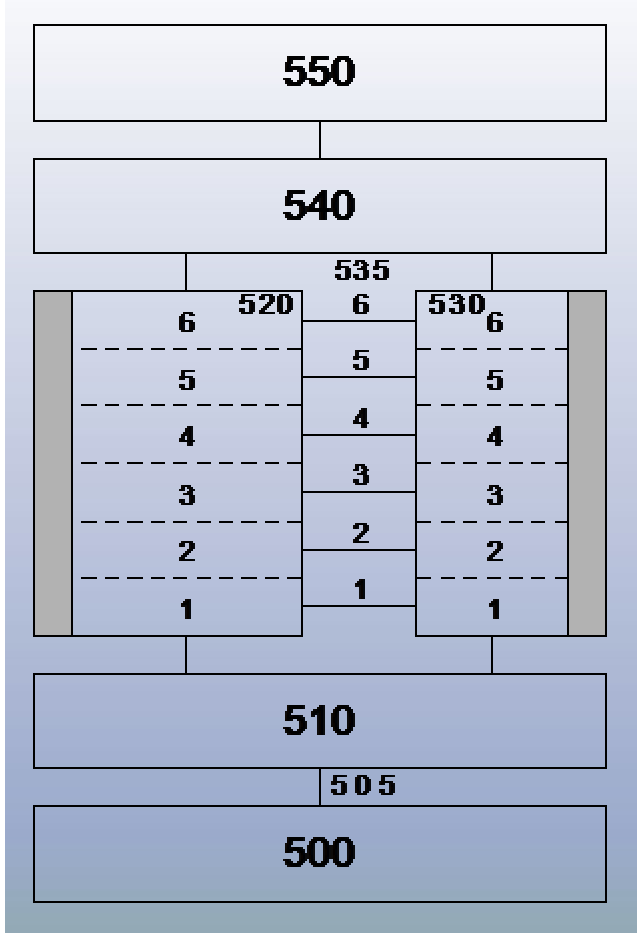
```
********************************
*   Branch/Sepatator - 510     *
********************************
*          Name       Type
5100000    inplen     branch
*          NumOfJunctions     Vel/Mfr
5100001    2                  1
*          Area     Length   Volume
5100101    4.0      1.0      0.0
*          AzimAng  InclAng   ElevationChange
5100102    0.0       90.      1.0
*          Roughness  HydraulicDiam  Tlpvbfe
5100103    0.0        0.0            0000000
*          Ebt        Initial-Conditions
5100200    003        15.0e6      550.
*          From       To          Area  Kt   Kr   Efvcahs
5101101    510010000  520010001   1.26  0.5  0.7  0000000
5102101    510010000  530010001   0.63  0.5  0.7  0000000
*          Liquid     Vapor     Interface
5101201    3.0        3.0       0.0
5102201    3.0        3.0       0.0
*
```



BYU

Hydrodynamic Components

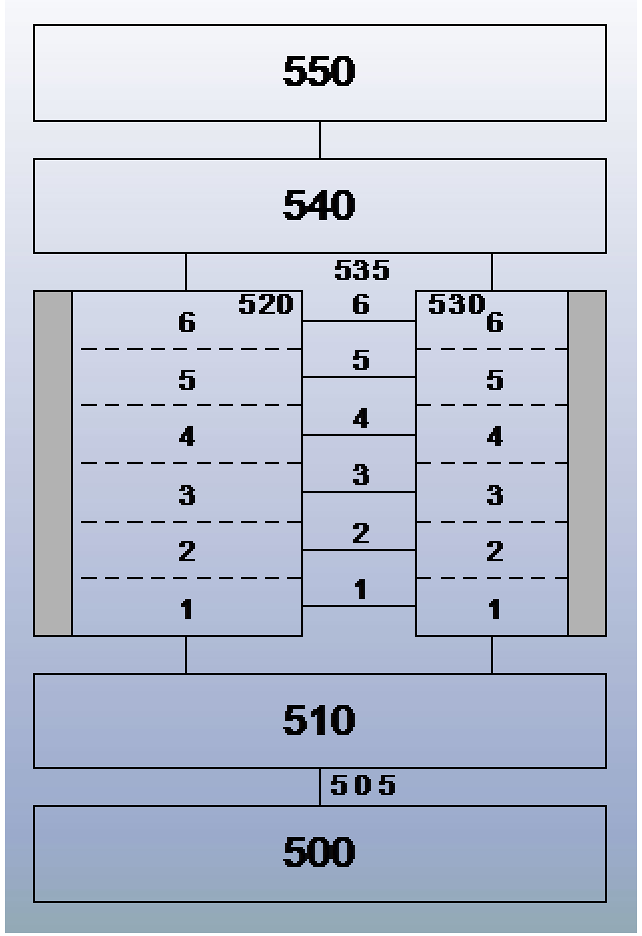
```
*********************************
*          Pipe - 520           *
*********************************
*          Name      Type
5200000    bigcor    pipe
*          NumOfVolumes
5200001    6
*          Area                       VolNum
5200101    1.4                        6
*          Length                     VolNum
5200301    0.6                        6
*          y-Length                   VolNum
5201801    0.45                       6
*          InclAng                    VolNum
5200601    90.0                       6
*          Roughness  HydraulicDiam   VolNum
5200801    0.00005    0.0132          6
*          y-Roughness  y-HydDiam     VolNum
5202301    0.0          0.0054        6
*          Af         Ar              JunNum
5200901    1.0        1.0             5
*          tlpvbfe                    VolNum
5201001    0000100                    6
*          tlpvbfe-y                  VolNum
5202701    0000010                    6
*          Jefvcahs                   JunNum
5201101    00000000                   5
*          Ebt   Initial-Conditions         VolNum
5201201    003   15.0e6  550.  0.  0.  0.   6
*          Vel/Mfr
5201300    0
*          Liquid  Vapor  Interface   JunNum
5201301    3.0     3.0    0.0         5
*          JunHydDia  Flooding  c     Slope  JunNum
5201401    0.0094     0.0       1.0   1.0    5
*
```



BYU

Hydrodynamic Components

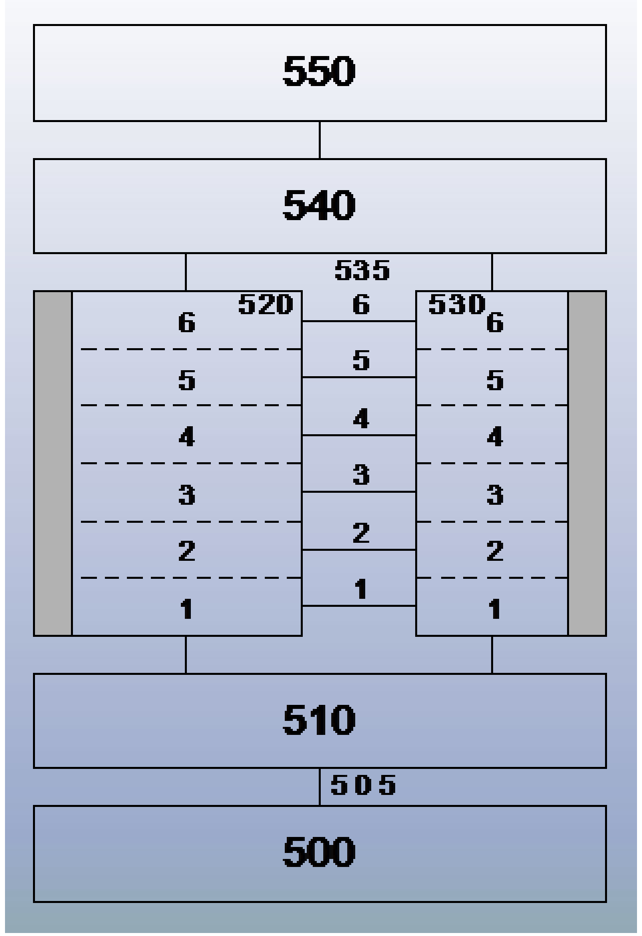
```
**********************************
*           Pipe - 530           *
**********************************
*          Name      Type
5300000    smallcor     pipe
*          NumOfVolumes
5300001    6
*          Area                          VolNum
5300101    0.7                           6
*          JunArea                       JunNum
5300201    0.0                           5
*          Length                        VolNum
5300301    0.6                           6
*          y-Length                      VolNum
5301801    0.45                          6
*          Volume                        VolNum
5300401    0.0                           6
*          AzimAng                       VolNum
5300501    0.0                           6
*          InclAng                       VolNum
5300601    90.0                          6
*          ElevationChange               VolNum
5300701    0.6                           6
*          Roughness  HydraulicDiam      VolNum
5300801    0.00005    0.0132             6
*          y-Roughness  y-HydDiam        VolNum
5302301    0.0          0.0054           6
*          Af         Ar                 JunNum
5300901    1.0        1.0                5
*          tlpvbfe                       VolNum
5301001    0000100                       6
*          y-tlpvbfe                     VolNum
5302701    0000010                       6
*          Jefvcahs                      JunNum
5301101    00000000                      5
*          Ebt   Initial-Conditions           VolNum
5301201    003   15.e6  550.  0.  0.  0.  6
*          Vel/Mfr
5301300    0
*          Liquid  Vapor  Interface      JunNum
5301301    3.0     3.0    0.0            5
*          JunHydDia  Flooding  c     Slope  JunNum
5301401    0.0094     0.0       1.0   1.0    5
*
```



BYU

Hydrodynamic Components

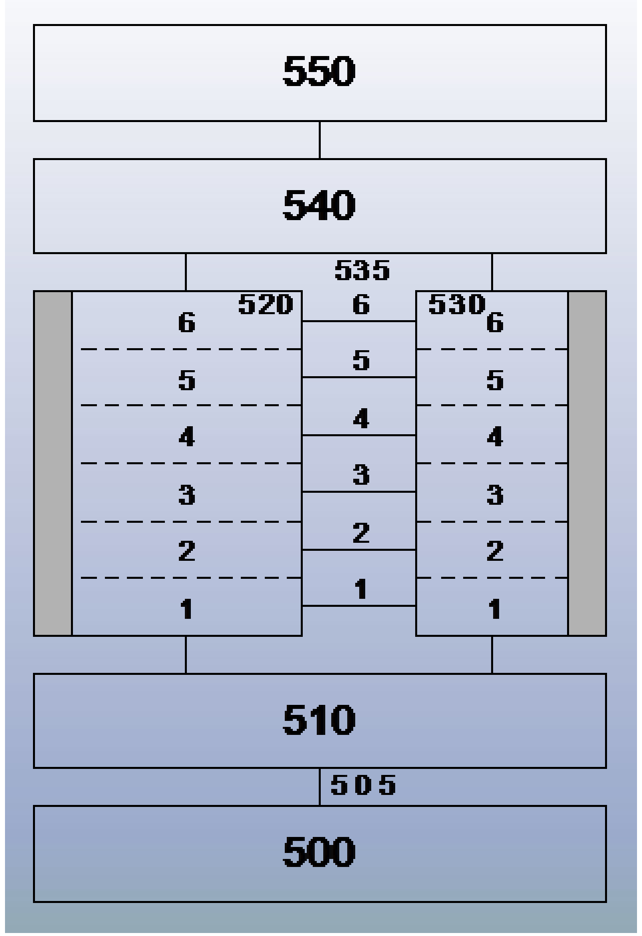
```
**********************************
*    Multiple Junction - 535     *
**********************************
*          Name        Type
5350000    corejun     mtpljun
*          NumOfJunctions    Vel/Mfr
5350001    6                 0
*          From         To           Area      Af     Ar     Jefvcahs
5350011    520010004    530010003    0.8424    10.0   10.0   00000003
*          SubDC    TPDC    SupDC   FromInc     ToInc       Zero    Limit
5350012    1.0      1.0     1.0     000010000   000010000   0       6
*          Liquid     Vapor     JunNum
5351011    0.0        0.0       6
*          HydDiam   Flooding    c      Slope     JunNum
5352011    0.0054    0.0         1.0    1.0       6
*
```



BYU

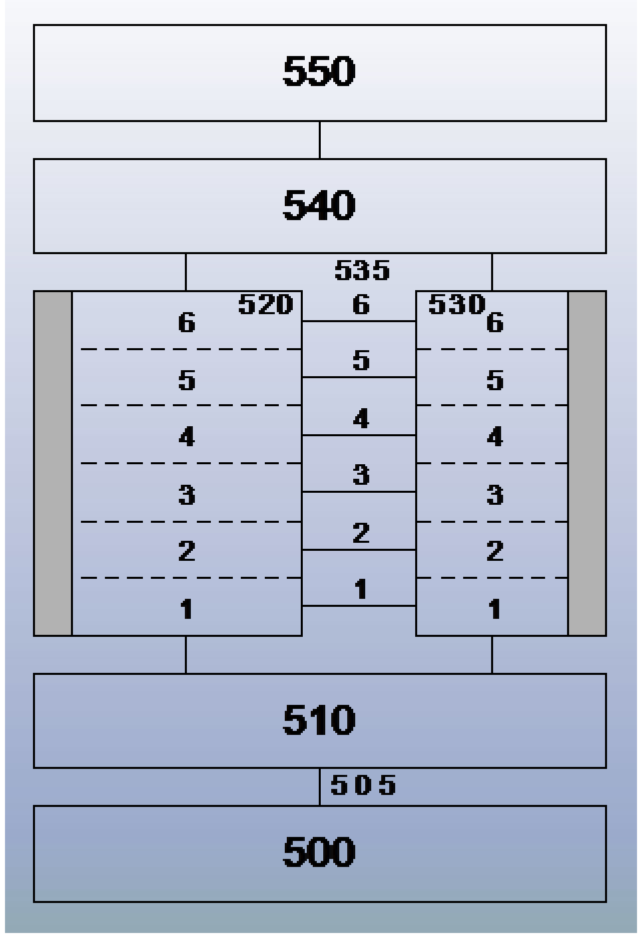
Hydrodynamic Components

```
*********************************
*   Branch/Sepatator - 540      *
*********************************
*          Name       Type
5400000    outplen    branch
*          NumOfJunctions     Vel/Mfr
5400001    3                  0
*          Area     Length    Volume
5400101    4.0      1.0       0.0
*          AzimAng   InclAng   ElevationChange
5400102    0.0       90.0      1.0
*          Roughness  HydraulicDiam  Tlpvbfe
5400103    0.00005    0.0            0000000
*          Ebt       Initial-Conditions
5400200    003       15.0e6     550.
*          From         To          Area  Kt   Kr   Efvcahs
5401101    530060002    540010001   0.63  1.3  1.3  0100000
5402101    520060002    540010001   1.26  1.3  1.3  0100000
5403101    540010002    550010001   0.0   0.0  0.0  0000000
*          Liquid    Vapor     Interface
5401201    3.0       3.0       0.0
5402201    3.0       3.0       0.0
5403201    1.5       1.5       0.0
```



Hydrodynamic Components

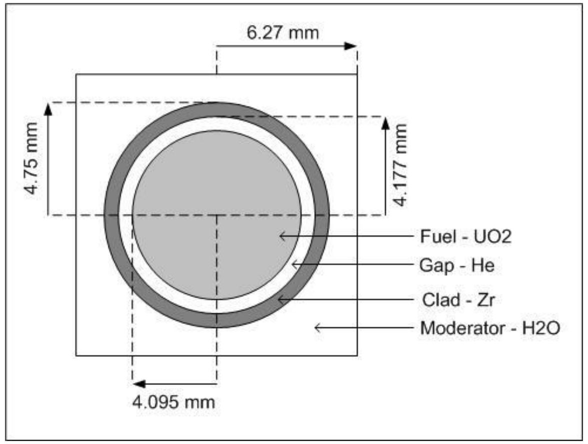
```
*********************************
*  Time Dependent Volume - 550  *
*********************************
*          Name     Type
5500000    sink     tmdpvol
*          Area     Length    Volume
5500101    4.0      1.0       0.0
*          AzimAng    InclAng    ElevationChange
5500102    0.0        90.0       1.0
*          Roughness  HydraulicDiam  Tlpvbfe
5500103    0.0         0.0            0000000
*          Ebt        TripNum    SearchVar
5500200    003        0          time
*          SearchVar       Initial-Conditions
5500201    0.0             14.2e6     550.
*
```

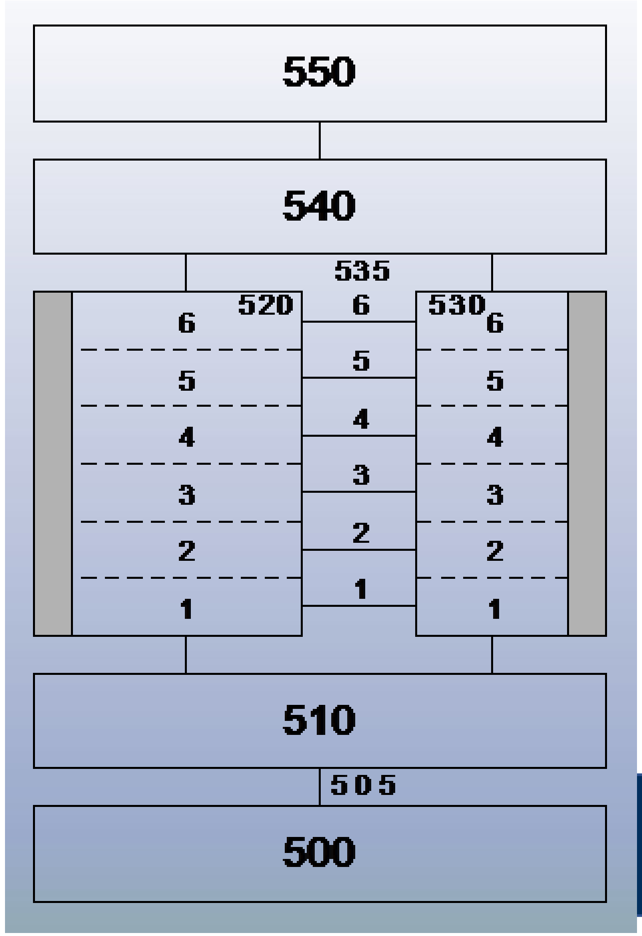


BYU

Heat Structures

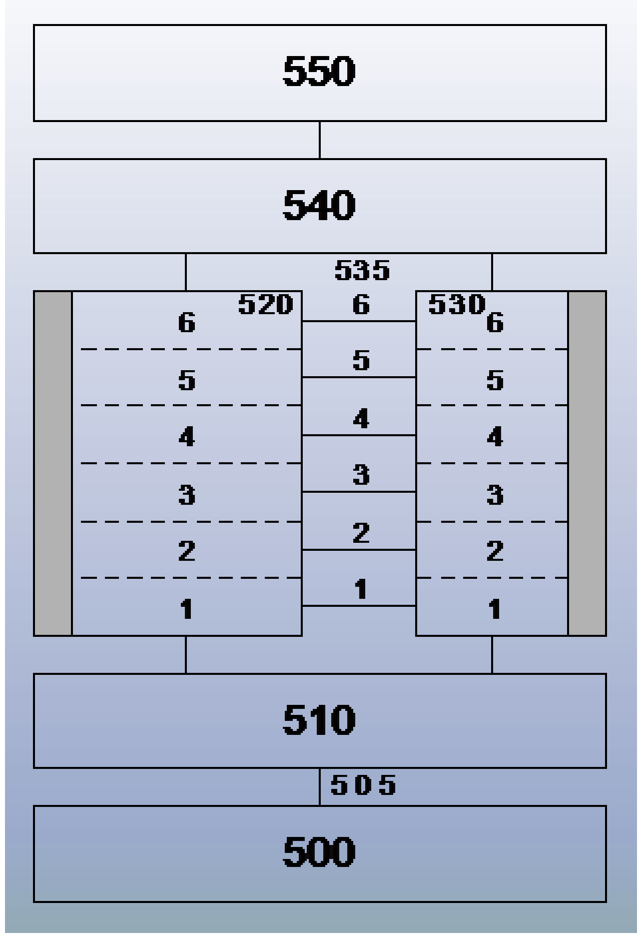
```
**********************************
*    Heat Structure - 520        *
**********************************
*
*            AxialHS  RadMesh  GeoType  SSFlag  LeftBound
15201000     6        10        2       1       0.0
*            MeshLocation      MeshFormat
15201100     0                 1
*            NumOfIntervals    RightCoordinate
15201101     6                 0.0038
15201102     1                 0.0039
15201103     2                 0.0045
*            CompositionNum    IntervalNum
15201201     200               6
15201202     -300              7
15201203     -400              9
*            SourceValue       IntervalNum
15201301     1.0               6
15201302     0.0               9
*            InitialTemp       MeshPointNum
15201401     550.0             10
*            BoundaryVol/Table  Incr   BCType  SACode  SA/Factor  HSNum
15201501     0                  0      0       0       0.0        6
*            BoundaryVol/Table  Incr   BCType  SACode  SA/Factor  HSNum
15201601     520010000          10000  111     1       9000.0     6
*            SourceType  Pf      LeftBoundMult  RightBoundMult  HSNum
15201701     1000        0.1186  0.0            0.0037          6
*            WordFormat
15201900     1
*            HydDiam HLFor HLRev GSLFor GSLRev GLCFor GLCRev Boil Ncl PtD  FF  HSNum
15201901     0.013   0.3   3.3   0.3    0.3    1.0    1.0    1.0  3.6 1.3  1.0 1
15201902     0.013   0.9   2.7   0.3    0.3    1.0    1.0    1.0  3.6 1.3  1.0 2
15201903     0.013   1.5   2.1   0.3    0.3    1.0    1.0    1.0  3.6 1.3  1.0 3
15201904     0.013   2.1   1.5   0.3    0.3    1.0    1.0    1.0  3.6 1.3  1.0 4
15201905     0.013   2.7   0.9   0.3    0.3    1.0    1.0    1.0  3.6 1.3  1.0 5
15201906     0.013   3.3   0.3   0.3    0.3    1.0    1.0    1.0  3.6 1.3  1.0 6
*
```





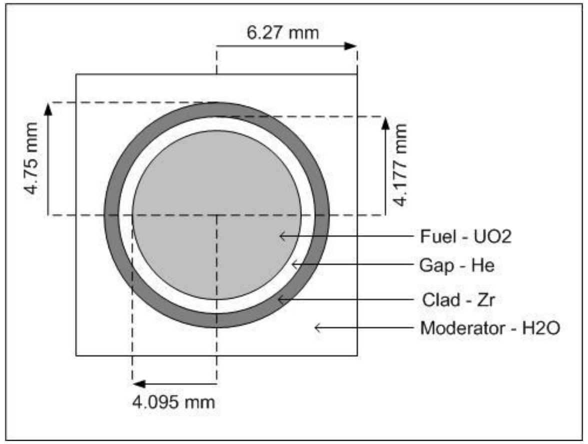
Heat Structures

```
*********************************
*    Heat Structure - 530        *
*********************************
*
*            AxialHS  RadMesh  GeoType  SSFlag  LeftBound  Reflood
15301000     6        10       2        1       0.0        0
*            MeshLocation
15301100     5201
*            InitialTemp      MeshPointNum
15301401     550.             10
*            BoundaryVol/Table  Incr   BCType  SACode  SA/Factor  HSNum
15301501     0                  0      0       0       0.0        6
*            BoundaryVol/Table  Incr   BCType  SACode  SA/Factor  HSNum
15301601     530010000          10000 111      1       4500.0     6
*            SourceType  Pf     LeftBoundMult   RightBoundMult  HSNum
15301701     1000        0.0444 0.0             0.0             6
*            WordFormat
15301900     1
*            HydDiam HLFor HLRev GSLFor GSLRev GLCFor GLCRev Boil Ncl PtD  FF  HSNum
15301901     0.013   0.3   3.3   0.3    0.3    1.0    1.0    1.0  3.6 1.3  1.0 1
15301902     0.013   0.9   2.7   0.3    0.3    1.0    1.0    1.0  3.6 1.3  1.0 2
15301903     0.013   1.5   2.1   0.3    0.3    1.0    1.0    1.0  3.6 1.3  1.0 3
15301904     0.013   2.1   1.5   0.3    0.3    1.0    1.0    1.0  3.6 1.3  1.0 4
15301905     0.013   2.7   0.9   0.3    0.3    1.0    1.0    1.0  3.6 1.3  1.0 5
15301906     0.013   3.3   0.3   0.3    0.3    1.0    1.0    1.0  3.6 1.3  1.0 6
*
```



Thermal Properties

```
********************************************************************************
*                                                                              *
*                            Thermal Property Data                             *
*                                                                              *
********************************************************************************
*
*           MaterialType
20120000    uo2
20130000    gap
20140000    zr
*
```



Kinetics

```
****************************************************************************
*                                                                          *
*                                  Kinetics                                *
*                                                                          *
****************************************************************************
*
*            KineticsType      FeedbackType
30000000     point             separabl
*            Decay      Power     React    NFrac YFact  U239
30000001     gamma-ac   900.e+6   -1.e-60  379.  1.0    1.0
*            Type      E/Fiss
30000002     ans79-1   200.
*            Power      Time     Units
30000401     900.0e6    180.0    day
*
.
```

BYU

Goal 2

- Using a power table, increase the power from 900 to 1200 MW over the first 100s, then steadily increase it to 3000 MW at 500s. When fuel rod heatup begins at the top of the core, reduce power back to 900 MW. Heatup is defined as exceeding 5 K superheat for at least 5s. Determine the power at which fuel rod heatup began.

BYU

Power Table

```
*******************************************************************************
*                                                                             *
*                            Power Table Data                                 *
*                                                                             *
*******************************************************************************
*
*           TableType  TripNum
20252000    power       602
*           Time    Power
20252001    -1.0    900.e6
20252002    0.0     900.e6
20252003    100.0   1200.e6
20252004    500.0   3000.e6
*
```

BYU

Trips

```
********************************************************************************
*                                                                              *
*                                    Trips                                     *
*                                                                              *
********************************************************************************
*
*      VarCode  Parameter  Rel  VarCode  Parameter  AddConst  Latch
501    tempg    520060000  gt   sattemp  520060000  5.0       n
502    time     0          gt   timeof   501        5.0       n
*      TripNum  Operator  TripNum  Latch
601    501      and       502      l
602    -601     or        -601     n
*
```

BYU

Control Variables

```
*******************************************************************************
*                                                                             *
*                     Control System Input Data                               *
*                                                                             *
*******************************************************************************
*
*           Format
20500000    9999
*           Name    Type         ScalingFactor  InitialValue  Flag
20500010    power   function     1.0            900.e6        0
*           Code     Value    Table
20500011    time     0        520
*
*           Name      Type         ScalingFactor  InitialValue  Flag
20500020    poweron   tripunit     1.0            1.0           0
*           TripNum
20500021    602
*
*           Name      Type         ScalingFactor  InitialValue  Flag
20500030    powerm    mult         1.0            900.e6        0
*           Name       Value  Name       Value
20500031    cntrlvar   1      cntrlvar   2
*
*           Name        Type         ScalingFactor  InitialValue  Flag
20500040    maxpower    stdfnctn     1.0            900.e6        0
*           Fnctn  Name       Value  Name       Value
20500041    max    cntrlvar   1      cntrlvar   2
```

BYU

What did we use?

- Miscellaneous control cards
- Time step control cards
- Variable trips
- Logical trips
- Time dependent volume
- Branch
- Pipe
- Time dependent junction
- Multiple junction
- Heat structure
- Thermal property data
- Kinetics
- Power table
- Control variables
- Terminator card (.)

BYU

Your Project

- You will need to use most (if not all) of the components discussed today.
- Become familiar with them
  - How to use them
  - How they work
- If you have questions, the sample problems in the DVDs are quite helpful
  - Use the DVDs or this presentation to try to work through this example
  - Dr. Memmott and I can help as well
- Are the any questions about your project so far?

Assignment

- Homework 7 due Tuesday (10/20) at midnight