Chemical Engineering 512

Nuclear Reactor Transient Modeling

Lecture 14

Modeling a PWR Core

Spiritual Thought

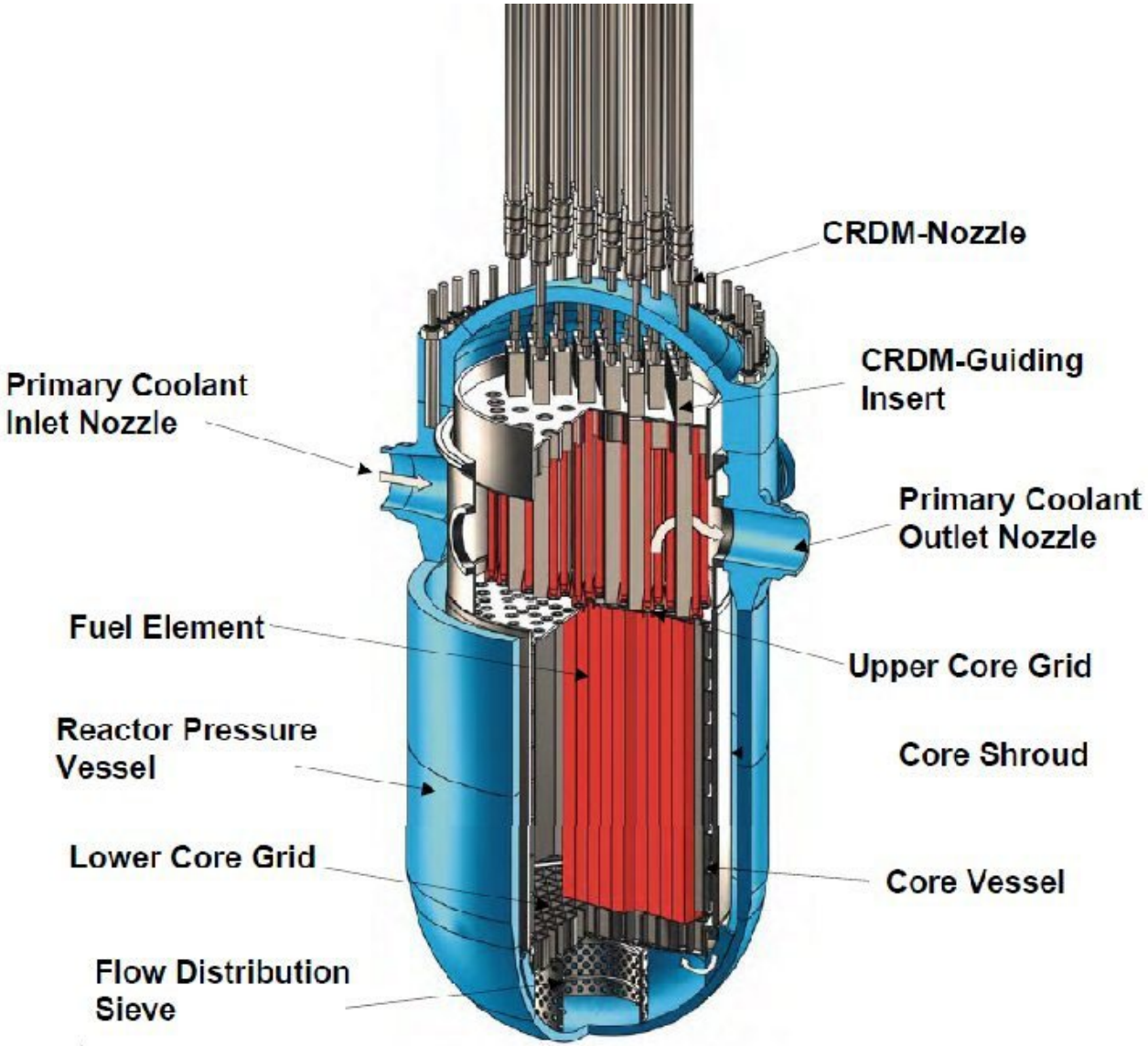
"Sooner or later, I believe that all of us experience times when the very fabric of our world tears at the seams, leaving us feeling alone, frustrated, and adrift. It can happen to anyone. No one is immune. Everyone's situation is different, and the details of each life are unique. Nevertheless, I have learned that there is something that would take away the bitterness that may come into our lives. There is one thing we can do to make life sweeter, more joyful, even glorious. We can be grateful!"

– Elder Dieter F. Uchtdorf

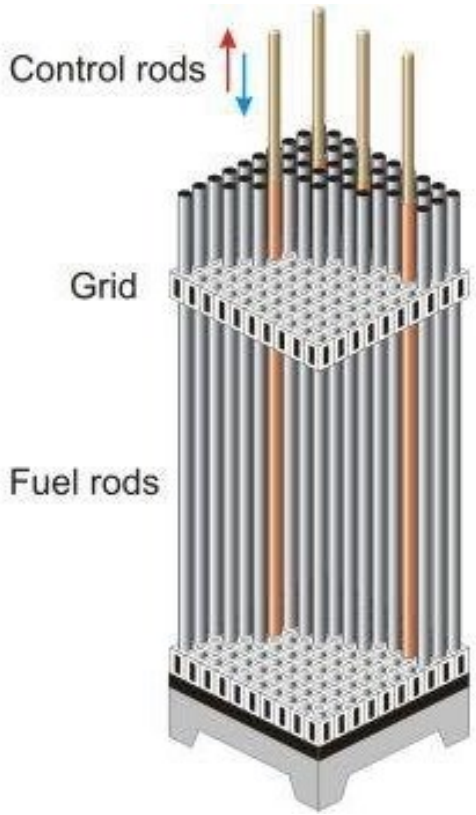
Objectives

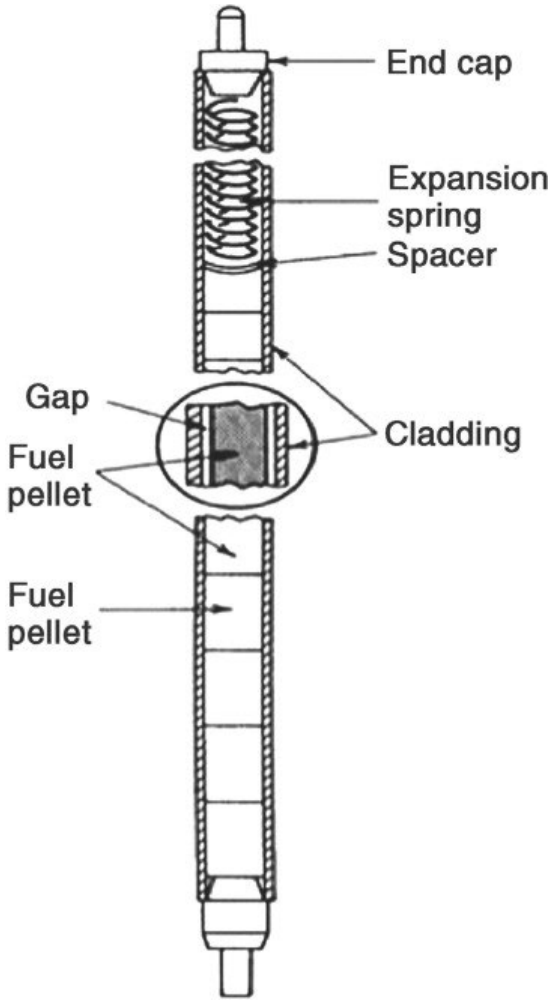
- Learn about the structure of a PWR core
- Learn about how a PWR core is modeled in RELAP

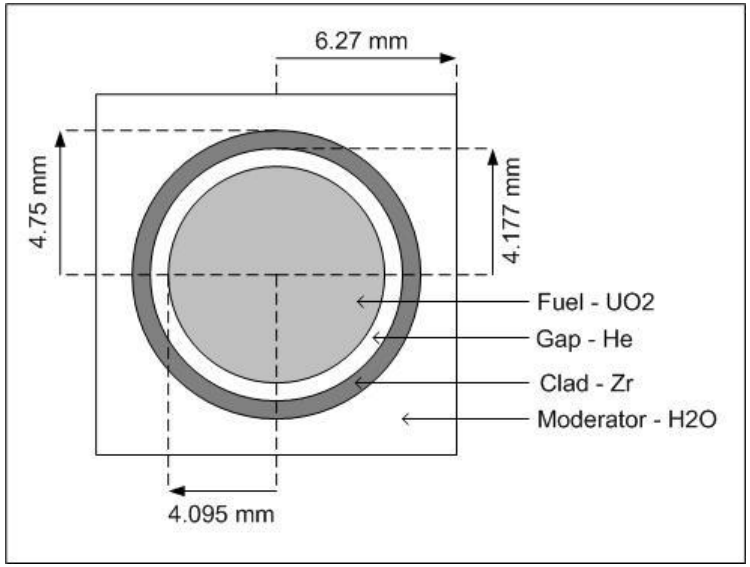
PWR Core


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

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.

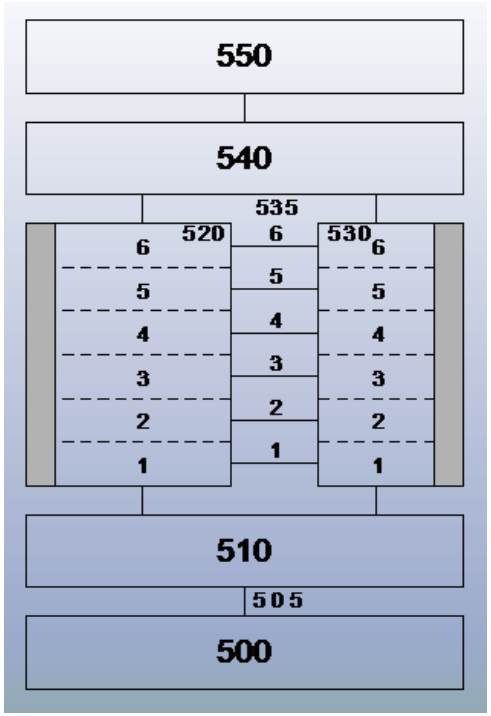
Problem Statement (3)

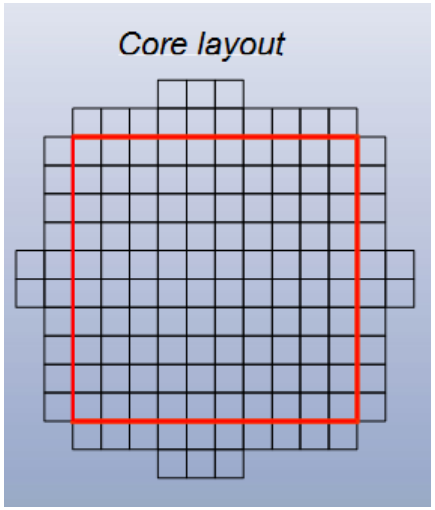
- Fuel Pin Data
  - Length = 3.6 m
  - Pellet O.D. = 7.6 mm
  - Cladding I.D. = 7.8 mm
  - Cladding O.D. = 9.0 mm
  - Axial Power Profile = flat (uniform)

Problem Statement (4)

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

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





Goal

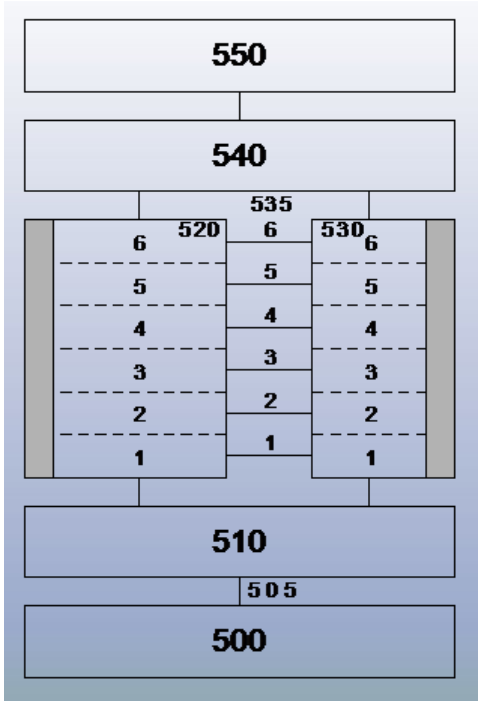
- Using reactor kinetics, determine the steady state conditions in the core.

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
*
```

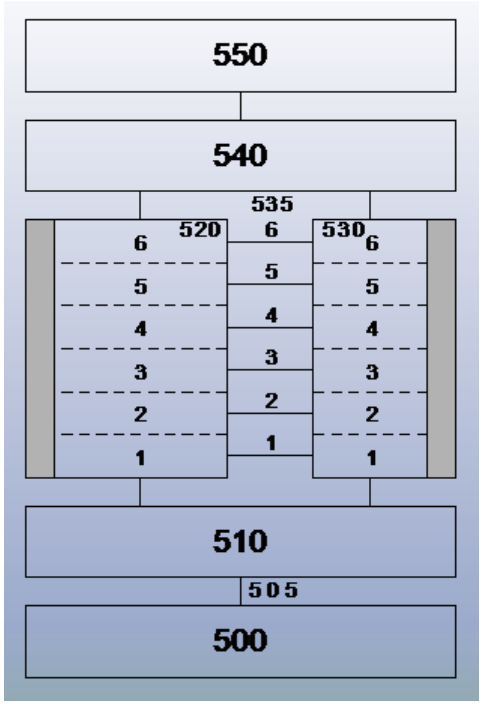
Hydrodynamic Components

```
**********************************
*  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
*
```



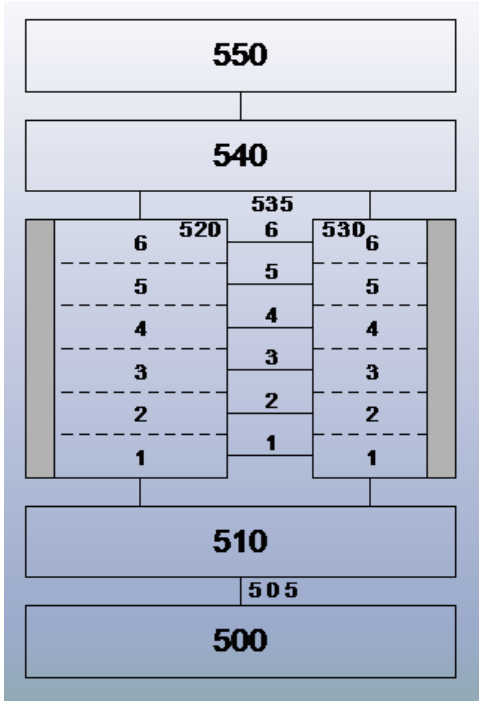
Hydrodynamic Components

```
**************************************
*  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
*
```



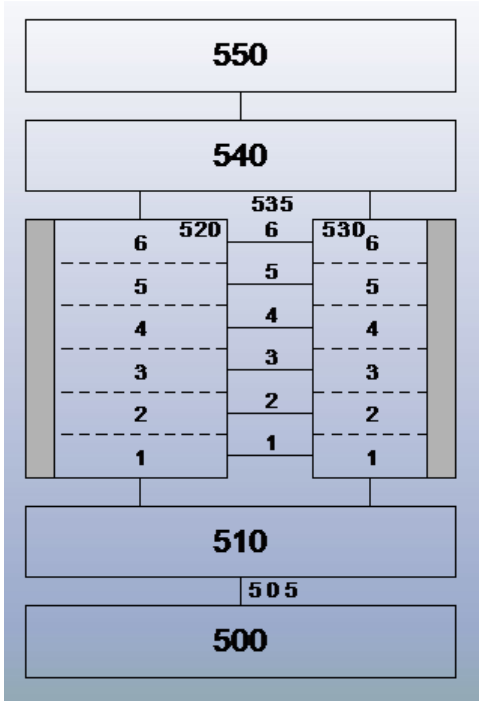
Hydrodynamic Components

```
**********************************
*   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
*
```



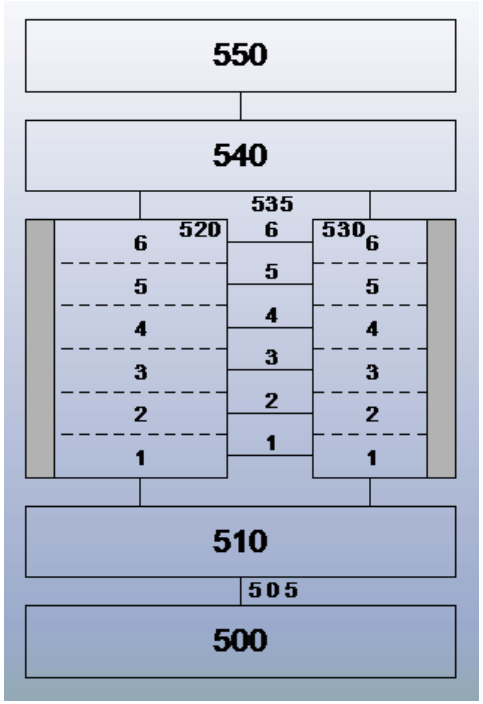
Hydrodynamic Components

```
**********************************
*           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
*
```



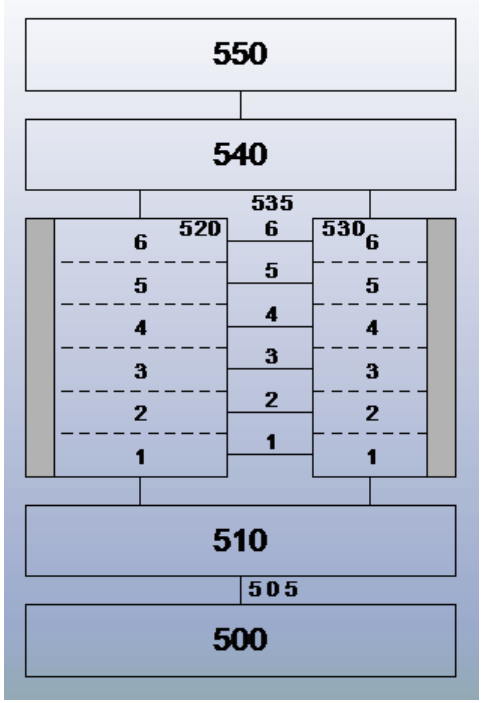
Hydrodynamic Components

```
**********************************
*           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
*
```



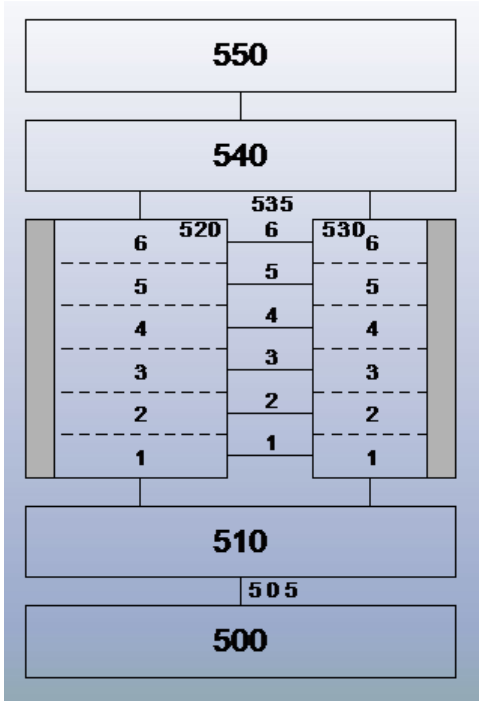
Hydrodynamic Components

```
**********************************
*    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
*
```



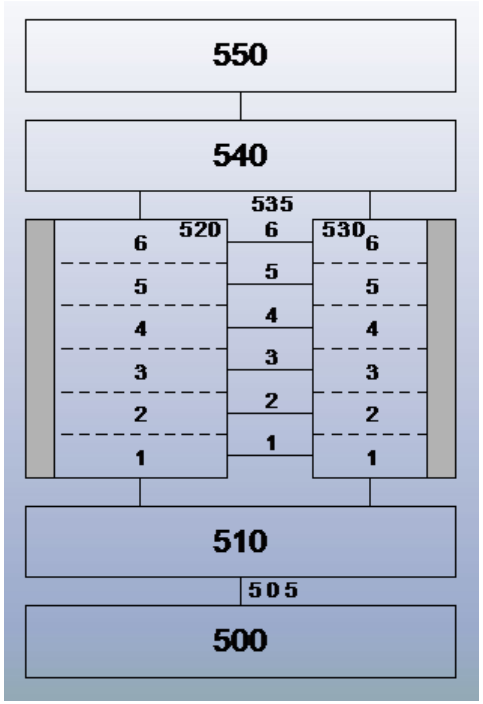
Hydrodynamic Components

```
**********************************
*   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
```



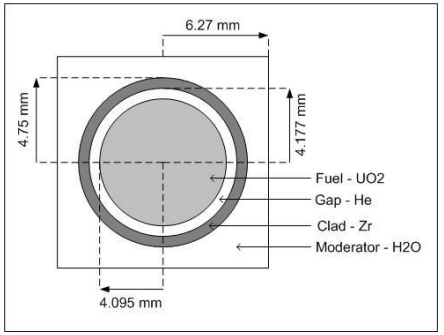
Hydrodynamic Components

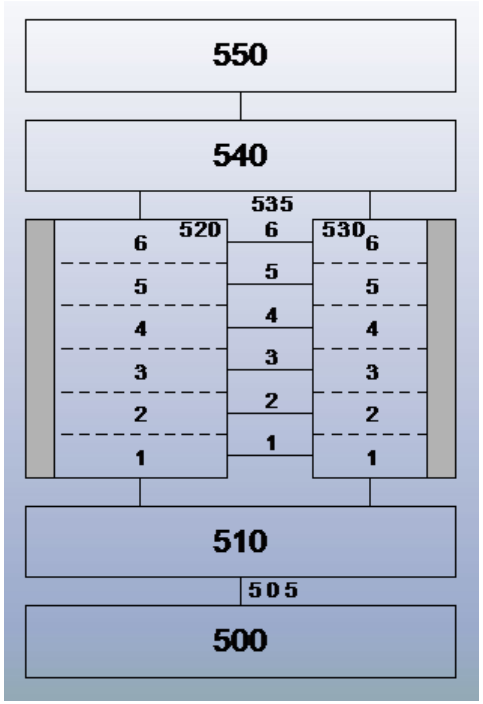
```
**********************************
*  Time Dependent Volume - 550  *
**********************************
*          Name     Type
5500000    sink     tmdpvol
*          Area     Length    Volume
5500101    4.0      1.0       0.0
*          AzimAng    InclAng    ElevationChange
5500102    0.0        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.
*
```



Heat Structures

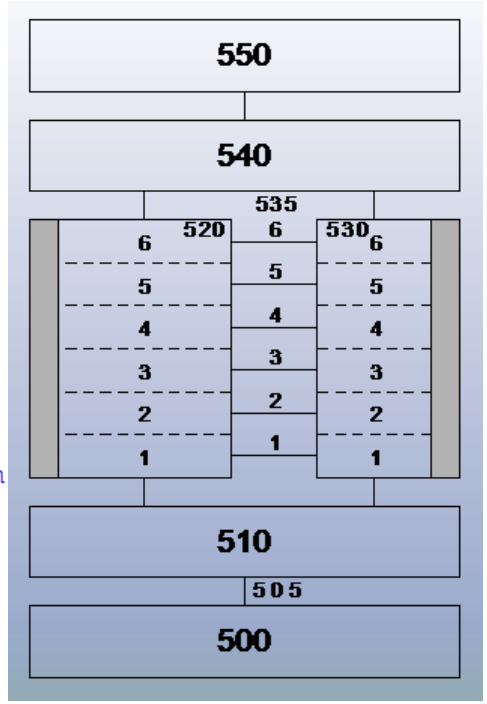
```
**********************************
*    Heat Structure - 520        *
**********************************
*
*           AxialHS   RadMesh   GeoType   SSFlag   LeftBound
15201000    6         10        2         1        0.0
*           MeshLocation        MeshFormat
15201100    0                   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
*
```





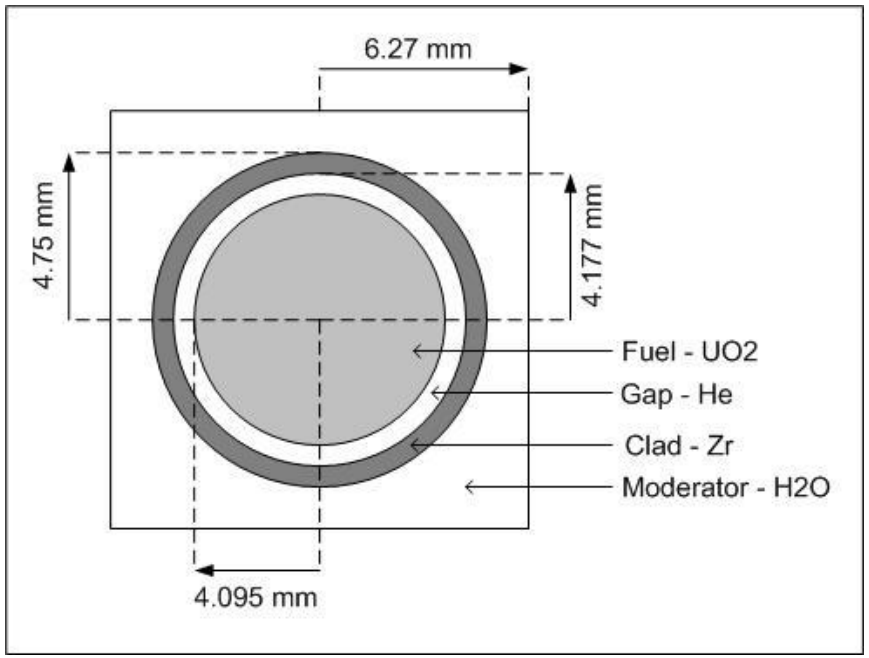
Heat Structures

```
**********************************
*    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
*
.
```

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.

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
*
```

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
*
```

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
```

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 (.)

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
  - Jackson and I can help as well
- Are the any questions about your project so far?

Assignment

- Homework 7 due Thursday (10/23) at midnight