Sun Valley 2004 RELAP5 I ATHENA Seminar
Startup Consideration for
SCWR Power Conversion Cycle

Burns and Roe

Introduction

– Background

- Supercritical Cooled Water Reactors (SCWR) are part the Generation IV International Program
- INEEL has established a research program for the Supercritical Cooled Water Reactor
- The SCWR Power conversion cycle is based on the proven technologies of the fossil plant and light water ABWR

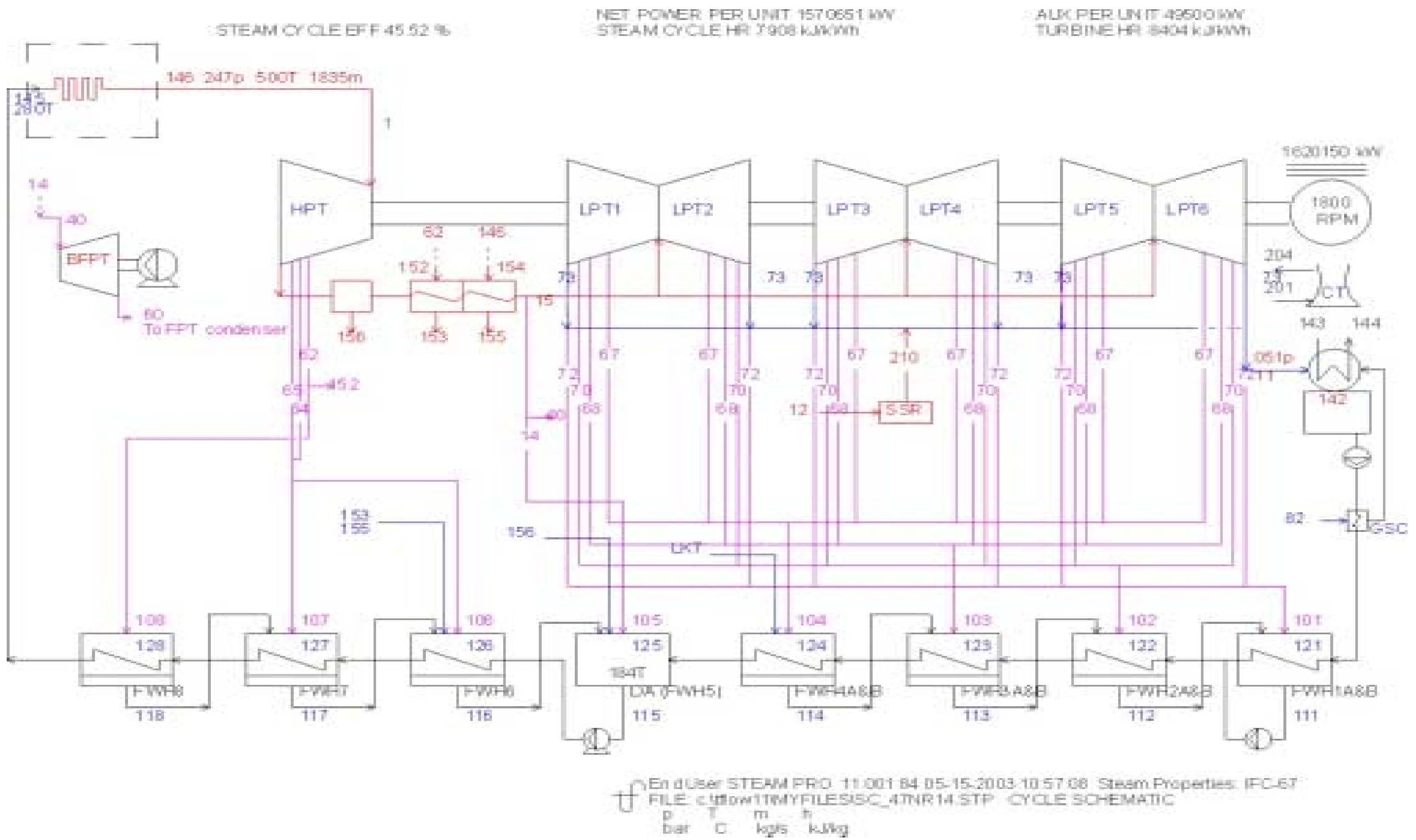
– Startup System Goals

- Avoid – fuel rod failure
- Control moisture content in steam at the turbine
- Control max. temperature gradient at the wall of RV

Boundary Conditions for the Heat Balance Calculation for Nuclear Cycle performance and for identification of the main components

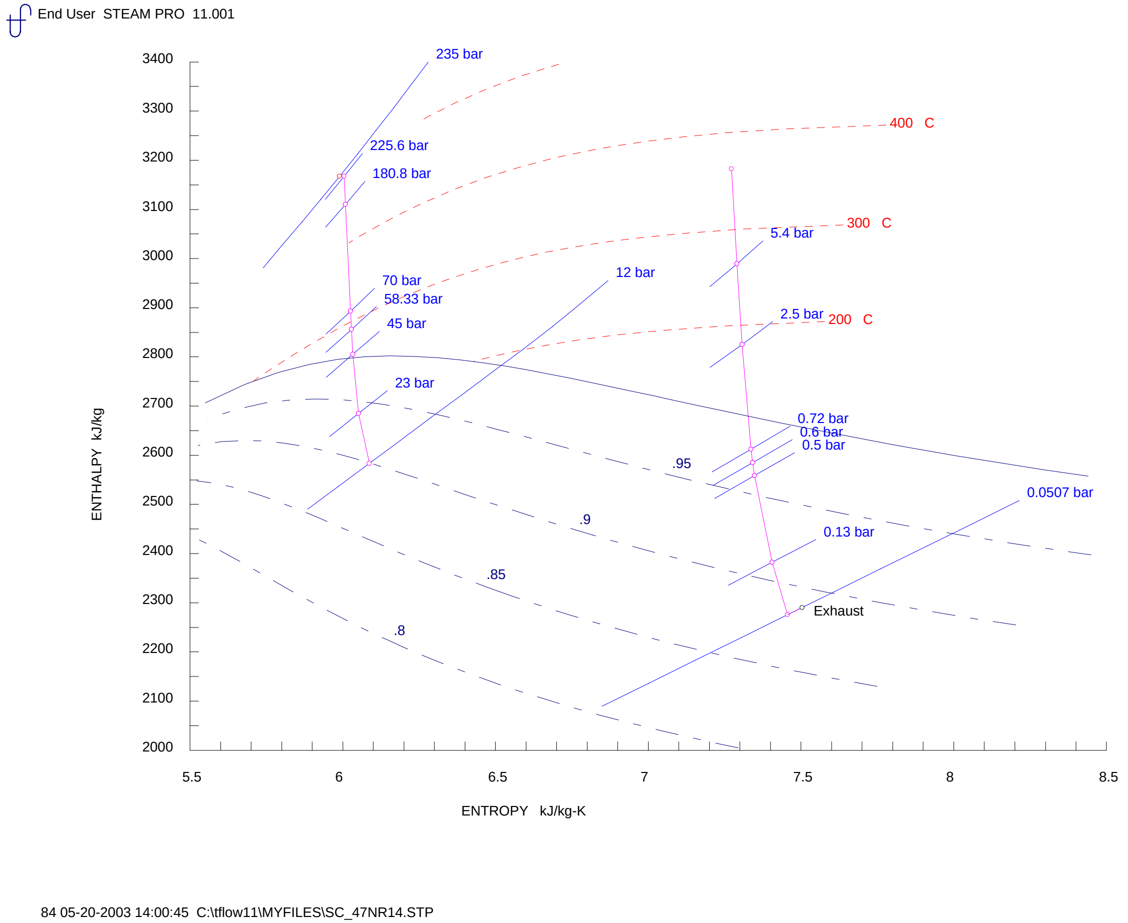
Reactor inlet / outlet temperature (ºC)	280 / 500
Reactor inlet / outlet pressure (Mpa)	25.00 / 24.5
Electric Power (MW)	1600

Sun Valley 2004 RELAP5 / ATHENA Seminar
Startup Consideration for
SCWR Power Conversion Cycle



Startup Consideration for SCWR Power Conversion Cycle

Spare #1



Sun Valley 2004 RELAP5 I ATHENA Seminar
Startup Consideration for SCWR Power Conversion Cycle

Two Startup alternative exist:

- Startup at constant pressure, used for a circular boilers of the fossil fired plants (temp. gradient: 0.75 – 1.0 deg.C / min)

- Startup at variable pressure, used for a once - through boilers of the fossil fired plants (temp. gradient: 2.75 – 3.0 deg.C / min)

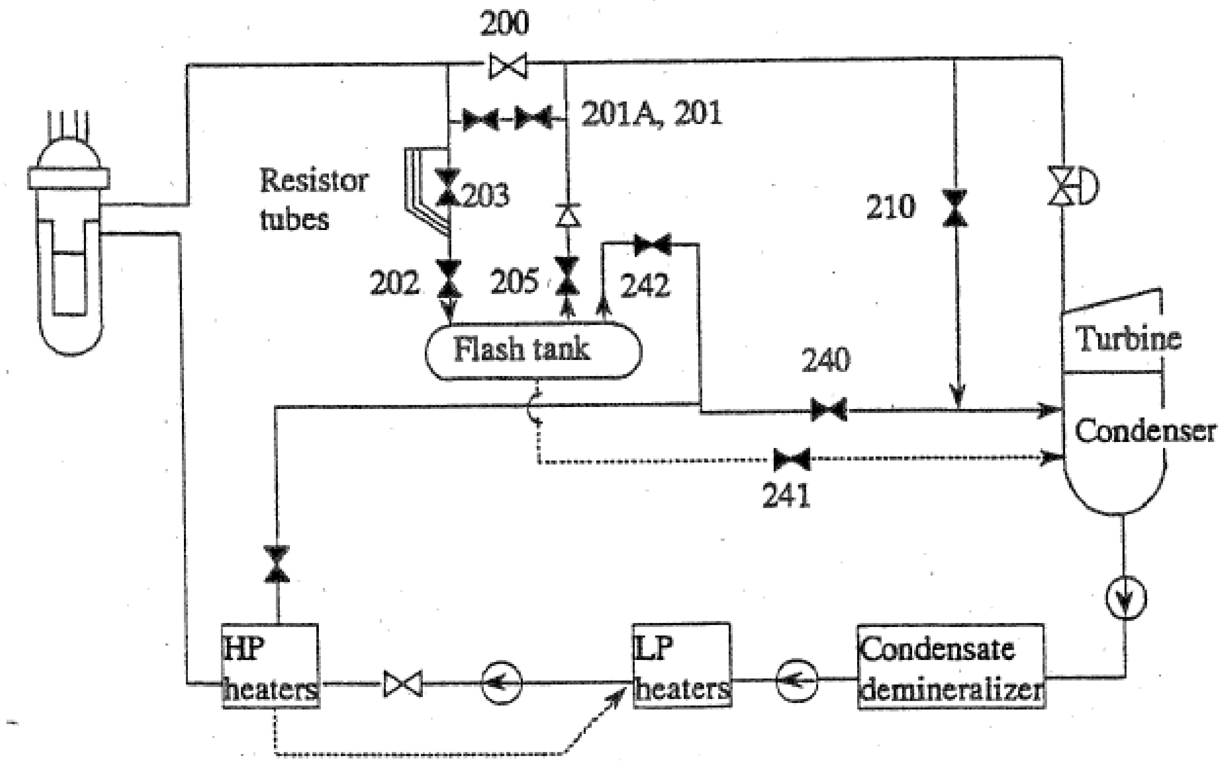
Constant Pressure Startup Components:

- Flash tanks
- Pressure-reducing valves
- Turbine bypasses
- Flash tank drain bypass

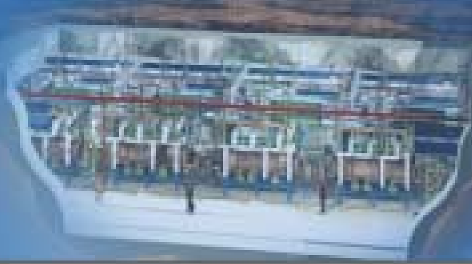
For this study of the plant system, the reactor
Starts at a supercritical pressure

Startup Consideration for SCWR Power Conversion Cycle

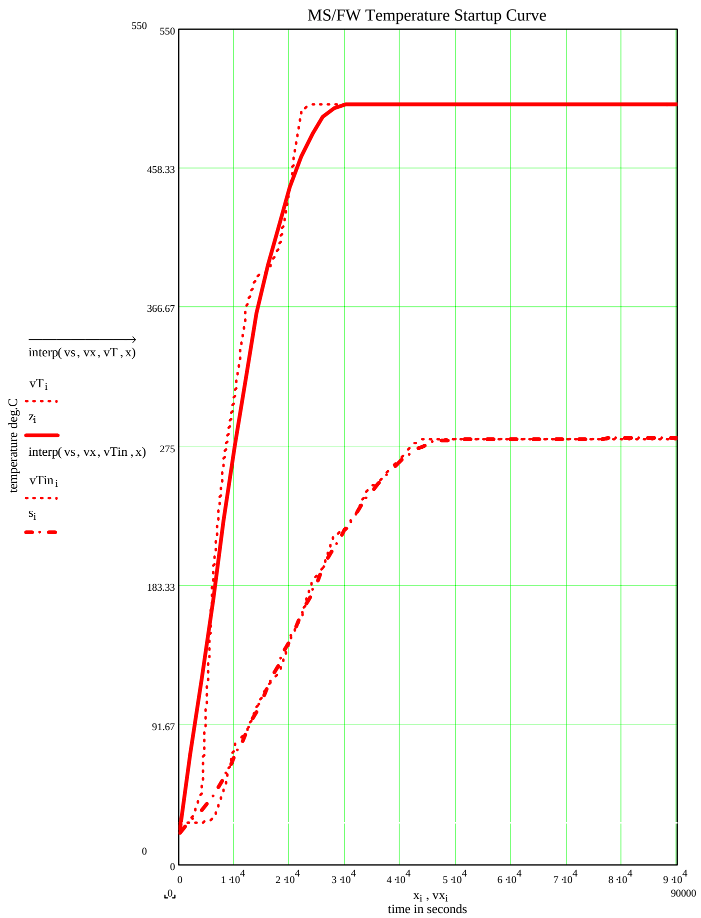
Constant Pressure Startup Component, Reference: Startup Thermal Consideration for Super Critical Pressure LWR (Nuclear Techn. Vol.134, June 2001, pg.221-230)

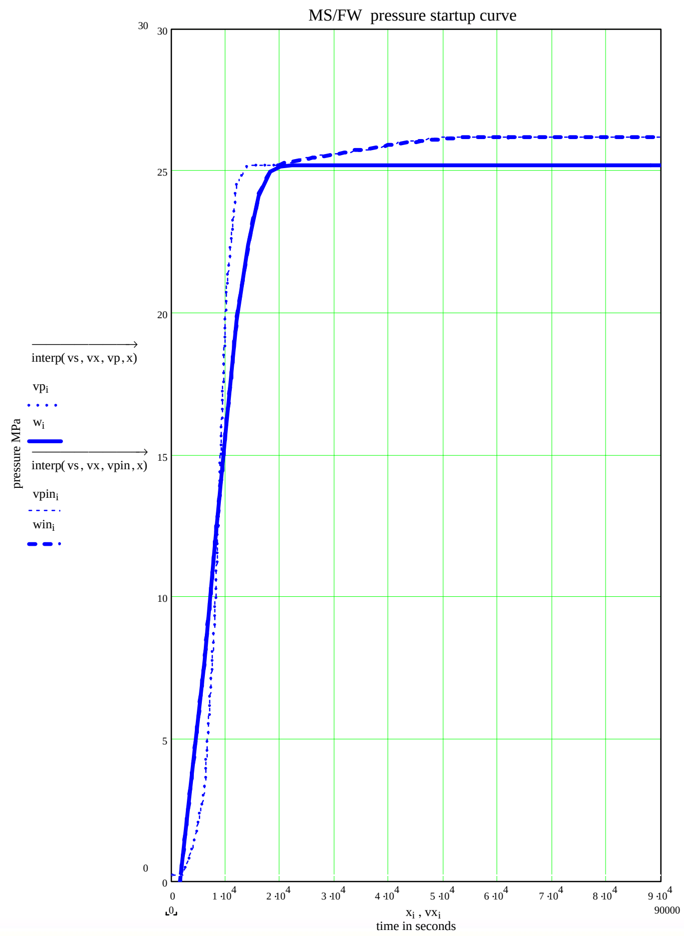


Sun Valley 2004 RELAP5 I ATHENA Seminar
Startup Consideration for
SCWR Power Conversion Cycle

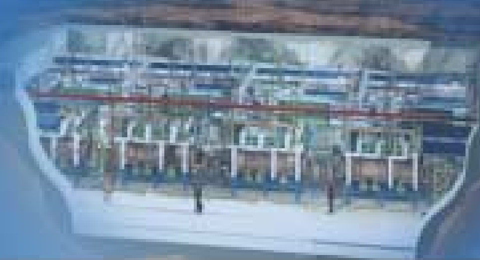


Cubic spline interpolation / Smoothing data for Main steam / Feed water temperature (deg.C) and for Main steam / feed water pressure (Mpa), constant – pressure startup curve, using Panlyon Technologies, Reference Relap5 Data (6/2/04)

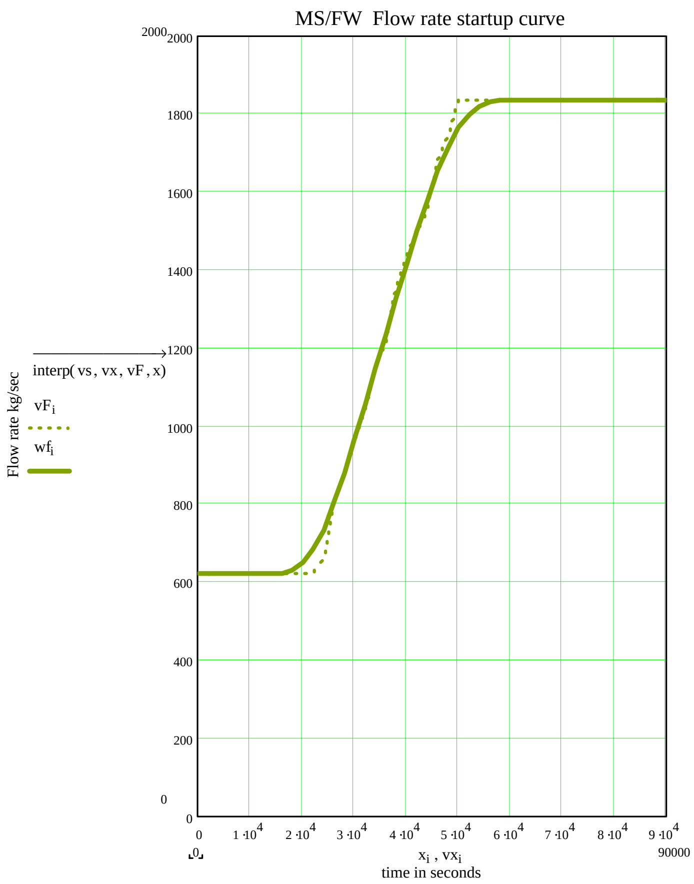


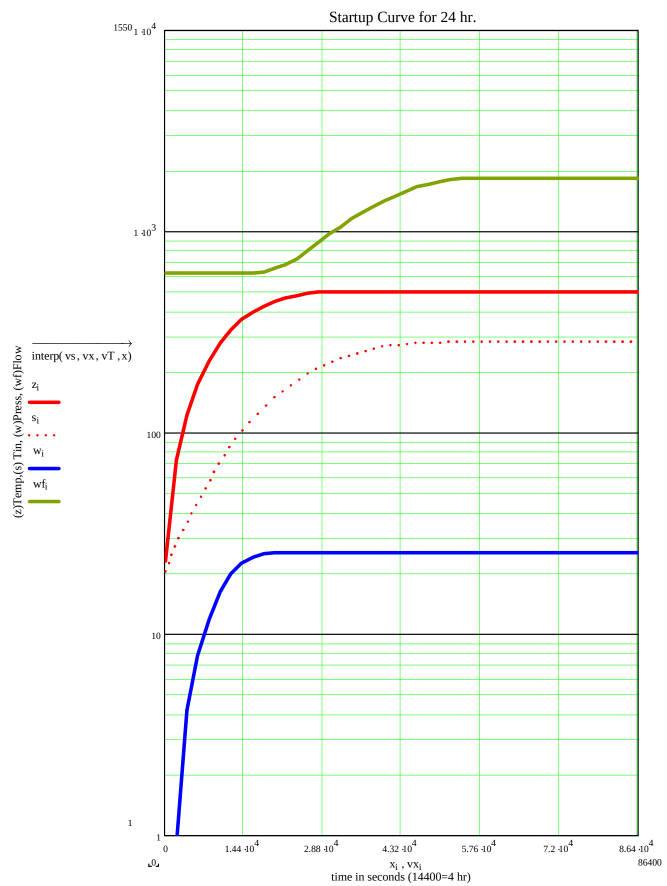


Sun Valley 2004 RELAP5 / ATHENA Seminar
Startup Consideration for SCWR Power Conversion Cycle



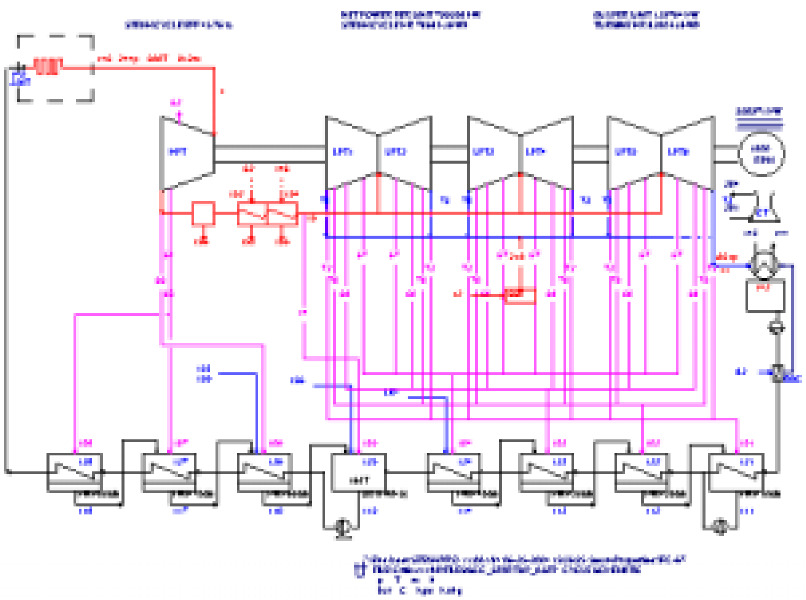
Cubic spline interpolation / Smoothing data for Main steam / Feed water flow (kg/s) and for Startup Curves for 24hr in logarithmic scale, constant – pressure startup curve, using Panlyon Technologies, Reference Relap5 Data (6/2/04)



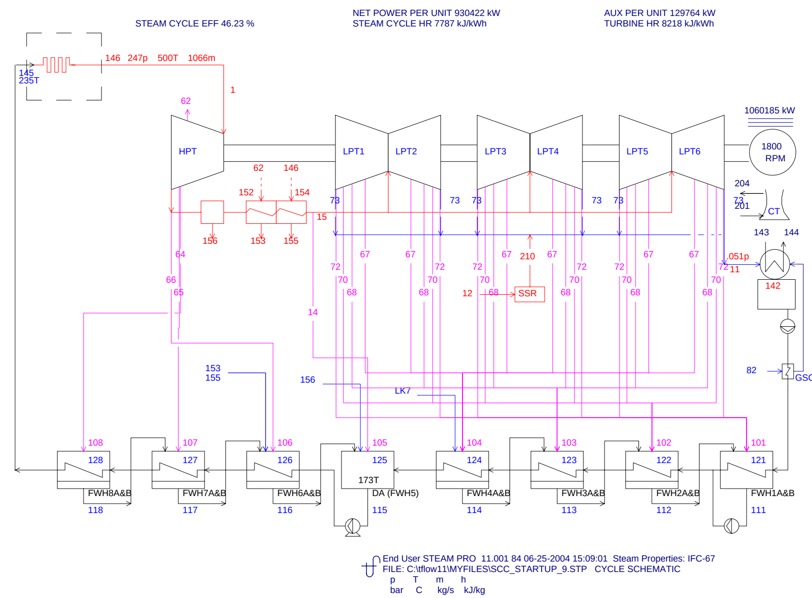


Sun Valley 2004 RELAP5 / ATHENA Seminar
Startup Consideration for SCWR Power Conversion Cycle

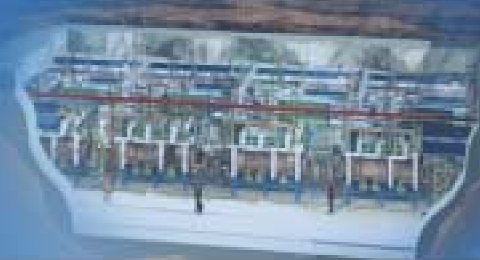
time @ 8 hr.(28800 sec)



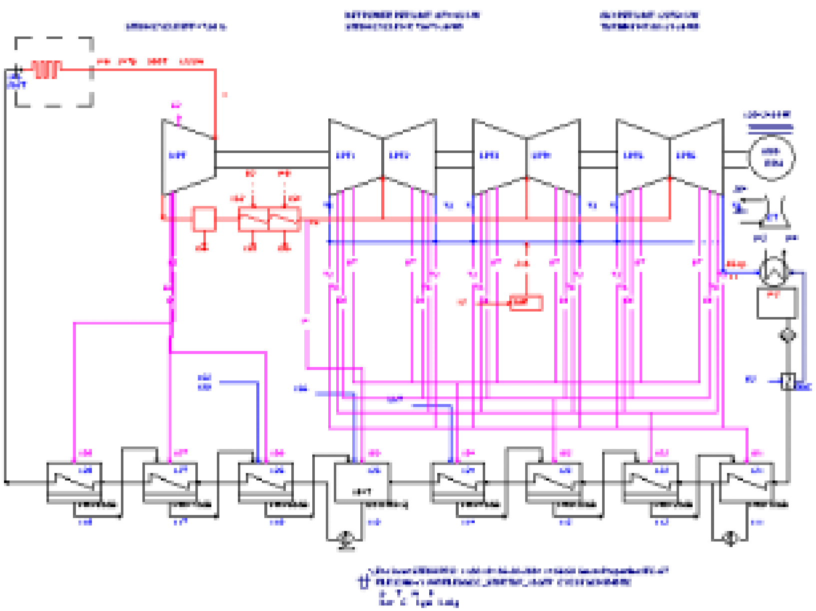
time @ 9 hr.(32400 sec)



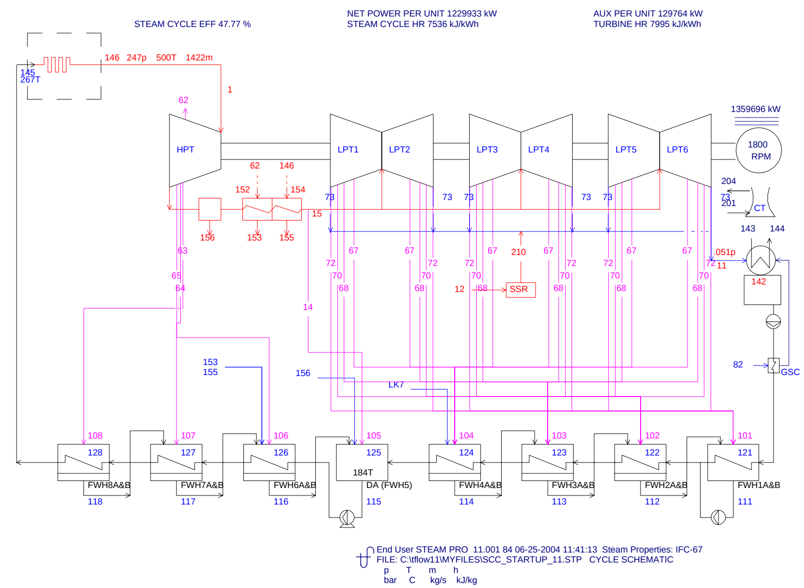
Startup Consideration for SCWR Power Conversion Cycle



time @ 10 hr.(36000 sec)

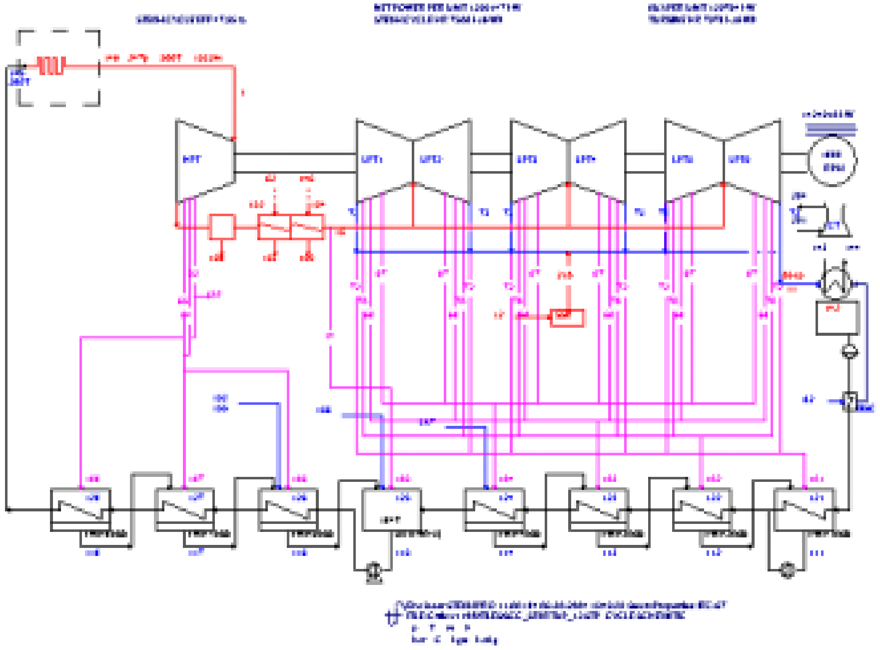


time @ 11hr.(39600 sec)

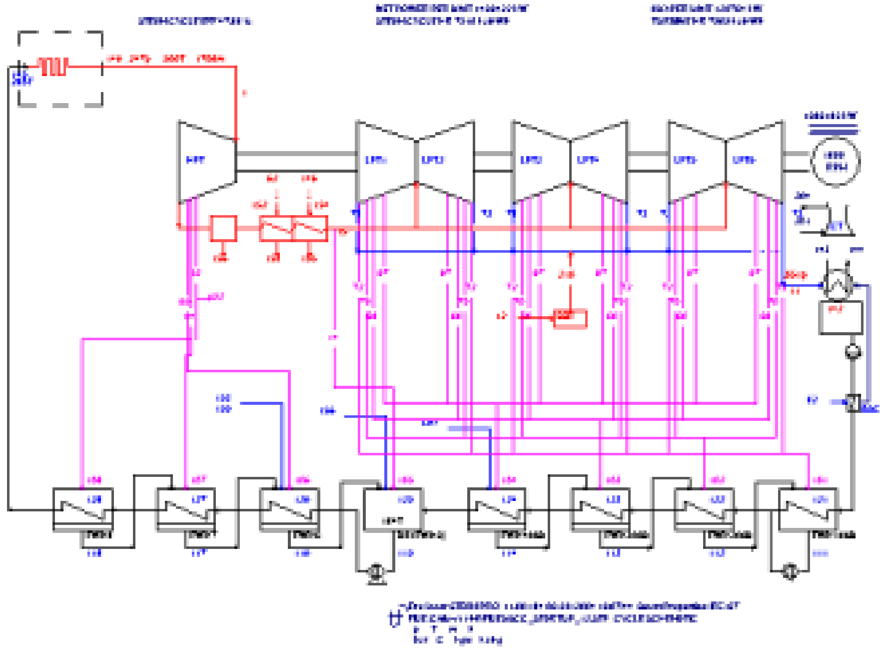


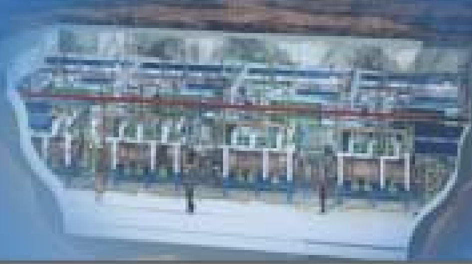
Sun Valley 2004 RELAP5 I ATHENA Seminar
Startup Consideration for
SCWR Power Conversion Cycle

time @ 12 hr.(43200 sec)



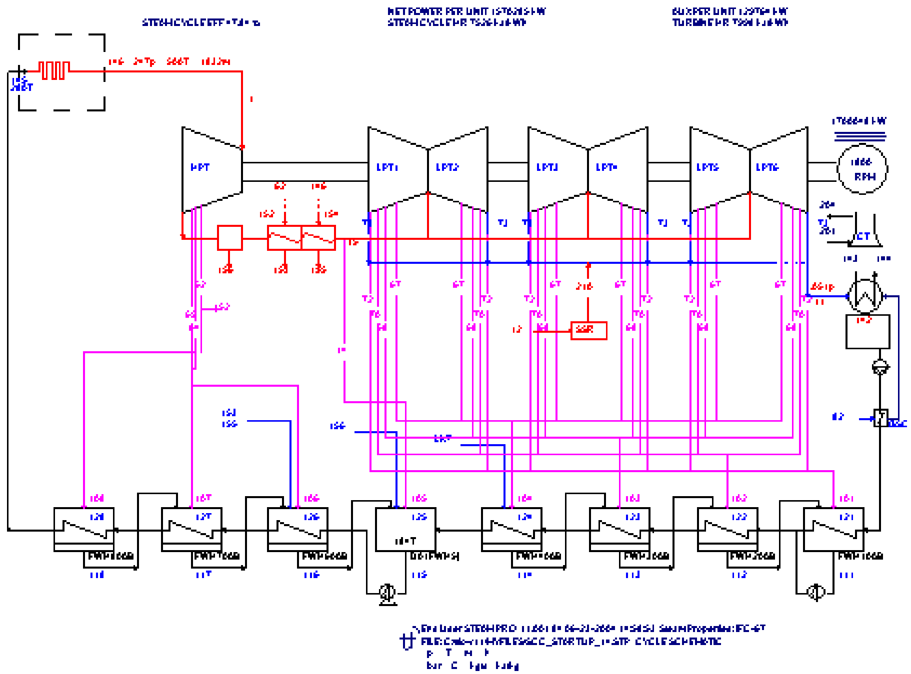
time @ 13 hr.(46800 sec)



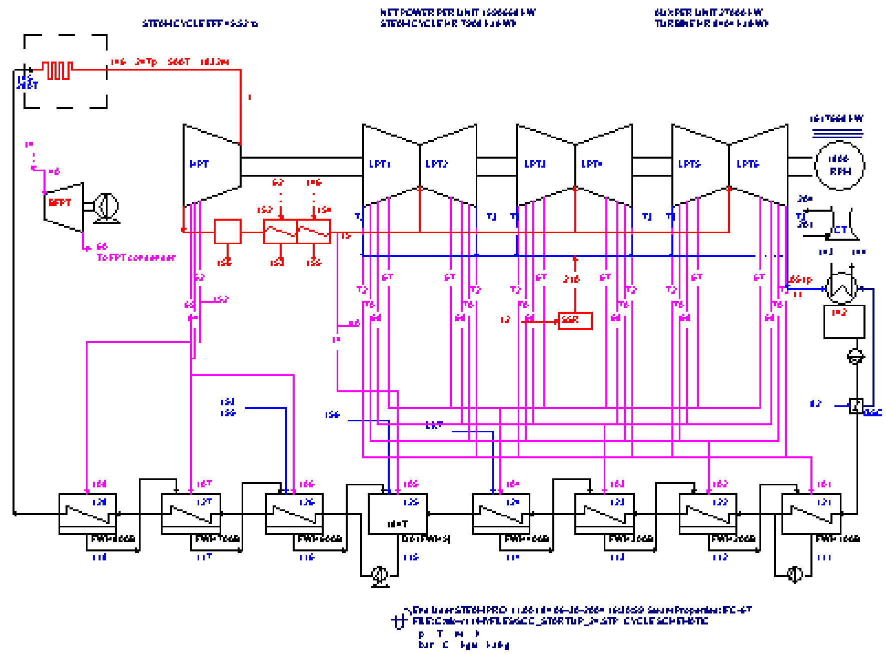


Startup Consideration for SCWR Power Conversion Cycle

time @ 14 hr.(50400 sec)



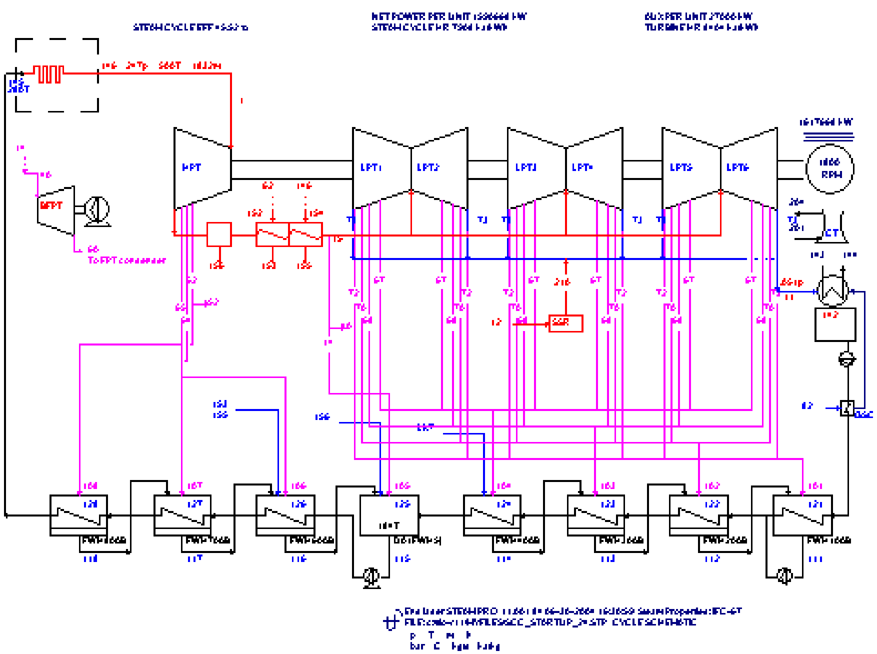
time @ 15 hr.(54000 sec)

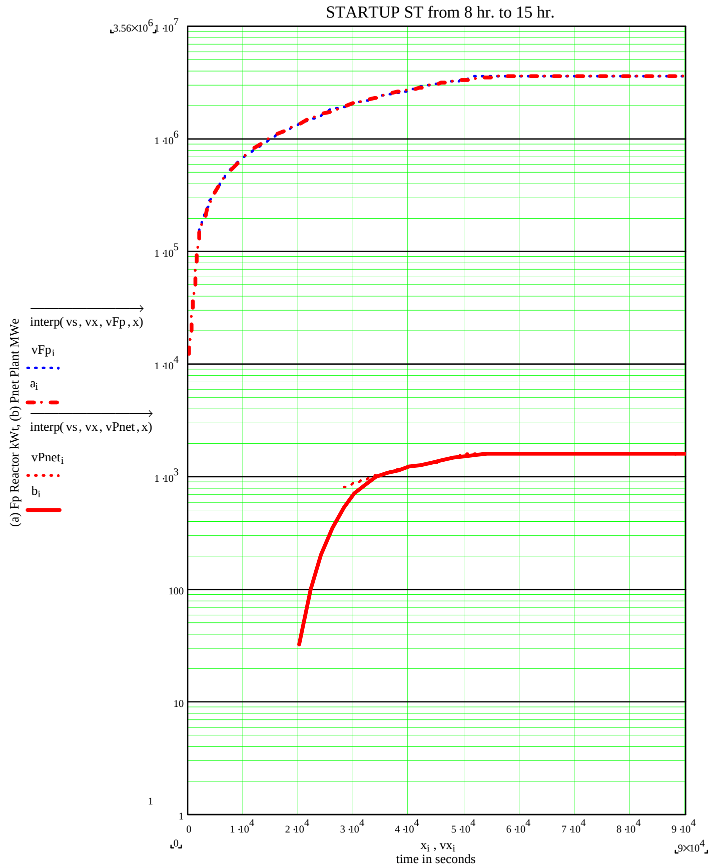


Sun Valley 2004 RELAP5 I ATHENA Seminar
Startup Consideration for SCWR Power Conversion Cycle

Cubic spline interpolation / Smoothing data in logarithmic scale for Fission power(kWt) and for Plant net output (MWe), constant – pressure startup curve, using output from code STEAMPRO / Termoflow 11 (7/28/03)

time @ 24 hr.(86400 sec)





Conclusions for Constant Pressure Startup

- The results from Relap5 simulations by Panlyon Technologies (http://www.panlyon.com/), using INEEL existing model show, that constant pressure startup achieve more stable conditions in the reactor core than variable pressure startup.
- Since the SCWR Plant conversion cycle has no internal circulating pumps, external circulating / feedwater pumps are required.
- In our startup study Two (2) El. motor driven Feedwater pumps are used to 14 hr. (50400 sec.), then FW pumps were changed to one (1) Turbine driven Feedwater pump from 15 hr. (54000 sec.).
- The startup cycle components were sized based on typical industry practices without specific manufacturers inputs. Total Startup time is **24 hr.** (86400 sec.) for Constant Pressure Consideration.
- For time reference of core flow we used information from ABWR Startup of Kashiwazaki Kariwa Unit No.7 (www.hitachi.com/rev/1998/revoct98/r4_102.pdf)

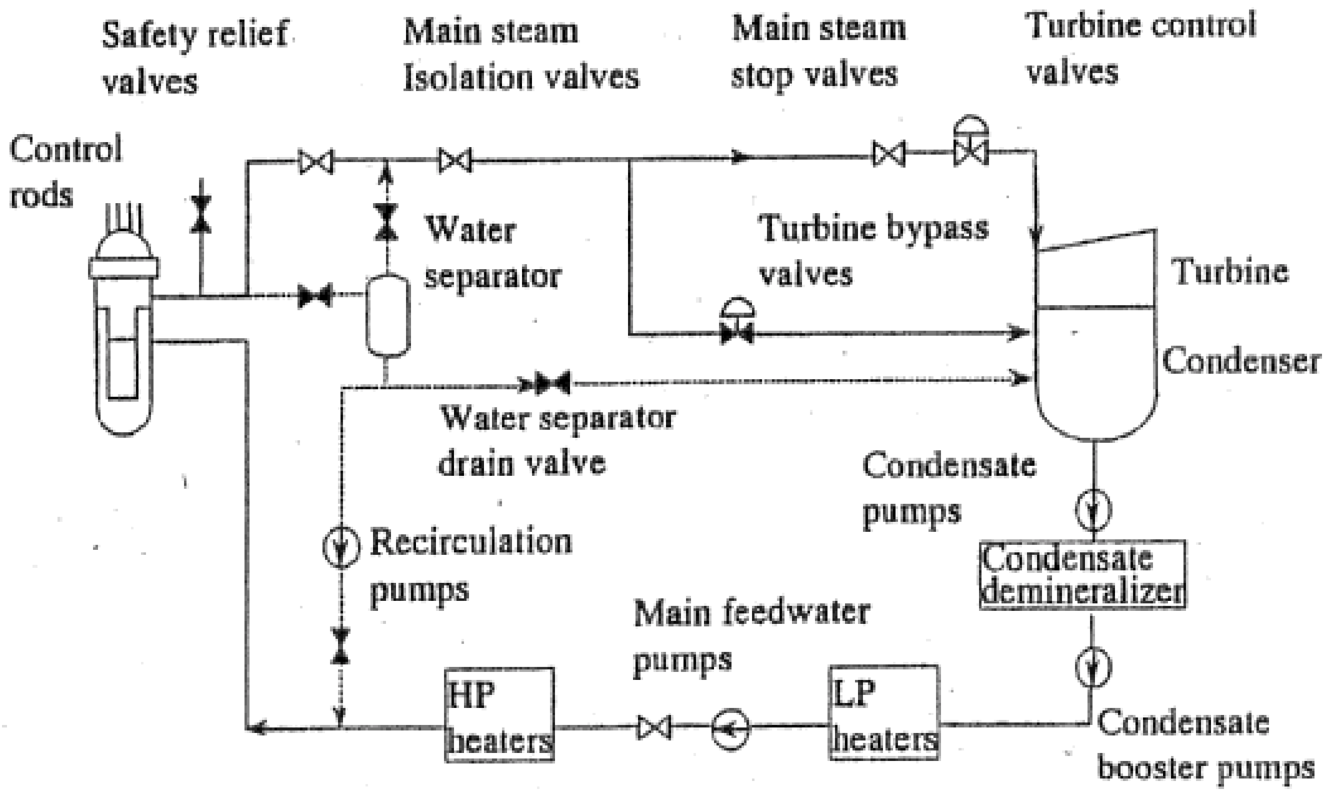
Variable Pressure Startup Components:

- Water separators
- Recirculation pumps
- Turbine bypasses
- Water separator drain bypass

For this study of the plant system, the reactor Starts at a subcritical pressure

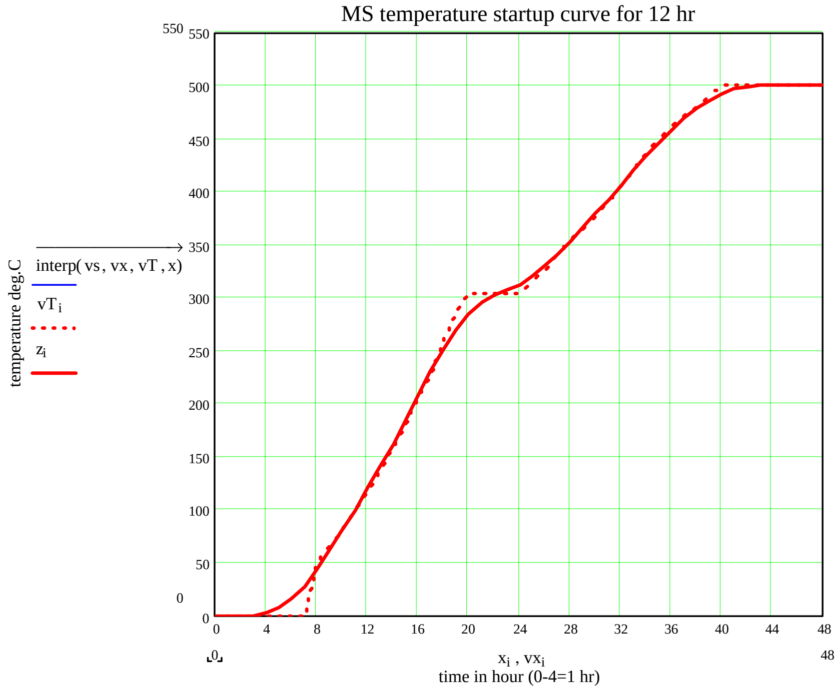
Sun Valley 2004 RELAP5 I ATHENA Seminar
Startup Consideration for SCWR Power Conversion Cycle

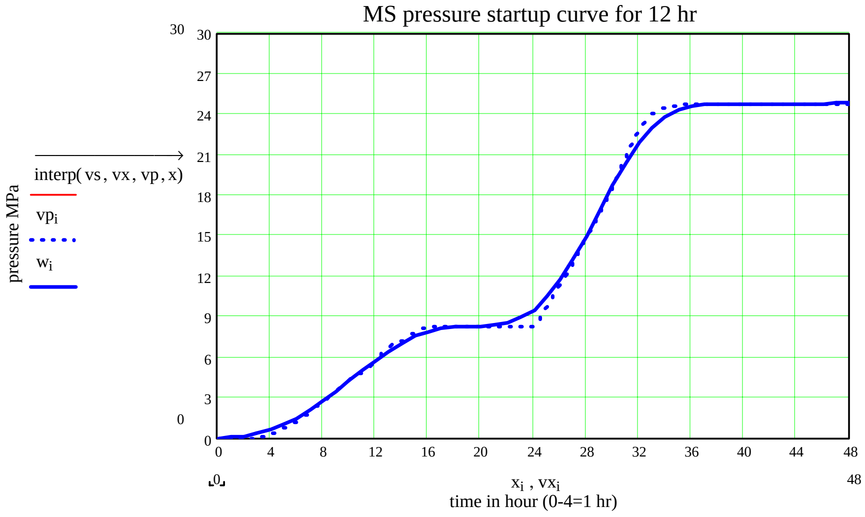
Variable Pressure Startup Component, Reference: Startup Thermal Consideration for Super Critical Pressure LWR (Nuclear Techn. Vol.134, June 2001, pg.221-230)



Sun Valley 2004 RELAP5 I ATHENA Seminar
Startup Consideration for SCWR Power Conversion Cycle

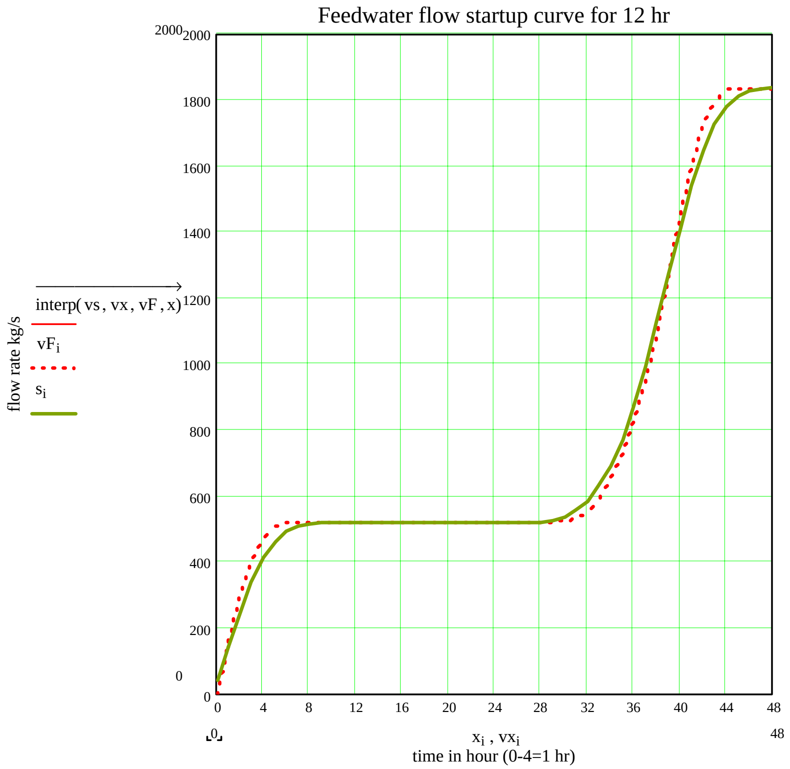
Cubic spline interpolation / Smoothing data for Main steam temperature (deg.C) and for Main steam pressure (Mpa), variable – pressure startup curve, using Reference: Startup Thermal Consideration for Super Critical Pressure LWR (Nuclear Techn. Vol.134, June 2001, pg.221-230)

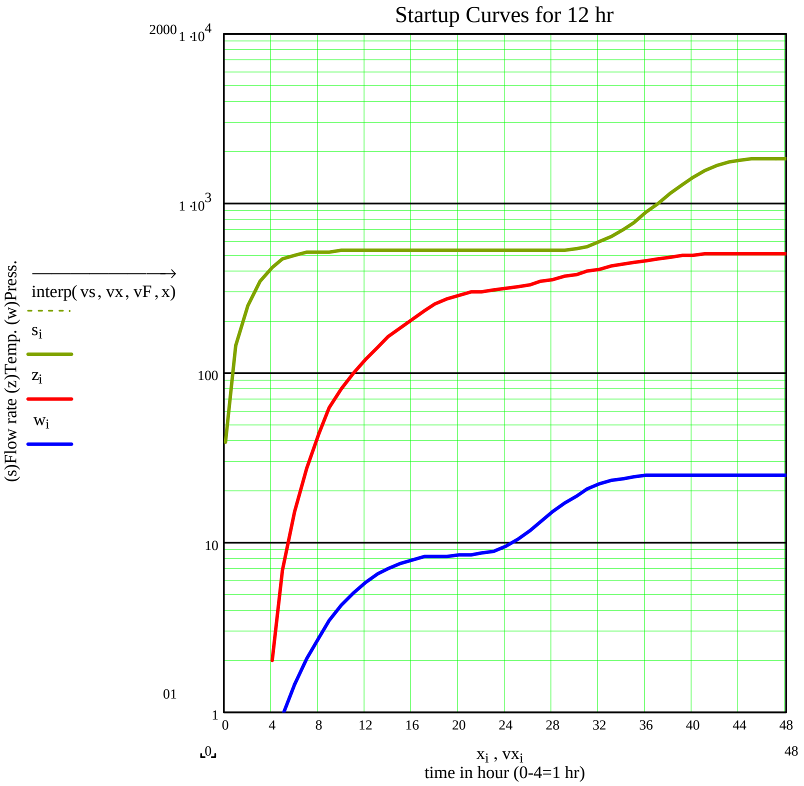




Sun Valley 2004 RELAP5 I ATHENA Seminar
Startup Consideration for SCWR Power Conversion Cycle

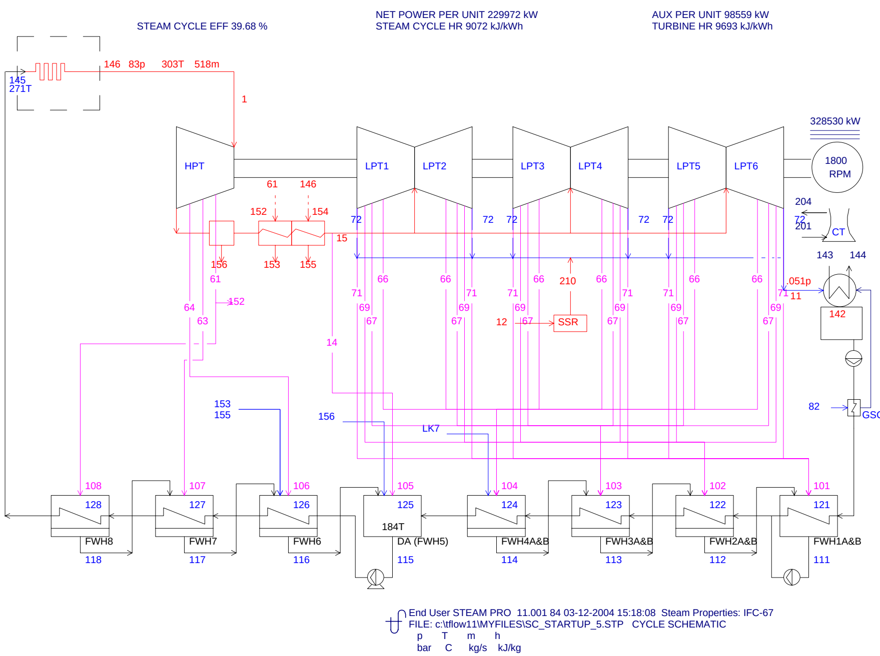
Cubic spline interpolation / Smoothing data for Feedwater flow (kg/sec) and for Main steam temperature / Main steam pressure / Feedwater flow in logarithmic scale, variable – pressure startup curve, using Reference: Startup Thermal Consideration for Super Critical Pressure LWR (Nuclear Techn. Vol.134, June 2001, pg.221-230)



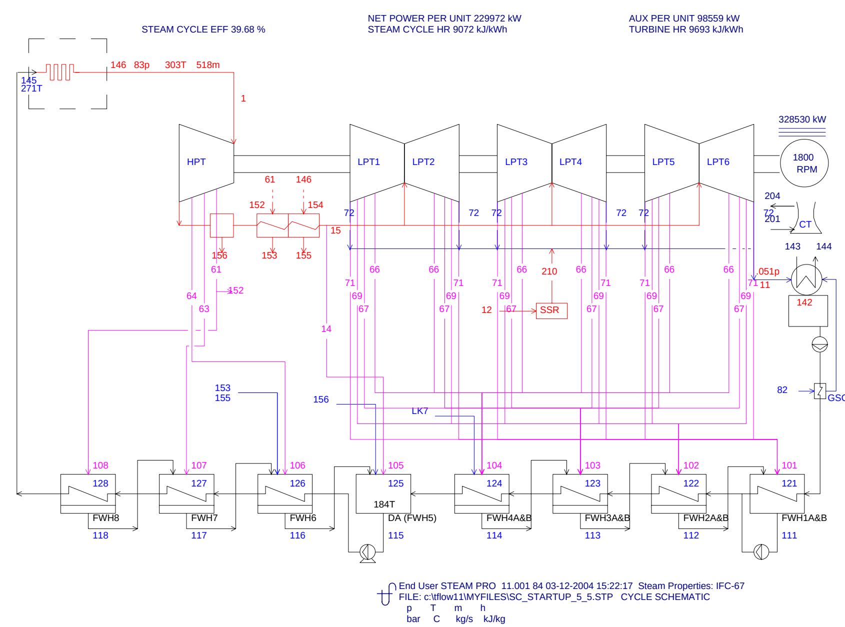


Sun Valley 2004 RELAP5 I ATHENA Seminar
Startup Consideration for SCWR Power Conversion Cycle

time @ 5 hr.(18000 sec)

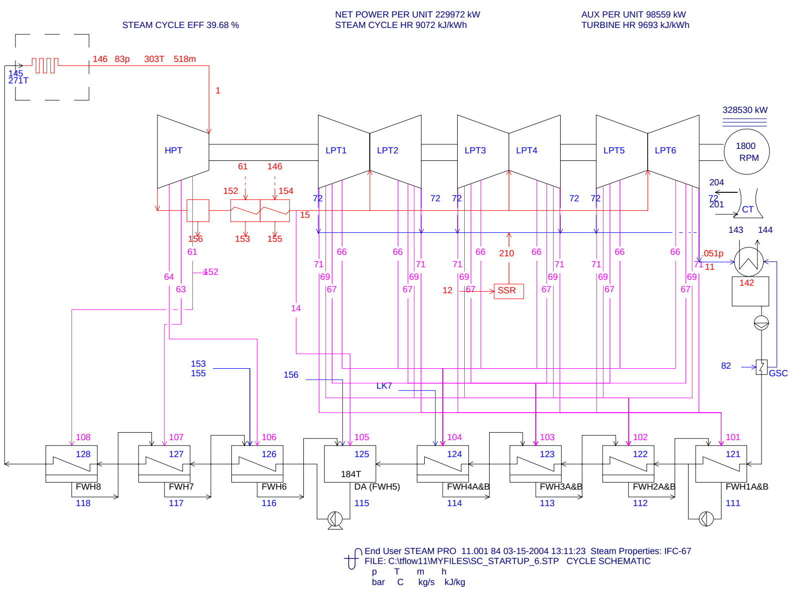


time @ 51/2 hr.(19800 sec)

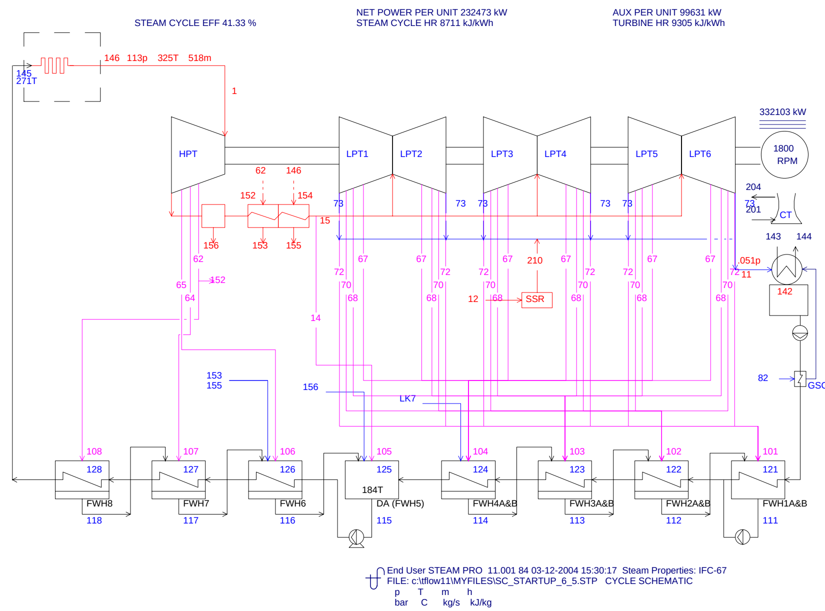


Sun Valley 2004 RELAP5 I ATHENA Seminar
Startup Consideration for SCWR Power Conversion Cycle

time @ 6 hr.(21600)

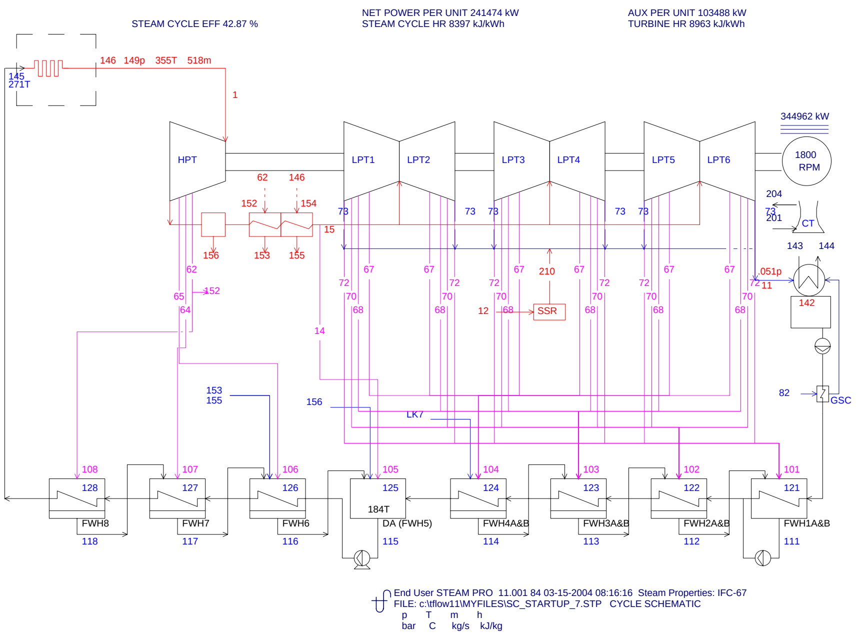


time @ 61/2 hr.(23400 sec)

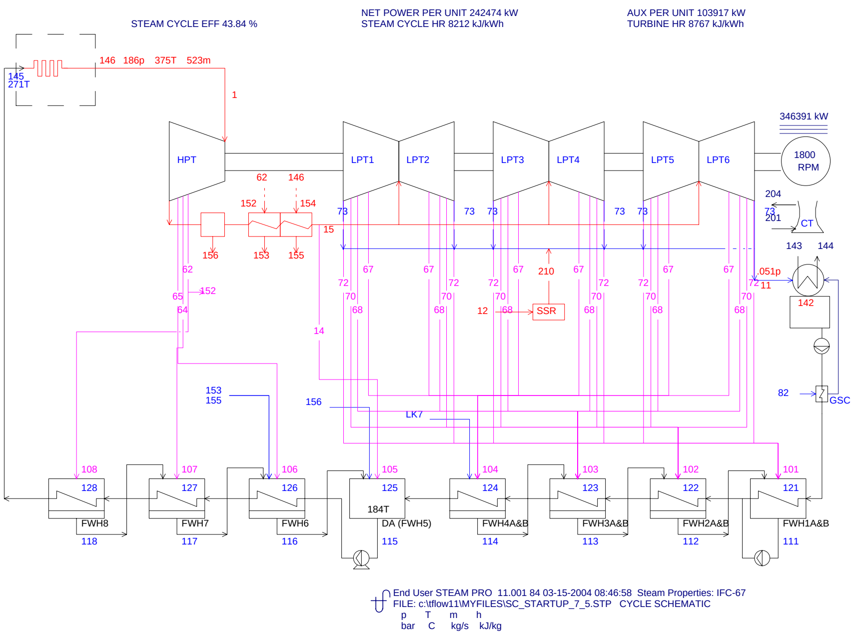


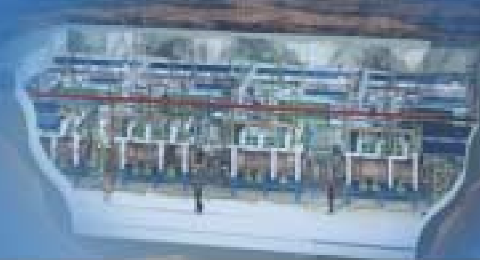
Sun Valley 2004 RELAP5 / ATHENA Seminar
Startup Consideration for
SCWR Power Conversion Cycle

time @ 7 hr.(25200 sec.)



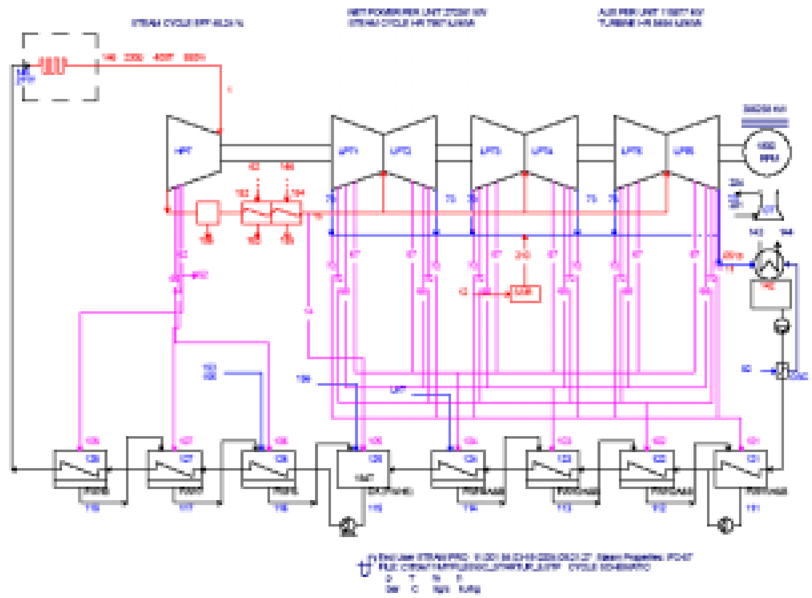
time @ 71/2 hr.(27000 sec.)



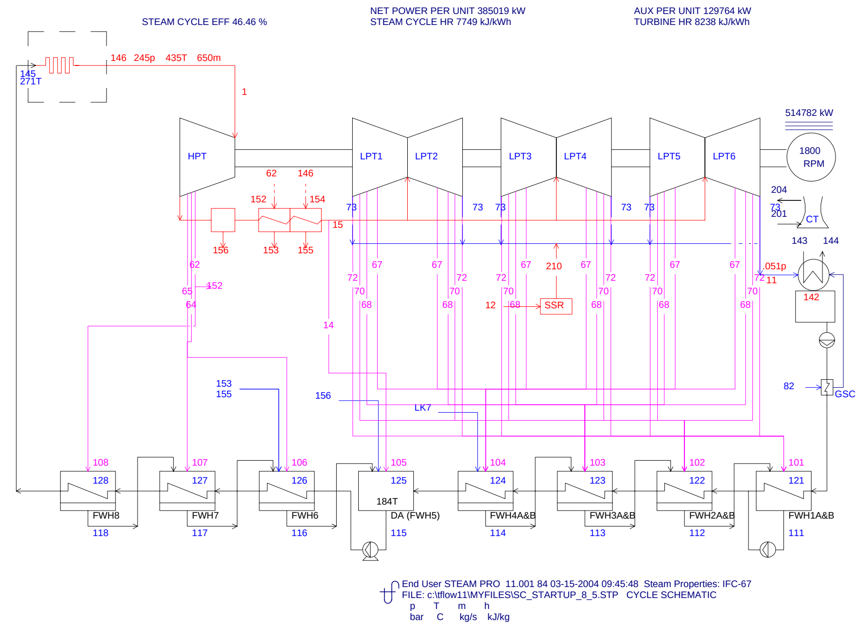


Sun Valley 2004 RELAP5 / ATHENA Seminar
Startup Consideration for
SCWR Power Conversion Cycle

time @ 8 hr.(28800 sec)

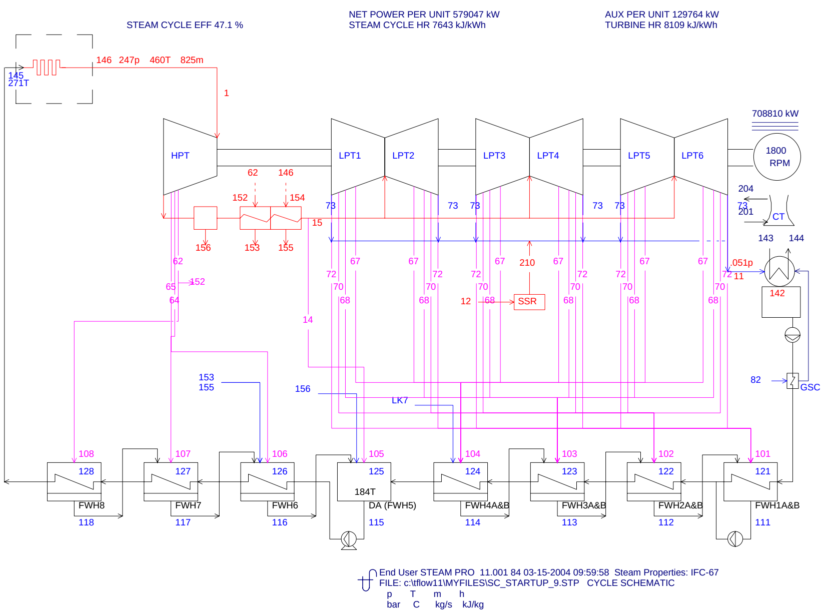


time @ 81/2 hr(30600 sec).

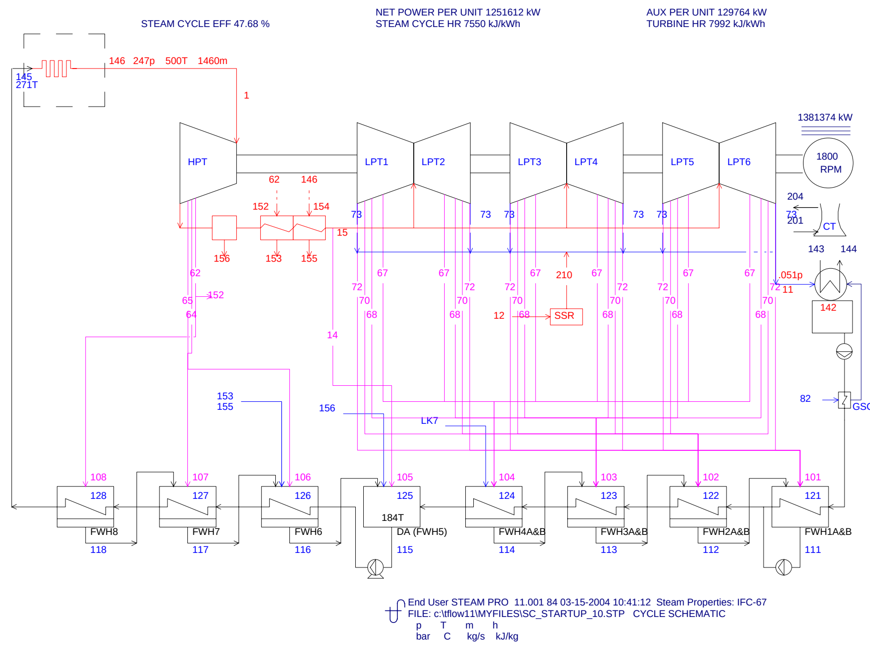


Sun Valley 2004 RELAP5 / ATHENA Seminar
Startup Consideration for SCWR Power Conversion Cycle

time @ 9 hr.(32400 sec)



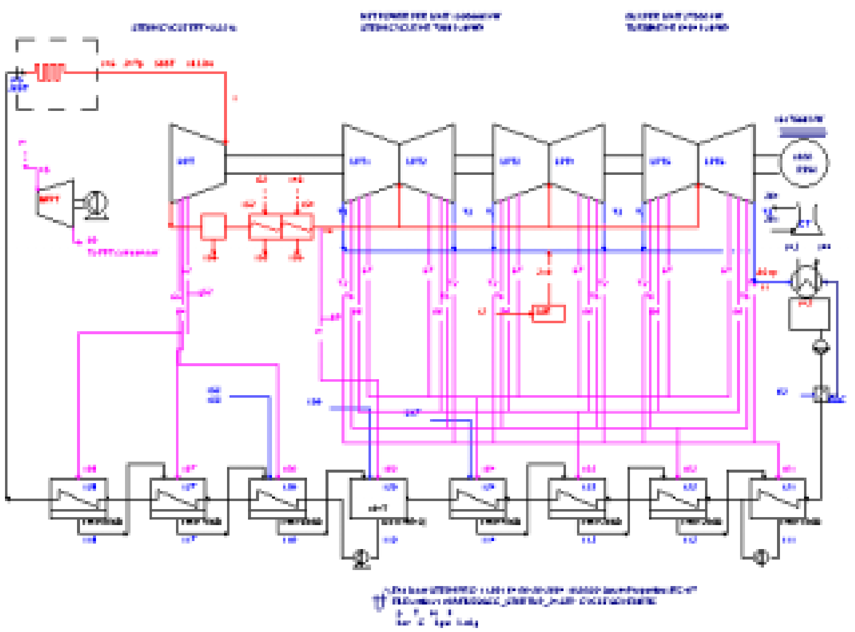
time @ 10 hr.(36000 sec)

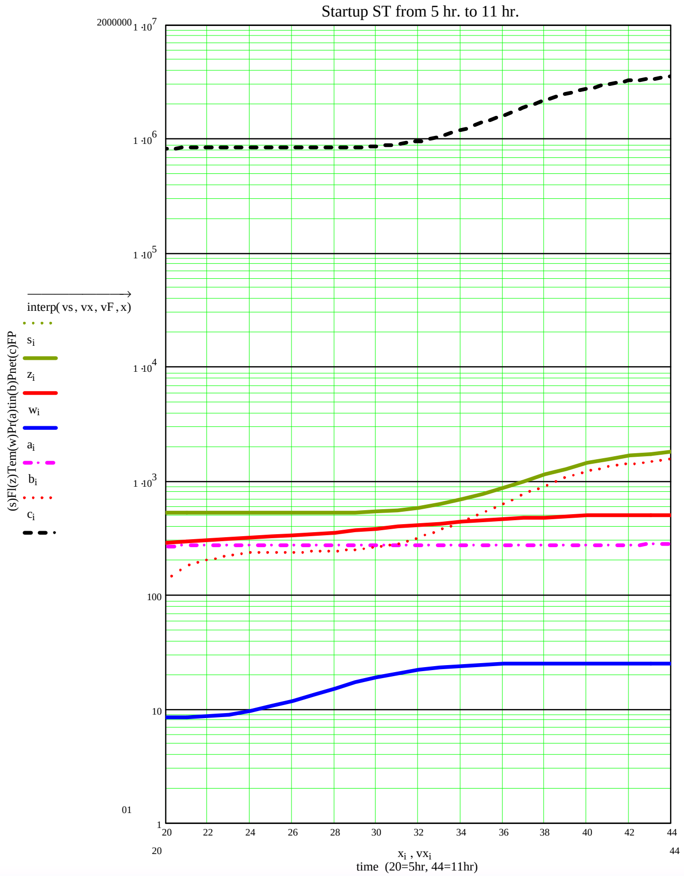


Sun Valley 2004 RELAP5 I ATHENA Seminar
Startup Consideration for SCWR Power Conversion Cycle

Cubic spline interpolation / Smoothing data in the logarithmic scale for: FW flow (kg/sec), MS temperature (deg.C), MS pressure (bar), FW temperature (deg.C), Plant net output (MWe) and Fission power (kWt) . The Variable – pressure startup curve, using output from code STEAMPRO / Termoflow 11 (7/28/03)

time @ 11 hr.(39600)





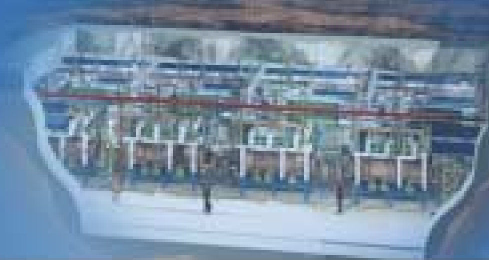
Conclusions for Variable / Sliding Pressure Startup

- The key requirement for the startup system is to maintain adequate flow in the core to protect the fuel rod integrity from overheating during startup.
- The results from Relap 5 by Panlyon Technologies (http://www.panlyon.com/), using INEEL existing model simulations show, that variable pressure startup could be unstable in the subcritical two-phase region.
- MIT Report #6 (June, 2004) for SCWR Stability Analysis suggested, that the instabilities can be avoided by revising the startup procedure to some extent as presented in Slide #28. The future analysis of startup system simulations will address these MIT modifications.
- SCWR Plant power conversion cycle with variable pressure has advantages during startup at subcritical pressure and operates at partial loads. In this study Two (2) El. motor driven Feedwater pumps are used till 10 hr. (36000 sec.), then FW pumps will be changed to one (1) Turbine driven Feedwater pump from 11 hr. (39600 sec.).

Startup Consideration for SCWR Power Conversion Cycle

Conclusions for Variable / Sliding Pressure Startup (cont.)

- The startup cycle components were sized based on typical industry practices without specific manufacturers inputs. Total Startup time is **12 hr**. (43200 sec.) for Variable Pressure Consideration.
- Based on SCWR information exchange Mtg. ICAPP'04 (June 15, 2004 Pittsburgh, Paper No. 4319), Prof. Oka proposed to improve core design for achieving high average coolant temperature during startup.



Startup Consideration for SCWR Power Conversion Cycle

MIT suggested following changes of Core fission power / Inlet FW temperature during of Variable pressure startup.

Time (hour)	System Pressure (MPa)	Core mass flow rate (kg/s)	Inlet temp. (^{o}C)	Core fission power (kW)
0 (BREI)	0	0	0	0
1 (BREI)	0.25	470	0	0
2 (BREI)	2.7	518	50	150,000
3 (BREI)	5.7	518	115	150,000
4 (BREI)	8.3	518	205	700,000
Revised 4(MIT)	**8.3**	**518**	**205**	**400,000**
5 & 6 (BREI)	8.3	518	271	827,940
Revised 5(MIT)	**12.0**	**518**	**205**	**400,000**
Revised 6(MIT)	**12.0**	**518**	**250**	**400,000**
7 (BREI)	14.9	518	271	827,940
Revised 7(MIT)	**14.9**	**518**	**250**	**600,000**
8 (BREI)	23	550	271	858,781
9 (BREI)	24.7	825	271	1504,762
10 (BREI)	24.7	1460	271	2897,029
11 &12 (BREI)	24.7	1832	280	3553,893