SOLUTION OF THE AER6 BENCHMARK PROBLEM WITH ATHLET/BIPR8KN CODE PACKAGE

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ABSTRACT

The solution of the sixth three - dimensional hexagonal dynamic AER benchmark problem obtained by the code package **ATHLET/BIPR8KN** is presented. A report contains the descriptions of the plant model, have been chosen for the solution of the benchmark problem. Models and approximations in use at the problem solution are given.

INTRODUCTION

The sixth three-dimensional hexagonal dynamic AER benchmark problems continues a series of the international benchmark problems defined during 1992-2000 in the frame of the international VVER cooperation forum AER. Some points, has not been considered in the previous benchmark problem are taken into accounts in current one. Some actuation of several safety related system are taken into consideration in this benchmark. There is not common neutron physical data and each participants of the benchmark problem use their own best-estimated neutron data. The fixed isothermal re-criticality temperature for nuclear data normalising is given. The response of the reactor core on the perturbation coming from the secondary side of the plant is investigated.

The initial event of the sixth AER benchmark is a double-ended break of the one main steam line. The break occurs in the end of cycle and full power conditions. Two of the most effective control rods are considered stuck in the upper position by the conservatism conditions. Coolant mixing in the lower and upper plenum is modelled. The full definition of the benchmark problem is presented in [1].

The solution of the sixth tree- dimensional hexagonal dynamic AER benchmark problem obtained by code package ATHLET/BIPR8KN is presented. The description of the plant model, have been chosen for the solution of the benchmark problem, models and approximations in use at the problem solution are given.

THE PLANT MODEL DESCRIPTION USED IN CALCULATION

Core model description

Due to the break asymmetric the full core configuration is to use. The used core map is shown on Figure 1. Hydraulically, the core modelled by 6 parallel channels (PIPE type object). The fuel assembly was modelled by 126 fuel rods, which were described as ROD type object divided in axial direction into 10 mesh points and in radial direction into 4 mesh points. Allocation of the fuel assemblies to the core sectors and thermal-hydraulic channels is presented on Figure 2.

For the preparation of the neutron physical data the code package KASSETA was used. The burn up calculation was fulfilled by BIPR8 code.

To receive the requested in the benchmark definition isothermal re-criticality temperature the turning of the cross sections of the absorption material were made. The adjustments were fulfilled by the multiplication of cross sections of the absorption material on some correction factor. The results of the adjustments are shown in Table 1.

Table 1

Adjustment results

Parameter	State	
	Unadjusted	Adjusted
Keff, at zero power state, inlet temperature into the core 210 °C, all control rods except the two stuck are in lower position	0.97742	1.00023
Scram worth, ppm	6612	4155
Isothermal temperature coefficient at 210 °C, all control rods except the two stuck are in lower position, pcm/K	-	- 41.3

Primary and secondary side model

The input data for the modelling of the primary and secondary side of the reactor were based on the standard input set for the ATHLET programs for the VVER 440/213 project.

According to the benchmark definition the next objects were modelled in the plant scheme (Figure 3, 4):

- ☐ Reactor pressure vessel;
- ☐ Cold leg;
- ☐ Hot leg;

☐ Steam generator;
☐ Main steam line;
☐ Main steam header;
☐ Pressurizer system;
☐ Volume control system;
☐ High pressure injection system;
☐ Feed water system;

The primary circuit of the plant consists of the six separate loops. The principal scheme of the primary loop is shown on Figure 3. The reactor pressure vessel is divided into six parallel channels without any inter connections between channels. The exception is the down camera and upper plenum, where the mixing between channels is applied (Figure 5). The double FILL in the down camera and upper plenum branches models the turbulent mixing. The mixing occurs with the equal mass exchange between the neighbouring channels. Percent rate is according to the benchmark definition [1].

The secondary circuit of the reactor also consists of the six separate loops connected through the two main steam header. The principal scheme of the secondary circuit is shown on the Figure 4. Figure 6 shows the nodalization of the steam generator. Two levels measure system of the steam generator is realised in this scheme. The first level is low range. It has the 600 mm base; the lower point of measurement is approximately 1.96 m from steam generator bottom. The operation of the steam generator level control system is based on the reading of this level. The second one is a high range level. It has the base by the all height of the steam generator. Feed water is described as a separate supply into each steam generator.

Break is realised as a double-ended break in the middle part of the main steam line 1. The mass flow rate through the break is determined on the base of the built in ATHLET one-dimensional critical discharge flow model.

All specified in the definition of the problem control signals have been modelled with the help of GCSM blocks.

RESULTS

Initial state

The initial steady state conditions are shown in Table 2.

Table 2

Calculated initial state

PARAMETER	SPECIFICATION	CALCULATED
Fission power (MW)	-	1278.6
Decay heat, %	-	7
Total thermal power in core (MW)	1375	1374.8
Upper plenum pressure (MPa)	12.25	12.255
Core inlet temperature (°C)	267.4	267.4.
Total mass flow rate (kg/s)	9300	9300.
Pressurizer collapsed level (m)	5.97	5.976
Pressure at SG outlet (MPa)	4.63	4.69
SG collapsed level (m)	2.015	1.90
Break opening time (s)	-	0.0

Transient

The sequence of events during the transient is listed in Table 3. The main parameters of the plant are shown on Figures 7- 22.

Table 3

Sequence of events

Time	Event
0.0	Double ended break opens
0.1	Leak is fully open
5.834	Turn on of the first pressurizer heaters group
7.349	Turn on of the second pressurizer heaters group
9.411	Turn on of the third pressurizer heaters group
11.948	Scram value is reached
12.487	Scram
18.893	Turn on of the fourth pressurizer heaters group
35.542	P1.T>255
35.979	Turn off the all group of the pressurizer heaters
37.304	PRZ.L<241
37.313	HPIS signal is turned on
52.086	Pressure in the MSH1 drops below 3 MPa
52.086	Pressure in the MSH2 drops below 3 MPa

52.099	Closing of all feed water supply
54.596	All MSIV are closed
217.482	Beginning of the HPIS supply into the core
400.	End of calculation

The accident is initiated at 0 seconds, when the double ended break of the main steam line 1 is occurred. The mass flow rate through the break during the transient is shown on Figure 7. During the several first second break flow consists only of pure steam (Figure 9). Then due to the rapid drop of the steam pressure in the steam generator, connected to the damaged first main steam line (Figure 12), the mixture level reaches the top of the steam generator and liquid is also flowing through the break. It leads to the rapid drop of the collapsed level of the first steam generator (Figure 14, Figure 13). The collapsed levels of other steam generators drops more slowly due to the work of the feed water system.

Fast secondary pressure decrease leads to the primary pressure decrease and to the power rise up to the scram set point (Figure 20). Resulting from the scram the turbines are turned off. It leads to the main steam header pressure drops below 3.0 m (Figure 17). Main steam isolation valves are closed. Feed water supply into all steam generators are disconnected. The consequence of the main steam isolation valves closing is that, mainly the first steam generator has performed the primary side cooling during the further transient course (Figure 22, Figure 23).

Due to the primary pressure drop, the pressurizer heaters are switched on and they are operating until the water level in the pressurizer drops below 3.0 m (Figure 16). The primary pressure behaviour is shown on Figure 15.

Descending secondary pressure leads to a drop of water temperature on the core inlet (Figure 18). As could be seen from figure the core inlet temperature is separated on four groups:

- ☐ The sector temperature corresponding the broken loop (sector 1);
- ☐ The temperatures beside the sector corresponding the broken loop (sector 2, 6);
- ☐ The opposite sector temperature to the broken loop (sector 4);
- ☐ The sector temperatures, neighbouring to the opposite sector of the broken loop (sector 3, 5);

Obviously, that the lowest core inlet temperature is observed in the sector corresponding to the broken loop, the highest one is in the opposite sector.

Decreasing of the core inlet temperatures up to the re-criticality temperature causes the second power rise (Figure 21). As could be seen from figure, the peak has not clear form and is not too big by the absolute value. The explanation of this phenomenon is that the re-criticality temperature has reached only in the first sector, but has remained above it in another (Figure 18). It is the sequence of the main isolation valve closing and that after it the core cooling is mainly performed by one (first) steam generator (Figure 22).

Injection of the high borate water into the core begins after the high-pressure injection signal had been actuated. It leads to a rapid power decrease (Figure 19).

CONCLUSION

The carried out calculation has shown that the next key points had influence on the results:

- ☐ Mixing in the down camera and upper plenum; it is obvious, that the smallest percent of mixing between sectors gives the lowest temperature in the sector with broken loop and maximum secondary power rise.
- ☐ Steam generator modeling scheme; It might influence on the time of closing the main steam isolation valves and thus, on the secondary power rise due to the more extensive heat exchange between primary and secondary circuit.
- ☐ Model of the leak flow through the break; It might influence on the pressure drop in the steam generator and main steam header and lead to the more late closing of the main isolation valves.

REFERENCES

1. S. Kliem, A. Seidel, U. Grundman „Definition of the sixth AER benchmark – main steam line break in NPP with VVER-440“

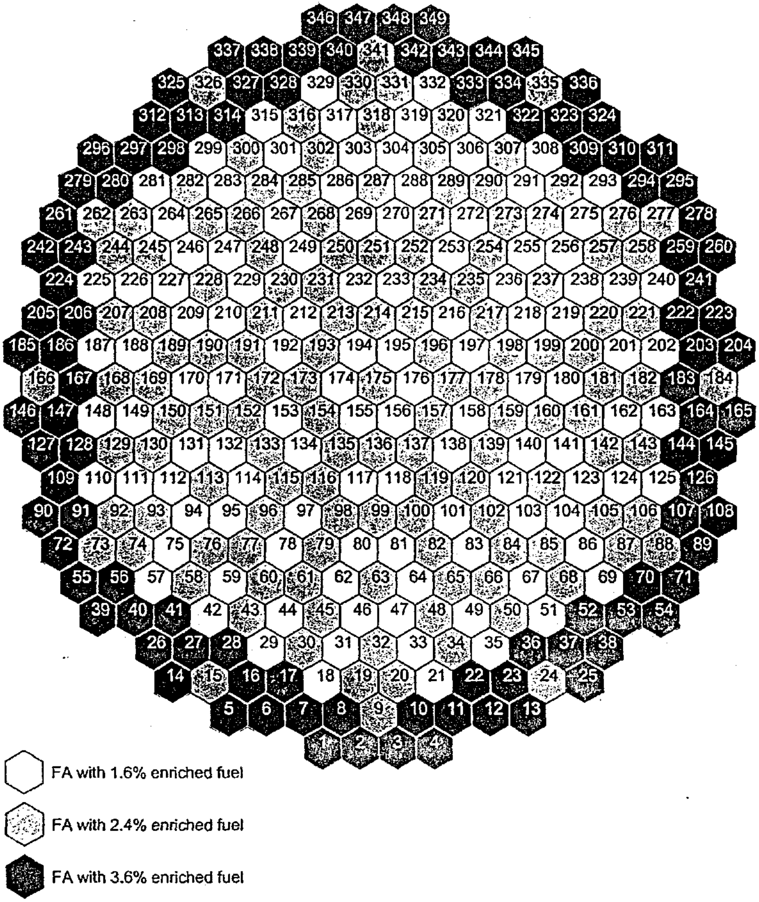


Figure 1. Core map

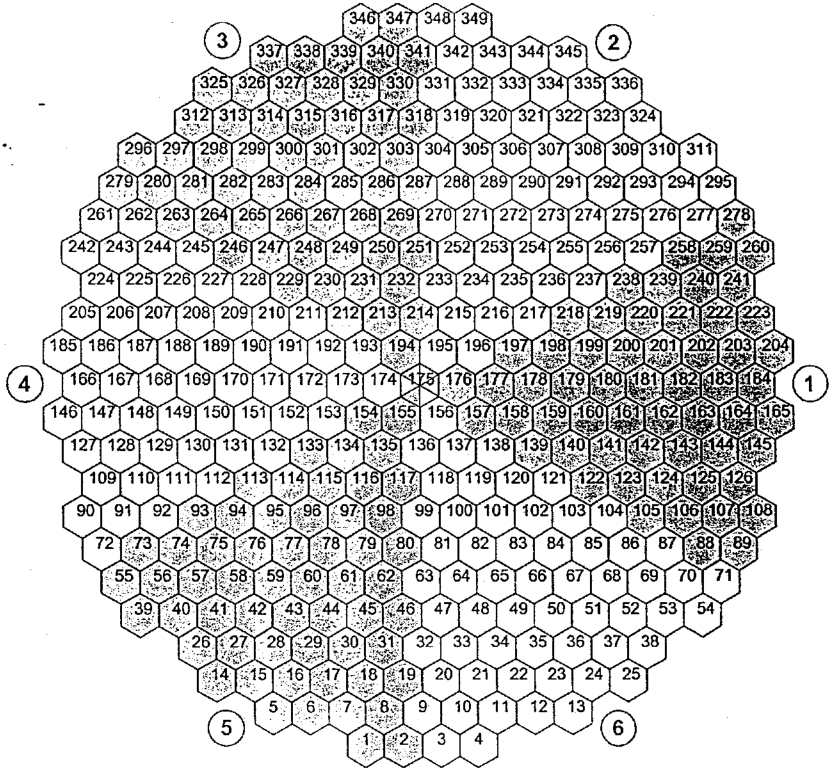
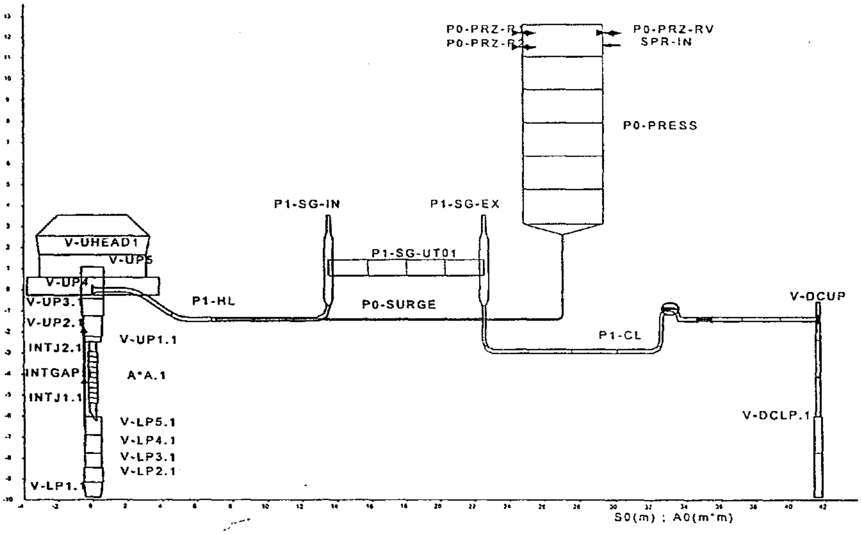
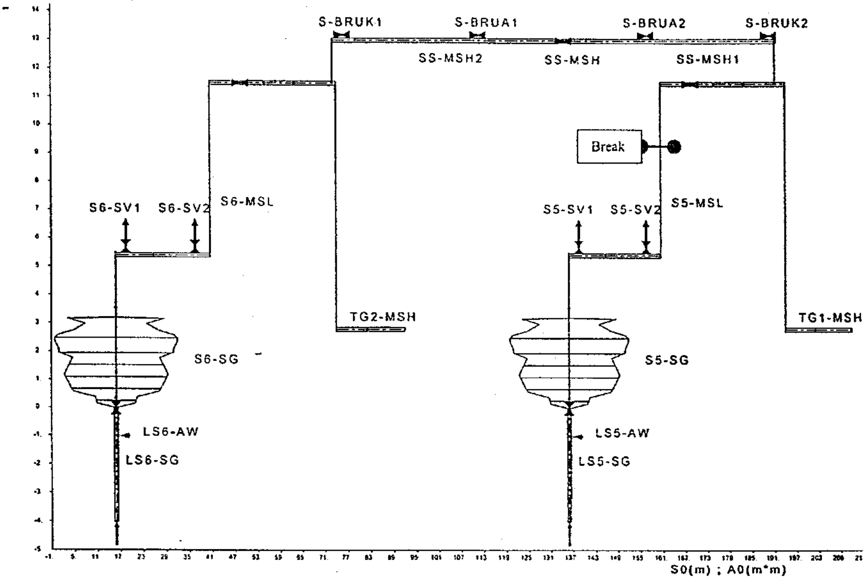


Figure 2. Allocation of the fuel assemblies to the core sectors and thermal-hydraulic channels



PO-PRESS - Pressurizer
PO-SURGE - Surge line of the Pressurizer
PO-PRZ-RV - Pressurizer unloading valve
PO-PRZ-R1 - First safety valve of the Pressurizer
PO-PRZ-R2 - Second safety valve of the Pressurizer
V-DCUP - Down camera of the reactor
V-DCLP.1 - Lower plenum of the reactor vessel
V-LP1.1 ÷ V-LP5.1 - Space below the core
A*A.1 - Fuel assemblies
V-UP1.1 = V-UP3.1 - Space above the core
V-UP4 - Outlet mixing camera of the reactor
V-UP5 ÷ V-UHEAD - Space under reactor head
P1-HL - Hot leg
P1-CL Cold leg
P1-SG-IN - Inlet collector of the steam generator
P1-SG-UTO1 - U-tubes
P1-SG-EX - Outlet collector of the steam generator

Figure 3. Primary circuit of the plant



S-BRUK1	-	BRUK1
S-BRUK2	-	BRUK2
S-BRUA1	-	BRUA1
S-BRUA2	-	BRUA2
LS6-SG	-	Line of the feed water supply in steam generator 5
LS6-AW	-	Line of the feed water supply in steam generator 6
S6-SG	-	Steam generator volume by the secondary side
S6-SV1	-	First safety valve of the steam generator 6
S6-SV2	-	Second safety valve of the steam generator 6
S6-MSL	-	Main steam line 6
TG2-MSH	-	Steam collector before the turbine 2
(LS5-SG) ÷ (TG1-MSH)	-	The same for the steam generator 5
SS-MSH2	-	Main steam header (common for SG 2, 4, 6)
SS-MSH1	-	Main steam header (common for SG 1, 3, 5)
SS-MSH	-	Main steam isolation valve

Figure 4. Secondary circuit of the plant

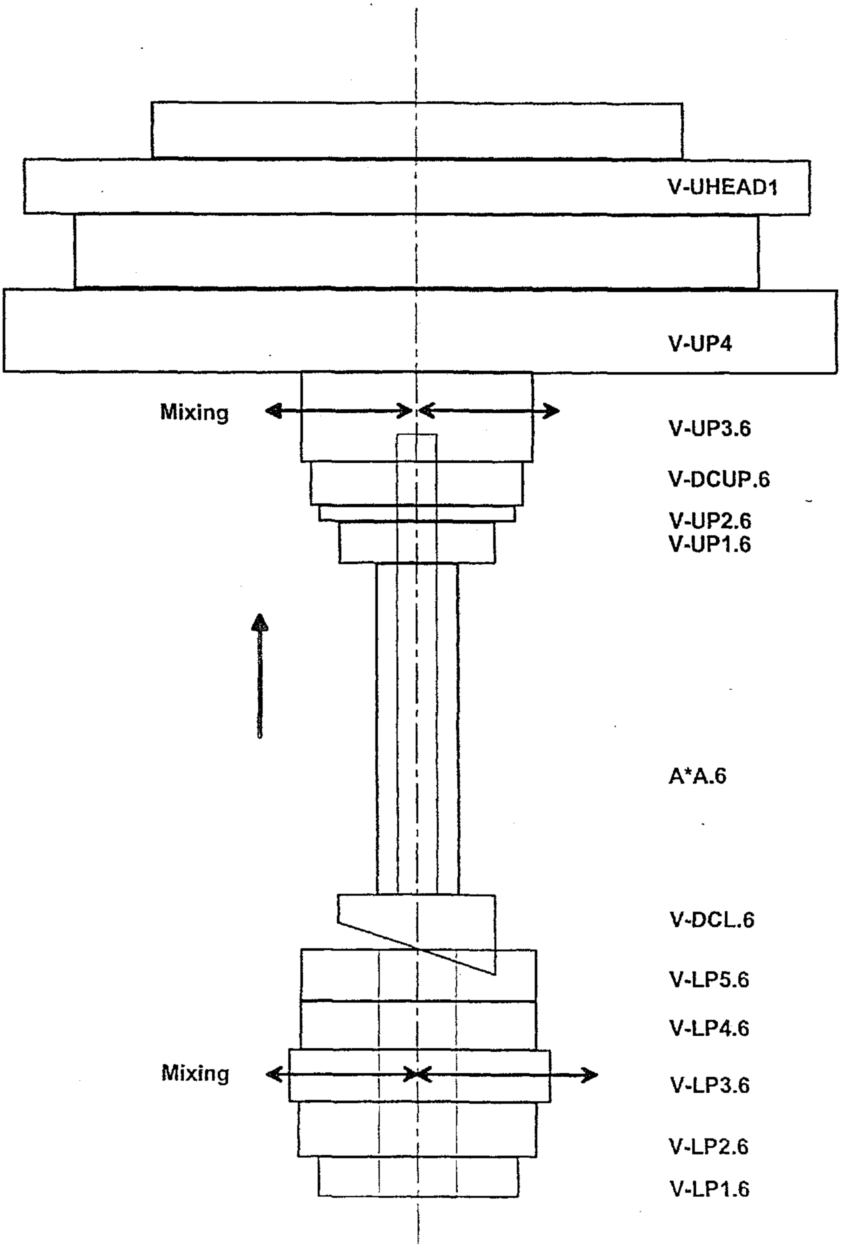


Figure 5. Nodalization of the reactor pressure vessel (sized, one channel is shown)

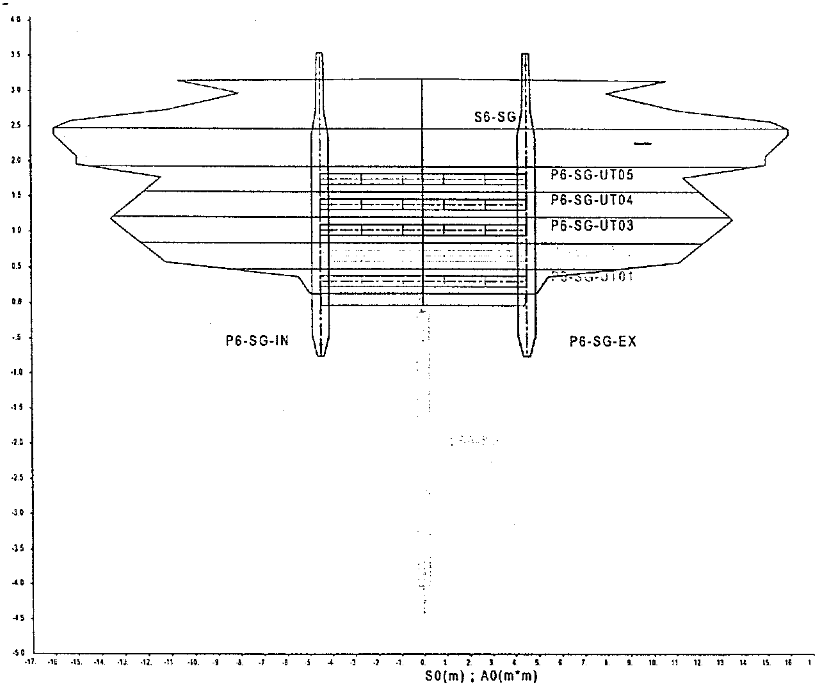


Figure 6. Nodalization of the steam generator (sized)

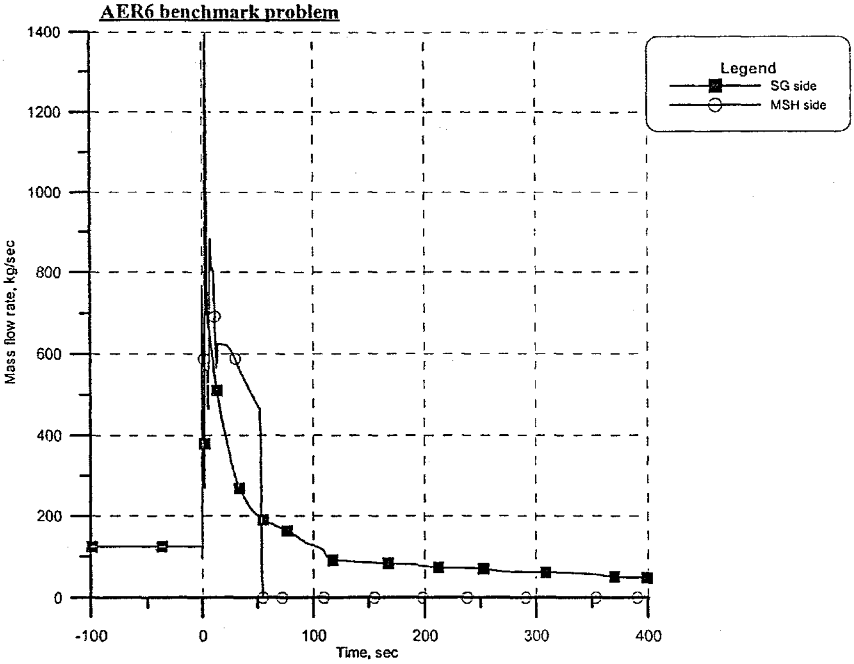


Figure 7. Leak flow through the break versus time

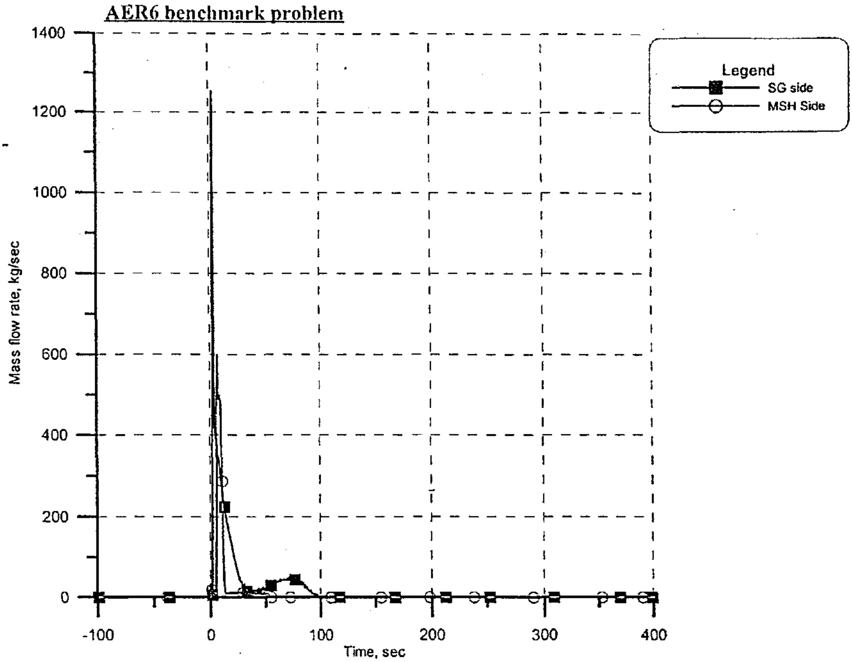


Figure 8. Liquid flow through the break versus time

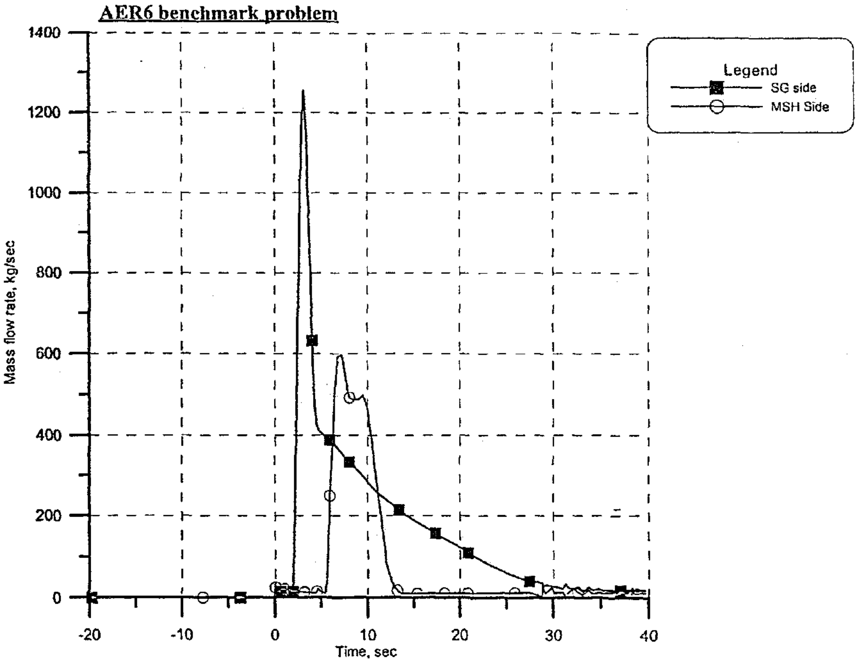


Figure 9. Liquid flow through the break versus time (sized)

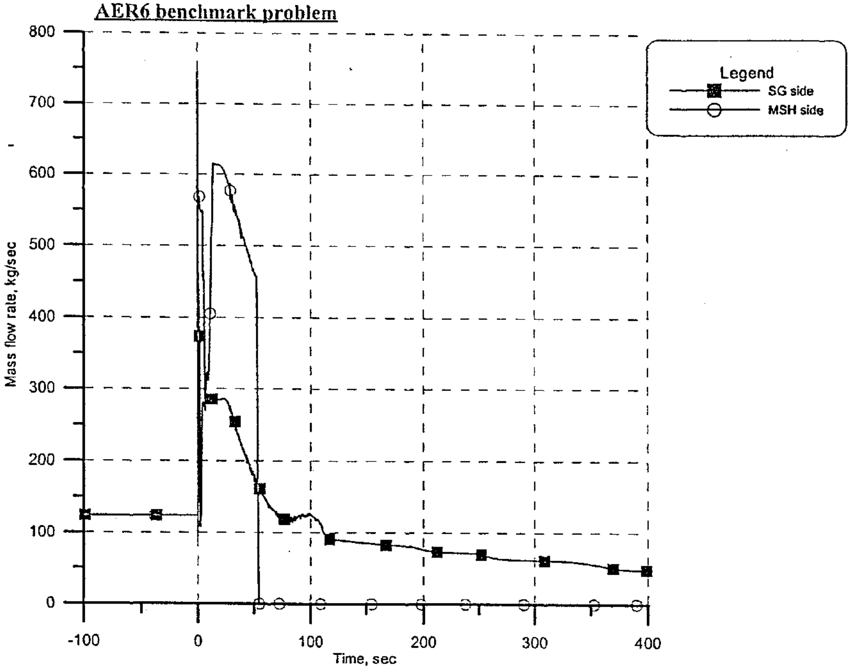


Figure 10. Steam flow through the break versus time

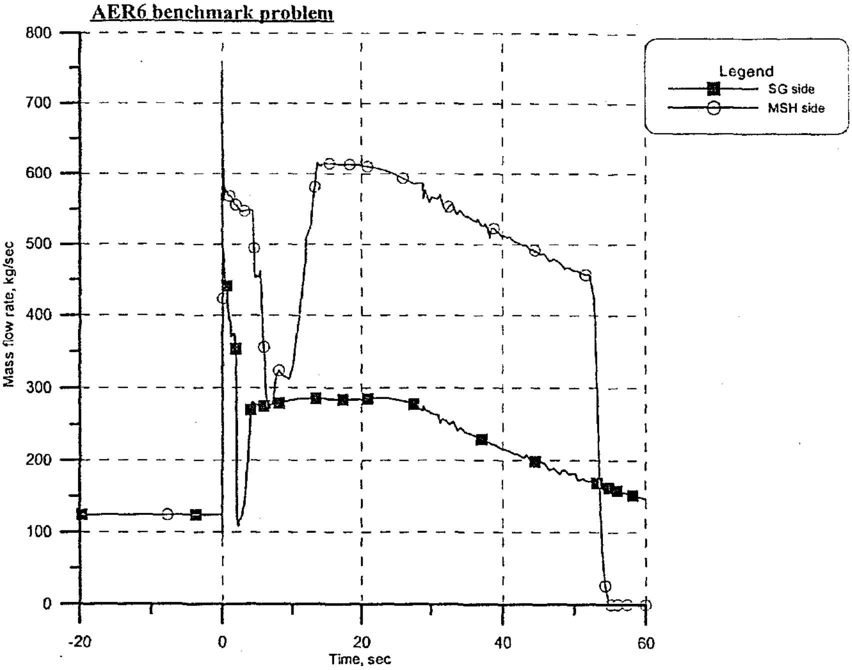


Figure 11. Steam flow through the break versus time (sized)

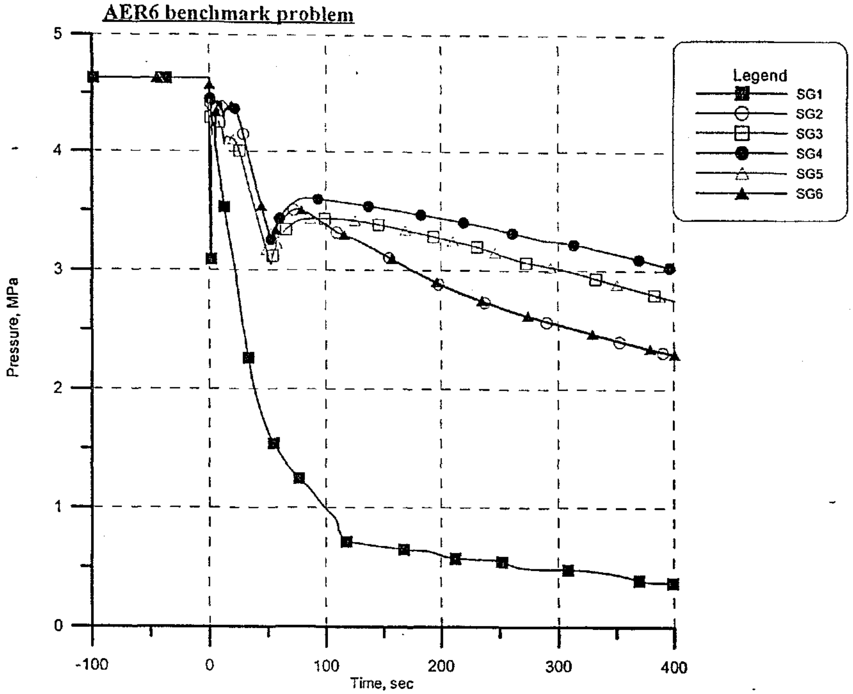


Figure 12. Pressure at the steam generator outlet versus time

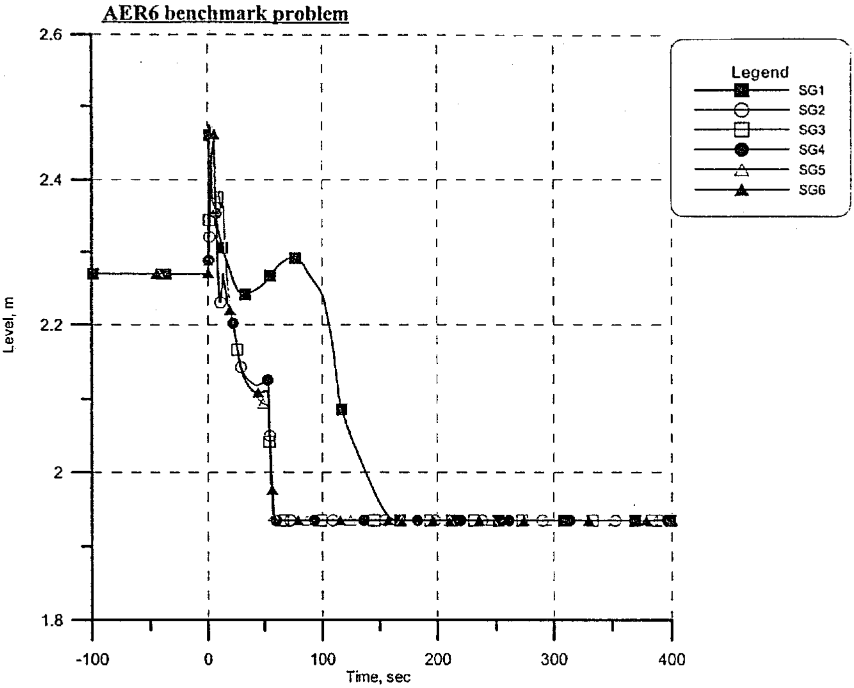


Figure 13. Steam generator level by the low range level gauge versus time

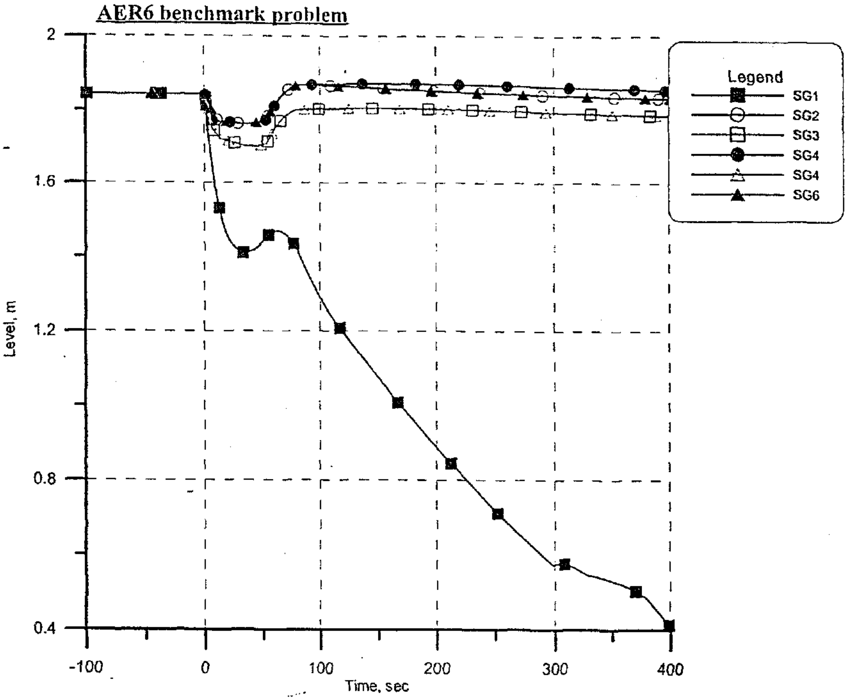


Figure 14. Steam generator level by the high range level gauge versus time

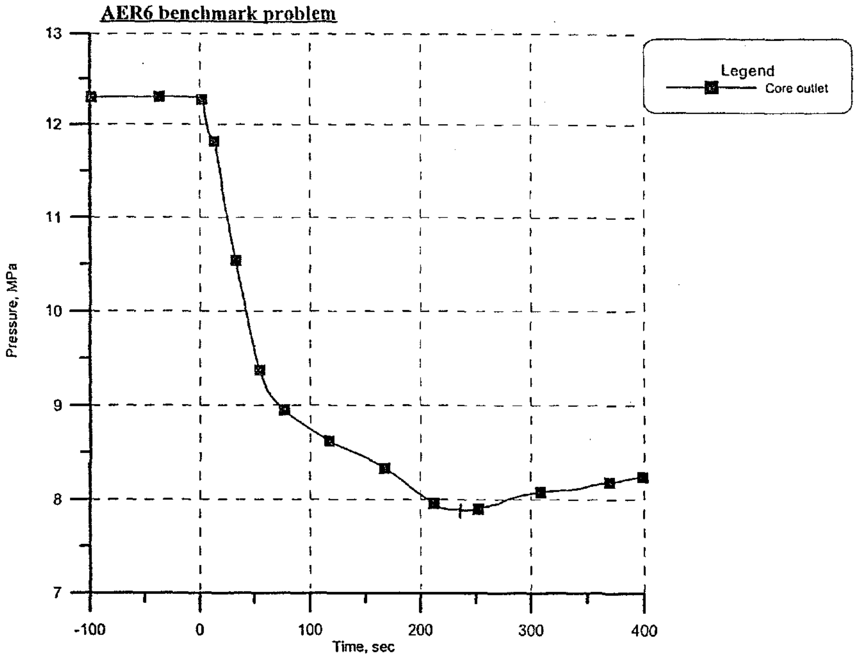


Figure 15. Upper plenum pressure versus time

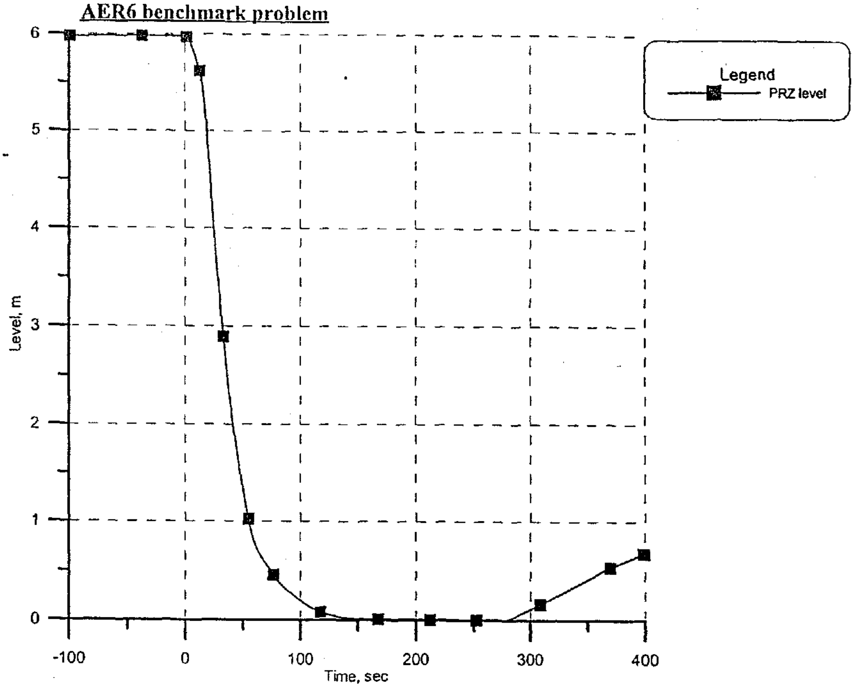


Figure 16. Pressurizer level versus time

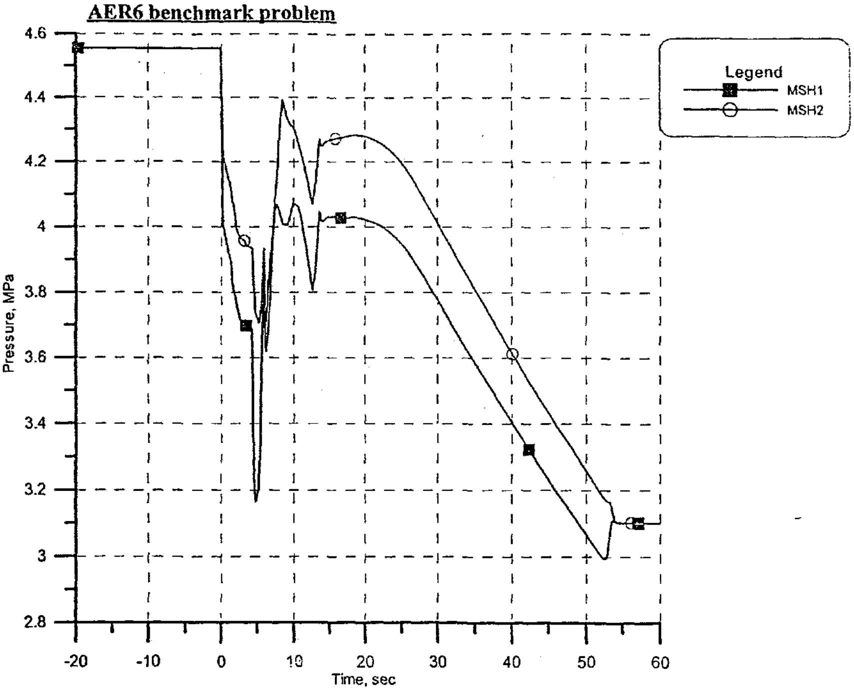


Figure 17. Main steam header pressure versus time (sized)

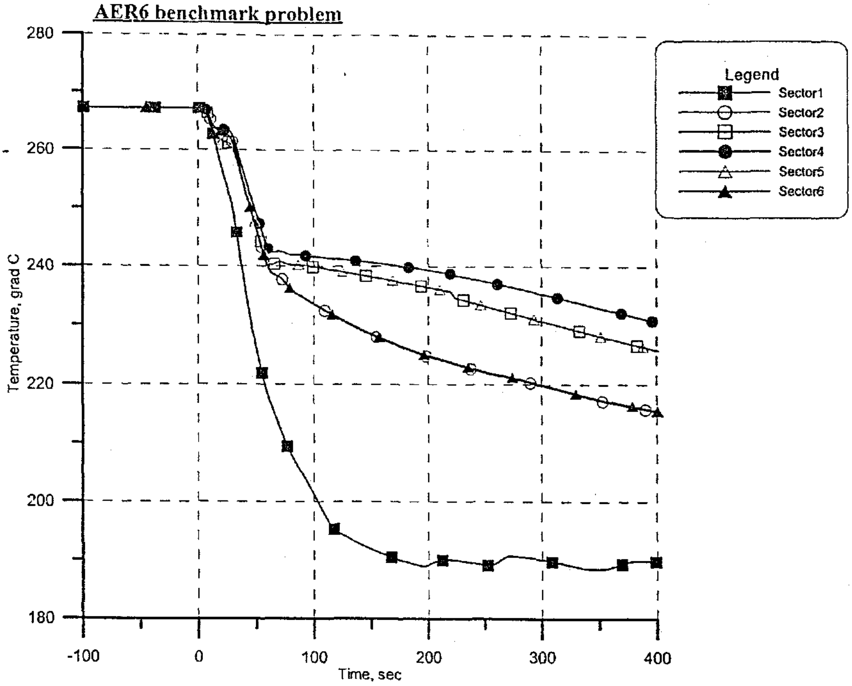


Figure 18. Inlet temperature into the core sectors versus time

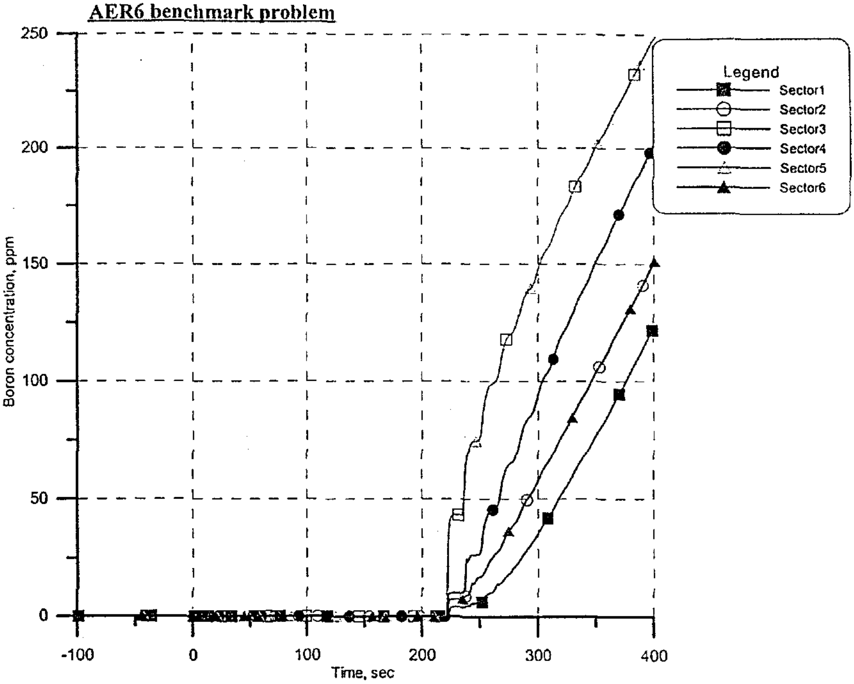


Figure 19. Boron concentration on the core sectors inlet versus time

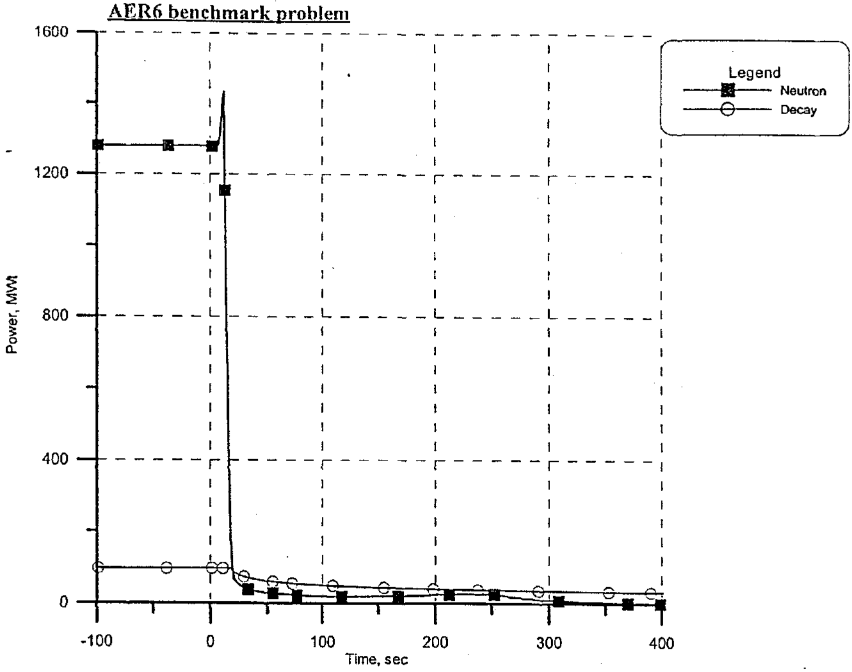


Figure 20. Power versus time

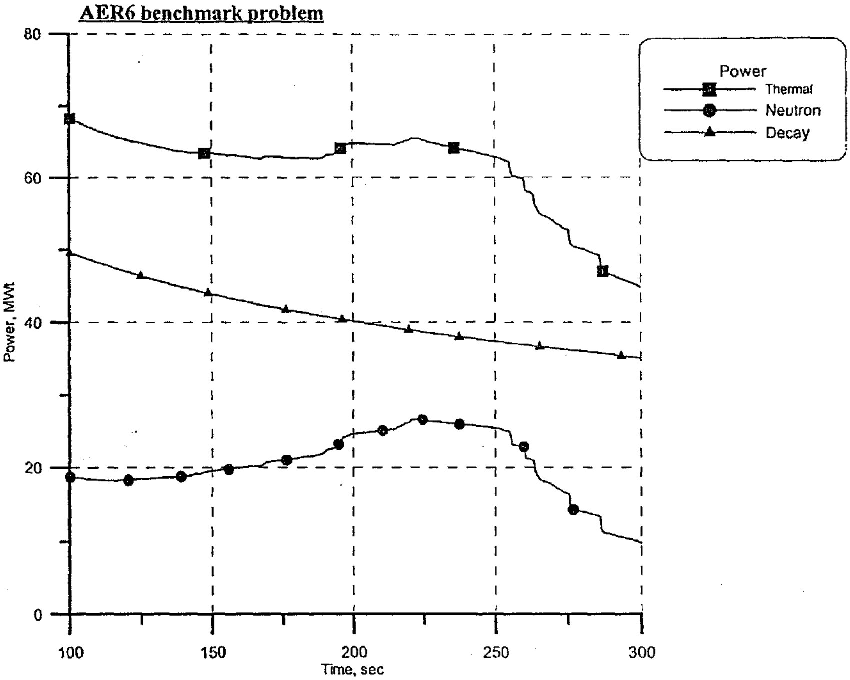


Figure 21. Power versus time (sized)

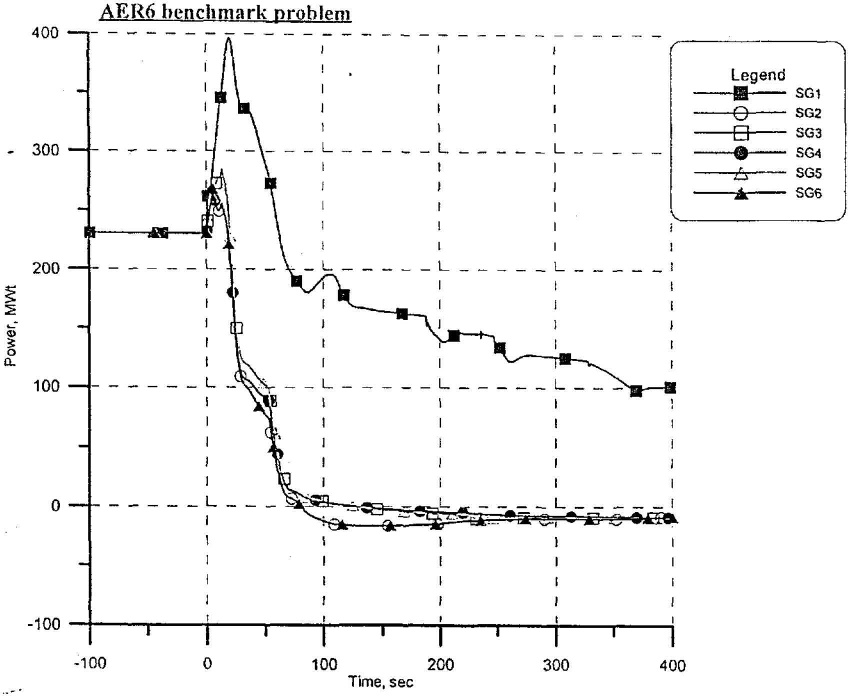


Figure 22. Power, transferred to the secondary side in steam generators versus time

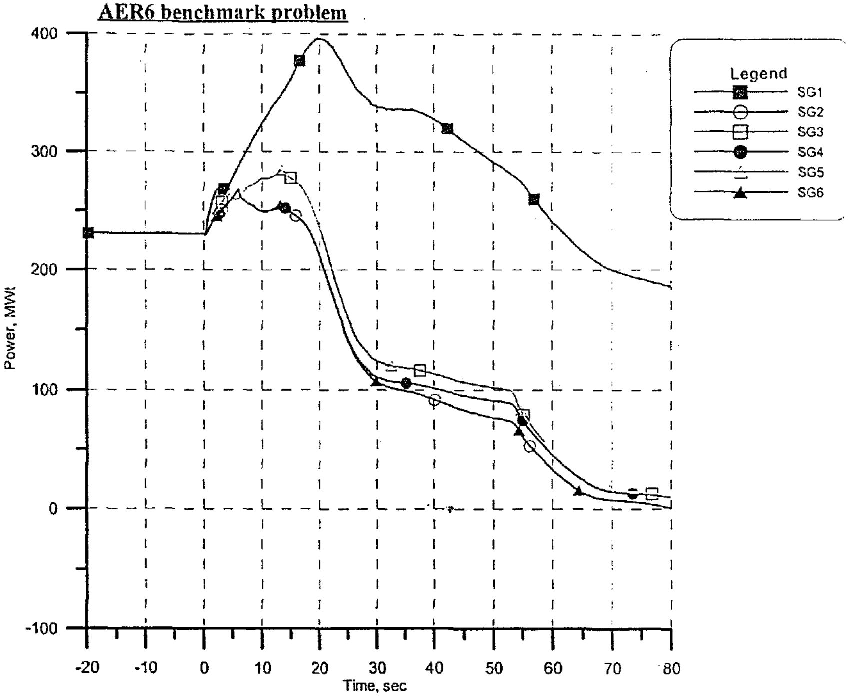


Figure 23. Power, transferred to the secondary side in steam generators versus time (sized)