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Quantitative Analysis of the Operational Reliability of the Equipment of Nuclear Power Plants

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ABSTRACT

A specialized Data Base Management System (DBMS) - a Local Data Base (LDB) is offered in this paper. The LDB is used to collect, process and analyze the information required for the Nuclear Power Plant (NPP) equipment reliability analysis. Five specific requirements about the LDB have been formulated and on their basis a software implementation has been completed. Fifteen criteria for operability of Nuclear Power Unit (NPU) Pressurized Water Reactor (PWR) W-230 type in relation to its available power output are offered after the functional and structural importance of the equipment is taken into account. The basic reliability parameters for the NPU have been obtained.

1 INTRODUCTION

At any Nuclear Power Plant (NPP) the equipment operates under unique conditions and is subject to specific external impacts, operational modes and maintenance procedures. That is why the authors offer a solution of these specific problems which are connected with the equipmet operational reliability at Kozloduy NPP-Bulgaria. Collection, analysis and retrieval of reliability data has been found to be a field of increasing importance for better knowledge about performance states of components and systems. Therefore the systematic accumulation of equipment performance data in Kozloduy NPP and a detailed investigation of the existing equipment reliability, availability and maintanability will contribute to reduction of the uncertainty of Probabilistic Safety Assessment (PSA).

2 SPECIALIZED DATA BASE MANAGEMENT SYSTEM - THE LOCAL DATA BASE

The structure of the specialized Data Base Management System-LDB which is suitable for the conditions of Kozloduy NPP is shown in Fig. 1. The LDB has three aims:

i/Collection of engineering, operational and failure data of NPP equipment performance;

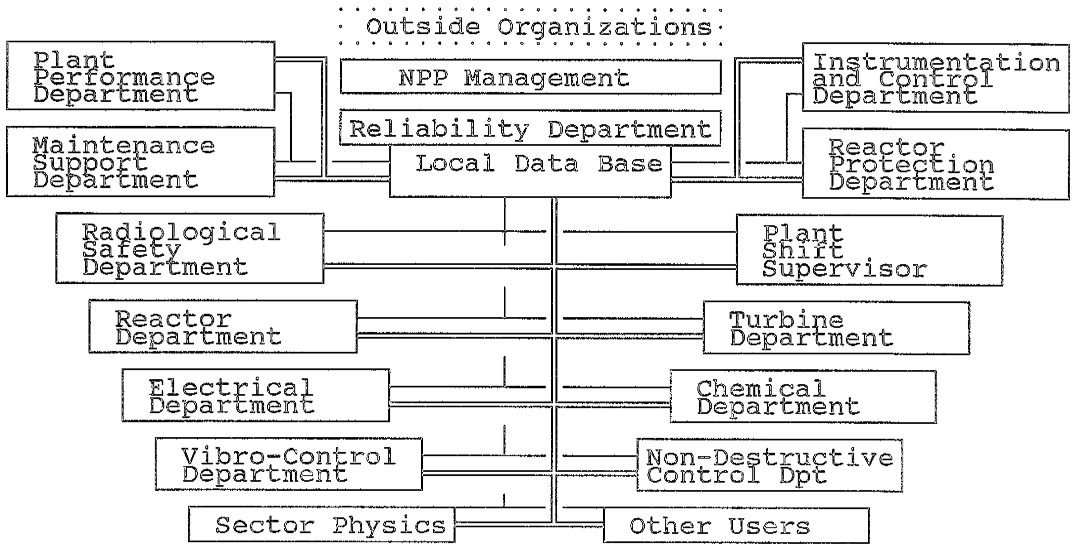


Fig. 1. BlOCK DIAGRAM OF KOZLODUY NPP DATA BASE - LDB

ii/Organization and structuring of the data into efficient DB;
iii/Dissemination of the data and/or information in appropriate form to various users.

3 SOFTWARE IMPLEMENTATION OF THE LOCAL DATA BASE

The organization and quantity of the data set which the LDB must handle and the capabilities of computer equipment on site forced the following software requirements:

i/Possibility for efficient work with data files containing up to 500,000 records of maximum size 200 bytes. Linear dependency of read and write data time;
ii/An open DBMS;
iii/The DBMS must be portable;
iv/Provision for the best possible users interface with the DBMS;
v/The DBMS must be a relational one, while providing some hierarchical layering in data organization.

The DBMS the authors chose was ADVANCED REVELATION. The DBMS is created by REVELATION TECHNOLOGIES INC. Terminal Control Language (TCL) is used for database management. The DBMS has its own powerful relational language for programming-the Relation's BASIC (RBASIC) and is described at top speed in the data search and data processing. The DBMS owns a complete generator of applied programs for screen shapering and program utilities set.

4 UNOPERABLE STATES AND FAILURE INDICATORS

Following power levels for NPU are accepted as criteria for unoperability of its particular components. Their selection is based on the functional and structural importance of the NPU equipment in its transition from operable to failure state. The functional importance presents how the NPU available output (Na) will be changed in relation to NPU rated output (Nn) after failure of K components of a given type (Table 1).

1. Na=1.0*Nn
2. Na=[0.99-0.96]*Nn
3. Na=[0.95-0.91]*Nn
4. Na=[0.90-0.84]*Nn
5. Na=[0.83-0.76]*Nn
6. Na=[0.75-0.61]*Nn
7. Na=[0.60-0.51]*Nn
8. Na=[0.50-0.46]*Nn
9. Na=[0.45-0.41]*Nn
10. Na=[0.40-0.36]*Nn
11. Na=[0.35-0.31]*Nn
12. Na=[0.30-0.26]*Nn
13. Na=[0.25-0.16]*Nn
14. Na=[0.15-MCL]*Nn Minimal Control Level=(10^{-5}-10^{0})*Nn
15. Na=0

Table 1. FUNCTIONAL IMPORTANCE OF NPU EQUIPMENT PWR W-230

N	Na/Nn%	NR	PS	RCPS	RCP	PSV	PCP	SG	ECCS	PMWS	SS	CVCS
1	100	0	0	0	0	0	0	0	2	1	1	0
2	99-96	*										
3	95-91	*										
4	90-84	*										
5	83-76											
6	75-61	*			1	1	0,1	1				
7	60-51				1,2	1,2	1,2	1,2				
8	50-46	*			2	2	2	2				
9	45-41						0					
10	40-36				1	1	1	1				
11	35-31				2,3	2,3	0,2,3	2,3				
12	30-26	*			1	1	1	1				
13	25-16	*			2,3	2,3	2,3	2,3				
14	15-MCL				3	3	3	3				
15	0	*	*	*	1-12	1-12	1-6	1-6	1-6	1-3	1-3	*

Table 1. FUNCTIONAL IMPORTANCE OF NPU EQUIPMENT PWR W-230

N	Na/Nn%	MSP	T	MS	C	CP	SJAS	LPFH	HPD	MDFP	EFP	HPFH	CWP	CCS	G	HG
1	100	0	0	0	0	0	2	0	0	1	1	0	0	1-5	0	0
2	99-96							1-4				3,6				
3	95-91															
4	90-84			1												
5	83-76				1								1			
6	75-61			1		3	3	3	1	2						0-2
7	60-51		1	2	2	4	3,4	1,4,5		3		3,6	2	5	1	0-2
8	50-46															0-2
9	45-41							2,3,4								0-2
10	40-36			3												0-2
11	36-31															0-2
12	30-26															0-2
13	25-16			3	3	5	4,5	3,6		4			3	6		0-2
14	15-MCL															0-2
15	0	*	2	4	4	6	6	2,8,10	2	5	1-2	3,6	4	6-8	2	2

For determination of the functional importance of particular NPU components the following features are taken into account:

availability of a structural excess;
availability of a functional excess;
the particular technological and lay-out solutions;
the particular type of equipment.

The NPU components are specified according to their place in the technological process (Fig.2, Fig.3). This depends on the structural level of the item (component or system). Failure tree is built for every NPU power level (Fig. 4).Its physical meaning is the NPU transition as a system from operable to partial or full failure states according to corresponding criterion.

The research of the reliability parameters is made according to the following assumptions:

i/Item has only two states (operable and unoperable);

ii/A failure means an event when the item turns from operable into unoperable state. This leads to a decrease of the NPU available output according to the corresponding criterion;

iii/The item failures are statistically independent;

iv/A type of the Annual Unit Maintenance (AUM) which coincides with reactor refueling is different for each item;

v/The repaired item is as good as new.

5 SOME RELIABILITY ANALYSIS RESULTS FOR KOZLODUY NPP-BULGARIA

The structural diagram of Kozloduy NPP PWR W-230 type is described in Fig. 2 and Fig. 3.

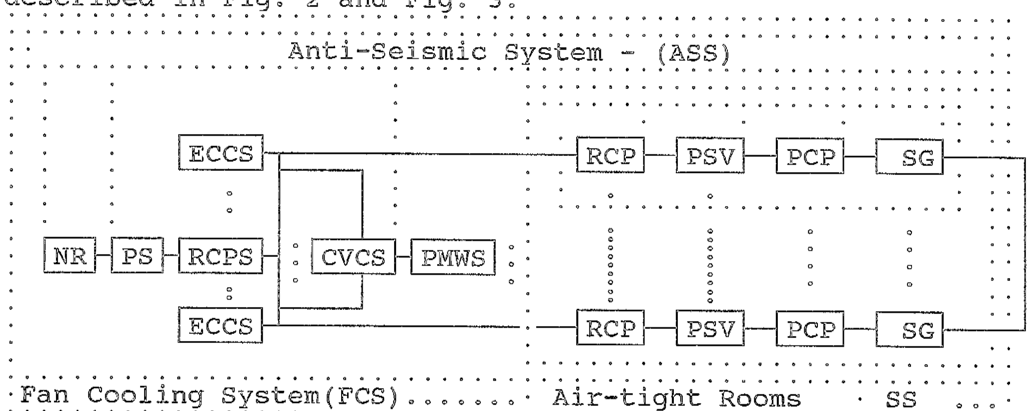


Fig.2 THE STRUCTURAL DIAGRAM OF NPU PRIMARY CIRCUIT PWR W-230

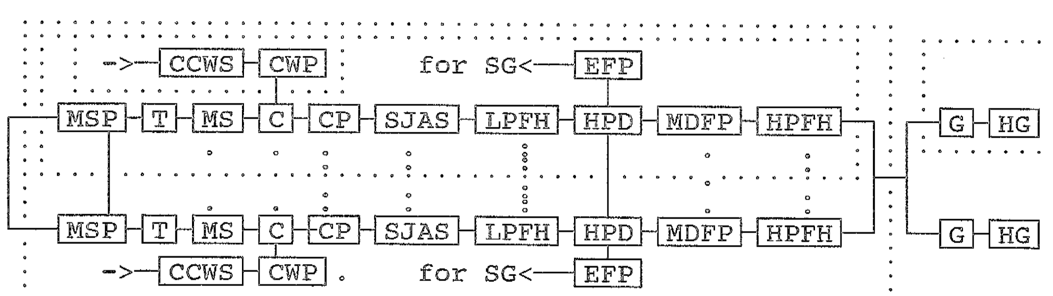


Fig.3 THE STRUCTURAL DIAGRAM OF NPU SECONDARY CIRCUIT PWR W-230

Some of the performance parameters of Kozloduy NPP for 1989/90 are presented in Table 2. Lower electric output for I and III NPU is due to the long Annual Unit Maintenance which were necessary for annealing of the reactor vessels.

In Table 1 the NPU power levels and the functional importance for some of the NPU equipment are presented. The basic parameters which have been obtained for accepting unoperable states are the Forced Outage Rate (FOR), the failure rate (λ) and the repair rate (μ). The estimation of these reliability parameters have been made for life time period of the NPU and method (1) is used.

Table 2. PERFORMANCE PARAMETERS FOR KOZLODUY NPP PWR 1989/90

N	Indicator		I NPU	II NPU	III NPU	IV NPU
1	Start Year		1974	1975	1980	1982
2	Installed Capacity	(MW(e))	440.0	440.0	440.0	440.0
3	Rated Output	(MW(e))	420.0	424.0	427.0	424.0
4	Electric Output	(GWh)	2,650.2	2,646.4	3,215.0	3,042.4
5	House Consumption Rate	(%)	8.18	8.33	7.66	7.66
6	Gross Efficiency	(%)	28.86	28.77	31.07	28.77
7	Net Efficiency	(%)	26.51	26.38	28.70	26.38
8	Inter AUM period	(h)	9,952.3	8,085.9	10,384.2	9,920.9
9	Annual Unit Maintenance	(h)	2739.4	796.5	2187.5	636.2

Table 3. RELIABILITY PARAMETERS FOR KOZLODUY NPP 1989/90

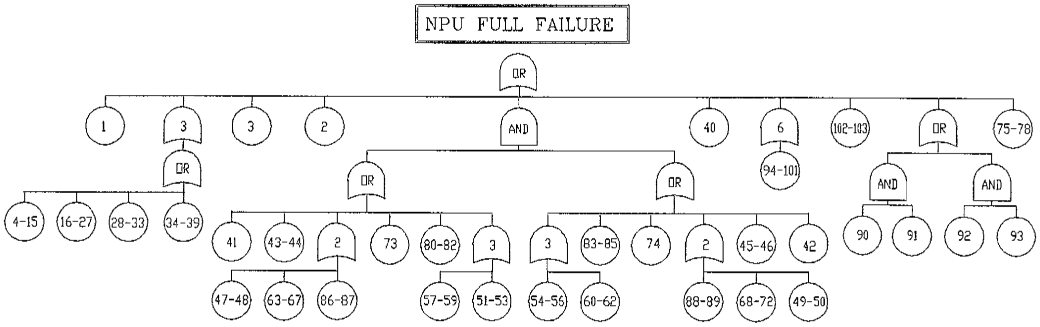
N	Na/Nn%	I NPU PWR W-230			II NPU PWR W-230		
		FOR(%)	λ(1/h)	μ(1/h)	FOR(%)	λ(1/h)	μ(1/h)
1	100	34.85	0.02469	0.04614	26.66	0.03124	0.08594
2	99-96	26.99	0.01842	0.04982	23.46	0.02635	0.08595
3	95-91	21.99	0.01368	0.04855	19.85	0.01986	0.08015
4	90-84	18.02	0.01065	0.04846	15.23	0.01327	0.07385
5	83-76	12.94	0.00860	0.05785	10.11	0.00946	0.08410
6	75-61	5.85	0.00574	0.09235	7.23	0.00680	0.08734
7	60-51	2.20	0.00312	0.13871	3.25	0.00496	0.14793
8	50-46	2.12	0.00283	0.13072	3.00	0.00396	0.12815
9	45-41	1.89	0.00226	0.11722	2.80	0.00353	0.12255
10	40-36	1.76	0.00212	0.11811	2.80	0.00353	0.12255
11	35-31	1.73	0.00169	0.09631	2.72	0.00296	0.10590
12	30-26	1.61	0.00155	0.09475	2.52	0.00225	0.08710
13	25-16	1.61	0.00155	0.09475	2.50	0.00197	0.07688
14	15-MCL	1.06	0.00056	0.05215	1.62	0.00070	0.04241
15	0	0.0	0.0	0.0	0.0	0.0	0.0

Table 3. RELIABILITY PARAMETERS FOR KOZLODUY NPP 1989/90

N	Na/Nn%	III NPU PWR W-230			IV NPU PWR W-230		
		FOR(%)	λ(1/h)	μ(1/h)	FOR(%)	λ(1/h)	μ(1/h)
1	100	19.97	0.01448	0.05804	24.82	0.01533	0.04644
2	99-96	16.63	0.01288	0.06456	24.32	0.01452	0.04516
3	95-91	13.65	0.01102	0.06970	22.90	0.01215	0.04092
4	90-84	10.70	0.00861	0.07182	19.27	0.00827	0.03465
5	83-76	8.09	0.00690	0.07843	18.72	0.00716	0.03108
6	75-61	6.74	0.00471	0.06512	17.57	0.00562	0.02635
7	60-51	3.31	0.00303	0.08856	4.01	0.00224	0.05371
8	50-46	2.23	0.00274	0.12028	1.25	0.00164	0.12953
9	45-41	2.20	0.00249	0.11068	1.25	0.00164	0.12953
10	40-36	2.12	0.00237	0.10913	1.02	0.00098	0.09259
11	35-31	2.05	0.00212	0.10131	1.01	0.00087	0.08556
12	30-26	1.93	0.00162	0.08217	0.90	0.00076	0.08353
13	25-16	1.90	0.00137	0.07047	0.90	0.00076	0.08353
14	15-MCL	0.96	0.00049	0.05057	0.06	0.00032	0.56604
15	0	0.0	0.0	0.0	0.0	0.0	0.0

The results of the investigation (Table 3) show that reliability parameters change weakly at NPU power levels lower than 60%. This is due to NPU steadiness toward full failure. For NPU power levels above 60% the reliability parameters change significantly The cause for this is the great NPU power level decrease as a result of component failure (e.g. PWP, T, etc.).

The failure tree for Na=0 criterion is shown in fig. 4.



1-NR; 2-PS; 3-RCPS; 4-15-RCP; 16-27-PSV 28-33-PCP; 34-39-SG; 40-MSP; 41-42-T; 43-46-MS; 47-50-C; 51-56-CP; 57-62-SJAS; 63-72-LPFH; 73-74-HPD; 75-79-MDFP; 80-85-HPFH; 86-89-CWP; 90-91-G; 92-93-HG; 94-101-CCWS; 102-103-EFP.

Fig. 4. FAILURE TREE OF THE NPU COMPONENT FOR Na=0 CRITERION

6 SUMMARY

The main goal of the quantitative reliability, safety and risk analysis of NPP is to reduce the probability of unexpected equipment failures, which may cause either losses of production capacity or pollution and fatal accidents. The monitoring and analyzing the equipment reliability requires a large investment and the joint efforts of a number of engineers and scientists. The returns on such an investment however are great, due to the losses, which can range anywhere between $30,000 to $50,000 per hour for the PWR W-230 and W-320 type employed in the Kozloduy NPP. Therefore the problem solution of NPP equipment reliability has an enormous importance. This paper presents the efforts of the authors to resolve some of these problems.

LIST OF ABBREVIATIONS

CCWS-Component Cooling Water System; C -Condenser
CVCS-Chemical and Volume Control System; CP -Condensate Pump
CWP -Circulating Water Pump; G -Generator
ECCS-Emergency Core Cooling System; HG -House Generator
EFP -Emergency Feedwater Pump; MS -Moisture Separator
HPD -High Pressure Deaerator; MSP -Main Steam Piping
HPFH-High Pressure Feedwater Heater; NR -Nuclear Reactor
LPFH-Low Pressure Feedwater Heater; PCP-Primary Coolant Pump
MDFP-Motor Driven Feedwater Pump; PS -Pressurized System
PMWS-Primary Makeup Water System; PSV-Primary Stop Valve
RCPS-Reactor Control and Protection System; SG -Steam Generator
RCP -Reactor Coolant Piping; SS -Spray System
SJAS-Steam Jet Air System; T -Turbine

REFERENCES

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