Enhancing NPP Safety through an Effective Dependability Management

Prepared and presented

by

Gheorghe VIERU, PhD

Senior Scientific Nuclear Security Research Worker

AREN/c.o. Institute for Nuclear Research Pitesti, ROMANIA

Enhancing NPP Safety through an Effective Dependability Management

OUTLINES

1. Background
2. Dependability Indicators Evaluations
3. Preliminary Results
4. Comments and Conclusion
5. References
6. Acknowledgements

Enhancing NPP Safety through an Effective Dependability Management

DEFENSE IN DEPTH PRINCIPLE :

To compensate for potential human and mechanical failures, a defense in depth concept is implemented centered on several levels of protection including successive barriers preventing the release of radioactive materials to the environment. The concept includes protection of the barriers by averting damage to the plant and to the barriers themselves. It includes further measures to protect the public and the environment from harm in case these barriers are not fully effective. *(IAEA INSAG –12)*

Enhancing NPP Safety through an Effective Dependability Management

1. BACKGROUND

- ***According to the IAEA Document INSAG-12, Defense in Depth (DID)*** *is singled out amongst the fundamental principle since it underlines the safety technology of NPP and all safety activities, whether organizational, behavioral or equipment related are subject to layers or overlapping provisions, so that a failure were to occur it would be corrected without causing harm to individual or the public at large.*
- ***Safety on the management for a nuclear power reactor involves a "****good dependability management****" of the activities, such as: Reliability, Availability, Maintainability (RAM).***
- ***In order to evaluate certain safety assessment criteria intended to be applied at the level of the nuclear reactor unit management, the performance dependability indicators and their impact over the availability and reactor safety have to be established.***

Enhancing NPP Safety through an Effective Dependability Management

- ***The present work concerns equipment dependability indicators which compliment the plant performance indicators.***
- ***There are five different equipment dependability indicators, all related to equipment maintenance activities and the impact these activities have on the loss of both system (equipment) functions and unit capability. These indicators have to be used as a complement to the DID concept and can provide an overall strategy for safety measures and features of NPP.***
- ***Reactor equipment dependability indicators provide a quantitative indication of equipment RAM performances (Reliability, Availability and Maintenance).***

Enhancing NPP Safety through an Effective Dependability Management

*The document **ISO 9000-4/IEC 300–1 "Dependability Management" (1995)**, describes five internationally agreed indicators of the reactor equipment dependability, each of them can be used for Corrective or for Preventive Maintenance, such as:*

***I1** – equipment Maintenance Frequency (actions per /item per /year);*

***I2** - equipment Maintenance Effort (maintenance man-hours per item per year);*

***I3** - equipment Maintenance Downtime Factor (%);*

***I4**- equipment Maintenance Contribution to the System Function Downtime Factor (%);*

***I5** - equipment Maintenance Contribution to the Reactor Capability Loss Factor (%).*

Enhancing NPP Safety through an Effective Dependability Management

One of the important benefits of equipment's maintenance and failure data gathering is that can be used as a support of DID and PSA. Other benefits may include e.g, the followings:

- ***To apply the two corollary principles of DID- accident prevention and accident mitigation***
- ***Assessment of the value of R&D projects to improve Dependability;***
- ***Maintenance optimization through RCM (Reliability Centered Maintenance) programs for each individual unit;***
- ***Also, the evaluation of those 5 reactor equipment dependability indicators is a valuable managerial tool at the reactor level and can pointed out certain safety criteria to be taken into consideration for the top management of the NPP for DID.***
- ***It is important to underline that the most valuable dependability data are for items which have a significant effect on safety and DID and data need only be analyzed for dominant equipment***

Enhancing NPP Safety through an Effective Dependability Management

- Each of those five indicators can be applied separately both for Preventive and Corrective maintenance (*PM & CM*), giving rise to as many as ten indicator values for each item of equipment.

- The indicators provide a comprehensive picture of the maintenance strategy employed for key pieces of equipment and its effectiveness as well as a valuable managerial tool for improving DID at the reactor level and certain safety criteria to be taken into consideration for the safe management of the nuclear reactor.

Enhancing NPP Safety through an Effective Dependability Management

- **DEPENDABILITY INVOLVES THE MANAGEMENT OF:** *RELIABILITY, AVAILABILITY , MAINTAINABILITY (RAM);*

- **DEPENDABILITY -** ***the collective term used non-qualitatively to describe the availability performance and its influencing factors: Reliability performance, maintainability performance and maintenance support performance.***

- **It is recommended that the equipment dependability parameters should be used within reactor to improve *equipment dependability and, hence, to manage DID activities at the unit level.***

Enhancing NPP Safety through an Effective Dependability Management

2. DEPENDABILITY INDICATORS EVALUATIONS:

The five indicator mentioned before are to be calculated for PM & CM and have the following interpretations:

- **I_1 = (No. of Maintenance actions per time of equipment)/(Number of equipment items* Number of years);**
- **I_2 = (ΣMMh per item of Equipment) / (Reference time period)- where Reference Time (RT) period is the period during which the equipment is needed for its production or safety functions. Usually RT period is taken one year (8760 hrs.);**
- **I_3 = [(Equipment Maintenance Downtime per item of equipment (hours)]/RT period (hours);**
- **I_4= [System Function Downtime (hours)]/(Number of equipment items * Number of Years*8760 (hours)] *100;**
- **I_5 = [unit capability loss per item equipment (MWh)] / [(Reference Energy Generation (MWh)]**

Enhancing NPP Safety through an Effective Dependability Management

3. Preliminary Results:

All the determined calculation are referred only at the primarily circuit out of a NPP CANDU Power Reactor, as shown in the following picture – Figure 1 (a generic one).

To be continued

Enhancing NPP Safety through an Effective Dependability Management

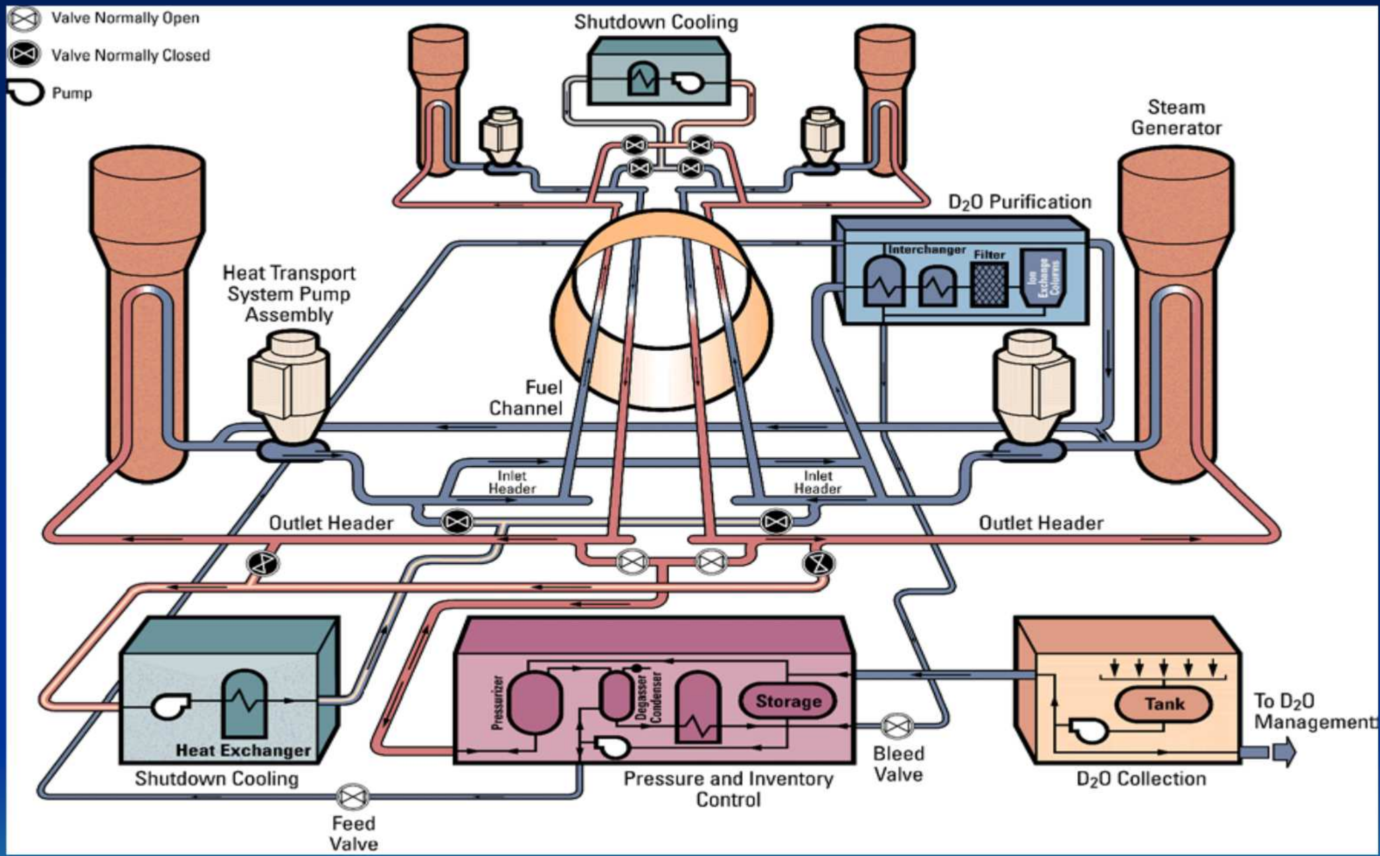


Figure 1

Enhancing NPP Safety through an Effective Dependability Management

The primary circuit includes the following main equipment:

- 4 *circulation pumps*, *2 heat exchangers, 4 valves NO (Normally Open), 6 valves NC (Normally closed);*
- 4 Heat Transport System Pump Assembly;
- 4 Steam Generators;
- 2 system Shutdown Cooling systems;
- 1 D2 O Purification System (from primary circuit itself and from the moderator system);
- *1 system for Pressure and Inventory control*
- 1 *emergency pump*; *instrumentation and control*

Enhancing NPP Safety through an Effective Dependability Management

- To facilitate the interpretation of dependability indicators, all equipment were classified according to its mode of operation.
- ***The dependability indicators*** will apply to all these different possibilities;
- For the equipment operation, a factor, ***Co*** is used to identify the equipment operational mode. **This factor is defined as the ratio of the time that the equipment was in operation to the overall duration of the period of**
- **time under consideration**: $Co = t_o / t_p$
- where ***to*** = total time the equipment was in operation; ***tp***=overall period of time under consideration (reactor operating time per year, in hrs.)

to be continued

Enhancing NPP Safety through an Effective Dependability Management

In principle, maintenance can be approached from a functional point of view at various levels within a NPP (part, component, system, unit, plant).

Generally, the system that merit a RAM analysis can quickly be pinpointed from the ones with:

- ***high concern with respect to DID, safety and environment;***
- ***large number of CM actions in recent years or predicted for the future;***
- ***frequent PM tasks/high PM costs;***
- ***large contribution to full or partial outages***

As an example, for NPP, 30 to 40 systems may be chosen from over one hundred possibilities for the RAM analysis. These can be grouped into 9 or 10 functional system groups. The division of NPP systems into functional system groups is consistent with the proposed by IAEA-Operating experience with NPP in Member States and NPRDS (Nuclear Plant Reliability Data System)-Reporting guidance manual,

Enhancing NPP Safety through an Effective Dependability Management

To facilitate a comparison between different equipment with similar operational modes, the values of the equipment operation factor are grouped into four different categories, such as:

a). based category (Co1): Co ≥ 0.5;
b). two shifting category (Co2): 0.1 ≤ Co <0.5;
c). Peaking category: (Co3): 0.01≤ Co <0.1;
d). Standby category (Co4): Co < 0.01

<u>NOTE</u>: As a recommendation, m*aintenance indicators need only to be applied to those of equipment (approx. 20%) that make the main contribution (approx. 80 %) to the unavailability and/or to the maintenance costs in the NPP. On the basis of historical information and group members experience, certain equipment types dominate unavailability and/or maintenance costs. Example types of equipment: a) Pipes, vessels; b)Electrical, c)Heat exchangers, d)Instrum. and control, e)Engine, turbines, f)Pumps, g)Valves, h)Other equipment, i)Fuel handling, j)Environmental*

Enhancing NPP Safety through an Effective Dependability Management

The period 2003- 2007 has been taken into consideration and the following table summarizes data (which are generic) for the calculation of the dependability indicators, as follows in Table 1:

TABLE 1

Data for calculation of the dependability parameters

Year	Reactor Operation time (Hours)	Unavailable time (Hours)	Reference time period (Hours)	Failures (Numbers)	Maintenance Manhours for repair (MMh)
2003	*7968*	*792*	*8760*	*12*	*350*
2004	*7920*	*840*	*8760*	*11*	*230*
2005	*7894*	*866*	*8760*	*22*	*456*
2006	*7796*	*964*	*8760*	*25*	*412*
2007	*7872*	*888*	*8760*	*23*	*275*

Enhancing NPP Safety through an Effective Dependability Management

TABLE 2-Numerical values for equipment dependability indicators

The calculating numerical values for the equipment dependability indicators ($I_1 \div I_5$) are shown in Table 2, as follows:

Year	$I_1(y^{-1})$	$I_2(Mmhy^{-1})$	$I_3(\%)$	$I_4(\%)$	$I_5(\%)$	Factor C_o
2003	*3.9*	*350*	*3.9*	*3.9*	*3.9*	*0.909*
2004	*2.6*	*230*	*2.6*	*2.6*	*2.6*	*0.904*
2005	*3.62*	*312*	*5.2*	*5.2*	*5.2*	*0.901*
2006	*3.45*	*297*	*4.7*	*4.7*	*4.7*	*0.889*
2007	*3.16*	*275*	*2.85*	*2.85*	*2.85*	*0.898*

Note: there is no possibility of derating, *I3=I4=I5*, whenever the repair on the equipment causes total unavailability of the reactor. These indicators can differ in a significant manner depending upon the maintenance practice and the degree of urgency associated with repair. Since there is clearly a trend with time, values averaged over a number of years must be treated with caution.

Enhancing NPP Safety through an Effective Dependability Management

A comparison concerns equipment dependability indicators for circulation pumps belonging to the CANDU NPP nuclear reactor's primary circuit are presented below:

II.1.1. Corrective maintenance indicators

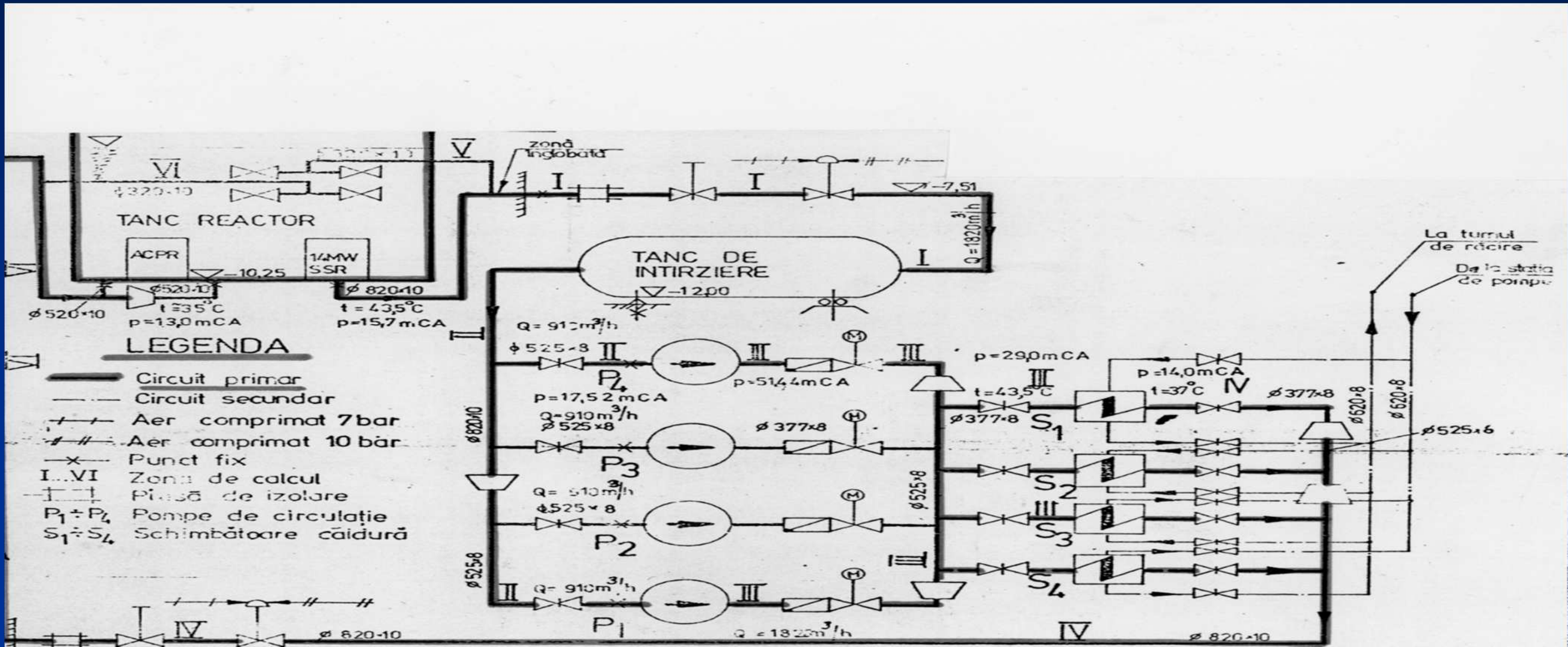
Heat Transport System Pump Assembly	I_1 -Maintenance frequency (Events/pump×year)	I_2 - Maintenance effort (Man-hours/pump× year)	I_3 - Equipment downtime (Downtime/ Reference time period) - %	I_4 - System Function downtime – (Reference time period) - %	I_5 - Reactor capability loss factor (Unavailable power/Reference power) - %
P_1	*1*	*50*	*0.25*	*0.03*	3.5×10^{-2}
P_2	*0.75*	*62*	*0.31*	*0.2*	2.3×10^{-2}
P_3	*1.5*	*69*	*0.72*	*0.13*	1.5×10^{-2}
P_4	*1.8*	*78*	*0.89*	*0.07*	2.1×10^{-2}

Enhancing NPP Safety through an Effective Dependability Management

- ***II. 1. 2. Preventive maintenance indicators***

Pump	I_1 - Maintenance frequency (Events/pump×year)	I_2 - Maintenance effort (Man-hours/pump× year)	I_3 - Equipment downtime (Downtime/ Reference time Period) - %	I_4 - System Function downtime (Reference time period) - %	I_5 - Reactor capability loss factor (Unavailable power/Reference power) - %
P_1	*0.5*	*45*	*1.12*	*0*	*0*
P_2	*0.7*	*47*	*1.21*	*0.25*	*0*
P_3	*0.90*	*63*	*1.05*	*0.5*	*0*
P_4	*1*	*65*	*1.7*	*0.8*	*0*

Enhancing NPP Safety through an Effective Dependability Management



For the INR's TRIGA research reactor analysed, all the determined calculations are referred only at the primarily circuit, as shown in the above figure. There are: 4 circulation pumps, P1-P4, 3 Heat exchangers (S1-S3), 1 Delay tank, pipes 820 x10mm, 20 relief and safety valves, 1 emergency pump, instrumentation and control.

Enhancing NPP Safety through an Effective Dependability Management

The following Table summarizes data for the calculation of dependability indicators for primary circuit of INR TRIGA research reactor: Table 3

Year	Reactor operation time (Hrs)	Unavailable time (Hrs)	Reference time period - (Hrs) -	Failures (numbers)	Maintenanc e Man Hrs - MMh-
1994	1689	22.75	8760	16	350
1995	1724	118.75	8760	12	230
1996	1762	162.6	8760	27	456
1997	1834	175.0	8760	26	412
1998	1925	213.0	8760	19	275
1999	2134	169.5	8760	25	436

Enhancing NPP Safety through an Effective Dependability Management

The calculated numerical values for the TRIGA equipment dependability indicators are shown below: Table 4

Year	I 1 1/y	I 2 MMh	I 3 %	I 4 %	I 5 %	Factor C0
1994	2.5	350	3.45	3.45	3.45	0.19
1995	2	230	2.17	2.17	2.17	0.21
1996	5	456	4.53	4.53	4.53	0.22
1997	4	412	3.22	3.22	3.22	0.23
1998	3	275	1.74	1.74	1.74	0.25
1999	3	436	4.88	4.88	4.88	0.26

Enhancing NPP Safety through an Effective Dependability Management

- Similarly, as in the case of the NPP CANDU analysed primary circuit, there is no possibility of derating, $I_3=I_4=I_5$, whenever the repair on the equipment causes total unavailability of the TRIGA research reactor.
- These indicators can differ also, in a significant manner, depending upon the maintenance practice and the degree of urgency associated with repair.
- The equipment operation factor C_0, as described in the beginning of this work, has clearly a value between ***$0.1 \leq C_o < 0.5$,*** which means that the research reactor is included in the second category-*two shifting category* (**C_{o2}**).

Enhancing NPP Safety through an Effective Dependability Management

4. COMMENTS AND CONCLUSION

- **From Table no. 2 is easily to observe that the factor C0 corresponding to the first category (a) which show a normality in operation. The high values of the indicators I1 and I2 shows that the equipment used have high reliability parameters with significant influences to the reactor DID and PSA analysis. Also, the determination of dependability parameters may lead to the establishment of programming aimed at protecting valuable nuclear power reactor, such as CANDU (or other types of NPP) from High Impact, Low Probability (HILP) failures. On the other hand, these indicators offer potential for wider application since:**

  - may be used to complement reactor level performance indicators in the field of operation, DID, maintenance and improving of operating parameters;

- ***Using the maintenance related indicators it is possible to follow trends with time and to compare different operating experience and maintenance strategies.***

Enhancing NPP Safety through an Effective Dependability Management

- **From Table 4, t**he equipment operation factor C_0, as described in the beginning of this work, has clearly a value between ***$0.1 \leq C_o < 0.5$,*** which means that the TRIGA research reactor is included in the second category- *two shifting category* (**C_{o2}**). Similarly, as in the case of the NPP CANDU analysed primary circuit, there is no possibility of derating, $I_3=I_4=I_5$, whenever the repair on the equipment causes total unavailability of the TRIGA research reactor.

- **It is recommended that these indicators should be used within reactor unit to improve DID measures and the management of equipment dependability. In particular, this can be of value in optimizing maintenance strategies.**
- **Provided that attention is paid to specifying equipment boundaries precisely and to record the size, type, level of redundancy and mode of operation of the particular equipment under DID consideration together with the size and work pattern of maintenance team.**

Enhancing NPP Safety through an Effective Dependability Management

5. REFERENCES

1. **IEC 300-1 *Dependability Management*, Part 1- Dependability Programme Management, 1993;**
2. **G. Vieru, "*Consideration on the Experimental Reliability Determination, Reliability Improvement for Nuclear Reactor Instrumentation*", Paper printed in the Proceedings of *ICONE*- 3 International Conference, Kyoto, Japan, 1995;**
3. **G. Vieru, INR Pitesti -**"*Safety Criteria for the TRIGA Reactor management and the evaluation of its applicability at NPP Cernavoda*", *2001,* **(*Internal Scientific Research Report-RI 6060*).**
4. **INSAG-10,** *Defense in Depth in Nuclear Safety*, **A report by the International Nuclear Safety Advisory Group (INSAG), IAEA Vienna (1996);**
5. **INSAG-12,** *Basic Safety Principles for Nuclear Power Plants* **75-INSAG-3 Rev. 1 INSAG-12, IAEA Vienna 1999;**

Enhancing NPP Safety through an Effective Dependability Management

6. ACKNOWLEDGEMENTS:

My special ACKNOWLEDGEMENTS goes to:

- **To the IAEA Vienna Secretariat for continuous technical support, to improve experience in the field of Safety of NPP, Dependability Management, DID and Improving Availability of a NPP;**

- **To the IAEA CN-205 Conference Scientific Secretaries – Dr. Peter Hughes and Dr. Hussam Khartabil, IAEA Safety Assessment Section, for their strong support and recommendations paid to me during preparation of this work.**

Special thanks to Ms. Julie Zellinger, IAEA Conference Service Section.

THANK YOU VERY MUCH FOR YOUR KIND ATTENTION!!!