EVALUATION OF DOSE PROBABILITY DUE INCIDENTS ACCORDING TO THE TYPE OF NUCLEAR RESEARCH REACTORS

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ABSTRACT

This work is intended to establish a risk probability analyses evaluation of incidents according to the type of nuclear research reactors. With this aim, two different IAEA databases were used: Research Reactor Data Base (RRDB) and Incident Report System for Research Reactor (IRSRR). This evaluation employs a Probabilistic Safety Analysis (PSA) for two distributions, Fischer and Chi-square, and the analyses were done considering a 90% confidence level. All calculations used theory and equations listed at IAEA TEC-DOC – 636 and applied to Scilab version 5.1.1, computational model. All results obtained with this probability analysis allowed to conclude that the incidents lead to events with radiation doses in a reference interval of normal and stochastic effects established by ICRP-64. The methodology applied to raise information from both databases, RRDB and IRSRR, made possible the construction of probability analyses of incidents. Hence, based on the survey it will be possible to forecast and prevent future nuclear research reactor incidents and their aftereffects.

Key Words: Incidents, type of nuclear research reactor, PSA, radioactive dose

1. INTRODUCTION

Nuclear research reactors have been considered important tools in the nuclear science knowledge. During more than 50 years they allowed scientists to obtain huge contributions for educational and development programs in more than 70 countries around the world. More than 675 research reactors were built until the year of 2007 and 278 of them are maintained in continuous operation (86 settled at development countries) [1]. Along all this period, considering all research reactors still under regulatory control, they account for an amount of 17,400 years of operational experience, (the operational experience is named demand (d) in this work)[1,2]. Safety and security concerns, as well as prevention policy, have stimulated the development of this work which leads to the comparison and analysis of incidents, here considered until level 3 in the International Nuclear Events Scale (INES) of the IAEA [3]. So, with basis on operational experience accumulated (d) [1] and with knowledge obtained from abnormal events [2], it is possible to obtain a classification by type of research reactor incidents [4] and calculate the occurrence probabilities. A comprehensive list of incidents with nuclear research reactors can be found within IRSRR reports [2, 4]: until March 2008 a total number of 154 incidents had occurred. These data, as well as partial operational experience by research reactor, were used to calculate the probabilities for these abnormalities. Doses foreseen for these situations are defined as potential expositions and the situations that generate them are defined as potential situations [5, 6]. This work determined the total occurrence probabilities, applying the Probabilistic Safety Analysis (PSA) suggested at TECDOC-636 [7]. Statistical evaluation for the occurrence risk of abnormal events provides a wide view of the radiological protection within nuclear research reactors design, allowing regulating bodies to obtain a complimentary database for new and updated guidelines implementation, thus lowering the occurrence of abnormal event at nuclear plant and improving the operational safety.

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2. OBJECTIVE

The main purpose of this work is to study the various types of nuclear research reactor incidents described by IRSRR [2] and produce a statistical analysis procedure for the prevention of possible occurrences, inside operational nuclear research reactors and new plants. Besides, it is also aimed to estimate maximum allowable doses for such events, so that annual risk limits established by ICRP [8, 9] may be enforced.

3. METHODS

Total operational experience (d) was obtained from RRDB [1] data for each nuclear research reactor by means of the operational experience summation, since the first criticality until March 2008. From IRSRR [2, 4], the incident number for the same time interval was obtained and, later, all data were co-related. Data from IRSRR are restricted to member countries of the IAEA and may be accessed only by authorization of the country nuclear regulatory commission. The data presented in this study was authorized disclosure. From RRDB and IRSRR data, it was possible to identify incidents by type of research reactor occurrence, Table 2, which is the most important for the IAEA Nuclear Research Reactors Safety Department. Data from IRSRR related to incident numbers were deployed by the IAEA as classified material, with an expiration date of March 2008, when it was obtained the last update of that survey.
A specific PSA calculation computational program [10], for the Chi-square and Fischer distributions, was developed inserting the equations recommended by the IAEA TECDOC-636- Appendix D, pages 77-79 [7] at Scilab 5.1.1.
This procedure allowed probability calculations by type of research reactor incidents described at the IRSRR [2, 4]. Using Sordi equations, the maximum admissible doses to compare with the risk limits established by the International Commission on Radiological Protection, ICRP-64, were achieved.

4. RESULTS AND DISCUSSION

Sordi equation $\left(D^2 - 100 \cdot D\right) \cdot P = 2$ (1), where: D= effective dose in mSv, P= occurrence probability of a potential exposure was presented at IRPA-10 [11] and used to calculate doses between 0.1 Sv - 2.0 Sv, in the quadratic range. Table 1 shows results obtained using this equation, were obtained the incident probabilities per year as a function of the maximum allowable doses established by risk limits – ICRP-64[9]. Using data from Table 1, the curve shown at Fig. 1 was adjusted. This adjustment allowed the following equation (2) to be obtained: $Y = a - \frac{b}{\left(1 + c \cdot X\right)^{1/d}}$ (2), where X represents a risk probability and Y is the evaluated dose, a, b, c and d are constant.
Incident by type of research reactor were classified according with the IRSRR classification guide [2, 4], see Table 1. Based on the values, the partial operational experience (d) and incident by type of research reactor number (nd) were related, for all

nuclear research reactors under regulatory control built until 2008, as shown in Table 1. The average probability occurrence of the incidents, according to type of research reactor were determined by PSA, using the equations recommended in the TECDOC-636 [7] and the maximum allowable dose was determined by equations adjust Fig. 1.

TABLE 1 – Maximum Incident Probability as a function of doses calculated by Sordi equation (1).

Dose (Sv)	Maximum Incident Probability/year
0.10	$1.0x10^{-2}$
0.11	$1.5x10^{-3}$
0.12	$8.0x10^{-4}$
0.15	$2.6x10^{-4}$
0.20	$1.0x10^{-4}$
0.50	$1.0x10^{-5}$
1.0	$2.5x10^{-6}$
2.0	$1.0x10^{-6}$

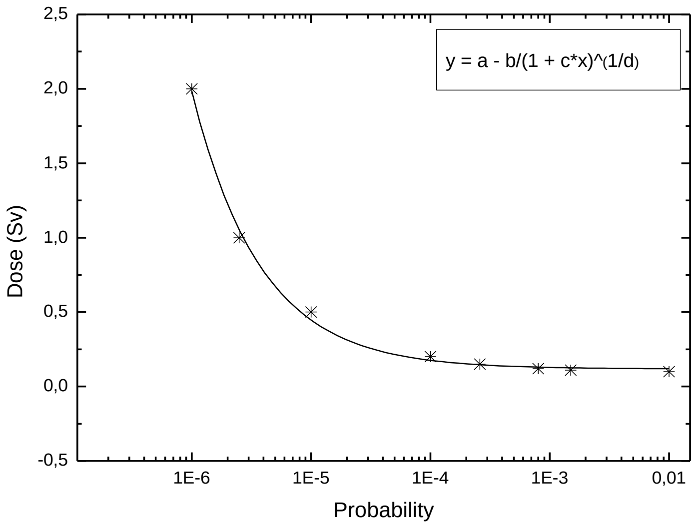

Figure 1 – Relation between maximum allowable dose and incident occurrence probability. Experimental error bar was set within the own graphic representation of experimental points.

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TABLE 2 - Type of nuclear research reactor, a operational experience in partial demand of nuclear research reactor without incidents and with incidents, sum of partial demand (demand total) and total number of the incidents [1,2,4].

Type of nuclear research reactor	**Demand partial without Incidents-year**	**Demand partial with Incidents-year**	**Demand total by type of research reactor(d) -year**	**Number of Incidents (nd)**
Argonaut	684.2	85.4	769.6	2
Critical assembly	2793.6	40.5	2834.1	4
Fast Breeder	166.4	12.1	178.5	1
Fast, Na cooled	12.1	31.0	43.1	1
Graphite	284.2	51.9	336.1	1
Heavy Water	762.7	296.8	1059.6	17
Homogenous (L)	379.7	56.6	436.3	3
Loop Type	0.0	49.9	49.9	2
Pool	3072.2	982.4	4054.6	54
Pressurized Vessel	0.0	47.2	47.2	1
Power PWR	0.0	24.9	24.9	1
Tank in pool	1298.3	371.9	1670.2	34
Tank WWR	285.9	271.2	557.1	13
Triga Conventional	355.4	70.7	426.1	2
Triga Dual core	0.0	28.4	28.4	3
Triga Mark II	613.7	180.0	793.7	8
Triga Mark III	70.2	63.2	133.3	7
Total	10778.6	2664.1	13442.7	154
95 Others reactors without incidents	503 reactors without incidents	77 reactors with incidents	Total of the 675 research reactors	
Operational experience research reactors, without incidents.	3959.5			
	14738.1	2664.1	17402.2	

Where:
nd = incident number
d= Demand (total operational experience for each type of research reactor incident in years)

The Table 2, shown the total operational experience (17402.2 years) for all nuclear research reactors about regulatory control (675), nuclear research reactor with incidents, operational experience (2664.1years) (77), that means 11.4 % of the all nuclear research reactor were with incidents, and other hand, 15.3 % of operational experience were with incidents, another type research reactor without incidents (95), operational experience, (3959.5 years) 22.75%.

The occurrence average probabilities by type of research reactor were determined by PSA by means of the equations recommended at TECDOC-636[7]. Show in Table 3.

TABELA 3 – Average Probabilities calculated by PSA, Fischer and Chi-Square distribution for all t**ype of nuclear research reactor** with incidents. Decreasing order and maximum allowable dose (mSv) increasing order

Type of nuclear research reactor	$P_{AvFischer}$/year	P_{AvChi}/year	Maximum allowable dose (mSv)
Triga Dual Core	$1.41x10^{-1}$	$1.53 x10^{-1}$	50.0
Power PWR	$8.90x10^{-2}$	$9.59 x10^{-2}$	50.0
Loop Type	$6.39x10^{-2}$	$6.65 x10^{-2}$	50.0
Triga Mark III	$6.07 x10^{-2}$	$6.17 x10^{-2}$	50.0
Fast, Na cooled	$5.84 x10^{-2}$	$5.57 x10^{-2}$	50.0
Pressurized Vessel	$4.90 x10^{-2}$	$5.10 x10^{-2}$	50.0
Tank WWR	$2.53 x10^{-2}$	$2.54 x10^{-2}$	50.0
Triga Mark II	$2.31x10^{-2}$	$2.31x10^{-2}$	50.0
Tank in pool	$2.10 x10^{-2}$	$2.10 x10^{-2}$	50.0
Heavy water	$1.71 x10^{-2}$	$1.71 x10^{-2}$	50.0
Pool	$1.33 x10^{-2}$	$1.34 x10^{-2}$	50.0
Fast breeder	$1.32 x10^{-2}$	$1.33 x10^{-2}$	50.0
Homogenous (l)	$9.78 x10^{-3}$	$9.83 x10^{-3}$	100.1
Triga conventional	$7.76 x10^{-3}$	$8.89 x10^{-3}$	100.3
Graphite	$7.09 x10^{-3}$	$7.80 x10^{-3}$	100.6
Argonaut	$4.30 x10^{-3}$	$4.32 x10^{-3}$	102.8
Critical Assembly	$1.17 x10^{-3}$	$1.17 x10^{-3}$	114.0

Where:
$P_{AvFischer} = P_{AvChi}$= average probability for two distribution are similar

The Table 3, shown average probabilities 10^{-2}, the according ICRP-64, the maximum allowable dose is 50.0 mSv and, the probability values calculated, indicated that to individual occupationally exposed the dose is within the allowable range. For average probabilities 10^{-3}, indicated that to individual occupationally exposed the dose is in the field of stochastic effects, if, the dose is upper 50.0 mSv / year. For the nuclear research reactor Triga Dual Core, have a probability of 10^{-1}, the according ICRP-64, this type of nuclear research reactor should be is your operation forbidden immediately.

5. CONCLUSION

Data from Table 3 show uniformity for average probabilities by type of research reactor incidents for two distributions calculated by PSA. The maximum allowable doses (114.0 mSv /year) for type of research reactor 'Critical Assembly' are 2.28 times the annual limit of the effective doses (50.0 mSv /year) for workers in radioactive and nuclear installations [8]. In TECDOC-636[7], the use of Chi–square distribution for the failure probability calculations is limited to 50 events. For a greater number of events, it is recommended Fischer distribution. From all results obtained, it can be observed that there is no difference in the application of both distributions for a number of events lower or greater than 50 of the Table 2. If consider questions about the confidence level by type of nuclear research reactor, it is necessary a better analysis for conclusion.

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