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PRE-RELEASE DETERMINATION OF RADIOLOGICAL SOURCE TERM FOR REACTOR ACCIDENTS

PhD thesis summary

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Budapest, 2005

1. INTRODUCTION

1.1. Definition of the scientific issue

The occurrence frequency of reactor accidents is very low, nevertheless due to their severe consequences, and especially after the reactor accident of Chernobyl in 1986, they require special attention from the experts dealing with emergency response and management. Protective actions are to be developed and implemented in order to relief the harmful effects of such accidents. The most important professional expectations for public protective actions are their optimization and justification. A protective action is optimized if its form, scale, time and duration makes the highest averted dose possible; while it is justified if it causes more good, than harm.

From the viewpoint of environmental consequences the most important technical parameter of reactor accidents is the so-called radiological source term, which defines the composition of the release, activities of the released nuclides, the time when the release starts, the duration and height of the actual or potential release.

Obviously the implementation of protective actions within the pre-cautionary and the urgent protective action emergency planning zones of the Paks Nuclear Power Plant could result in highest averted dose, if they are implemented early, prior to the actual release. The pre-release assessment of environmental consequences and the determination of necessary protective actions are performed applying environmental simulator software by the radiation protection experts of decision-support organizations. The input parameters of the calculations are the source term and the forecasted meteorological conditions.

The accurate, comprehensive and at the same time quick determination of the source term prior to the occurrence of a release requires the comprehensive assessment of the mechanisms that are significant for release, the actual and future conditions of engineering barriers and safety systems designed for preventing and mitigating the consequences, and reducing the quantity of the released radioactive isotopes.

In my PhD study I have analyzed various accidents and severe accidents of the Paks Nuclear Power Plant which are relevant from the viewpoint of environmental consequences and occurring at full power state of the reactor. Based on the results I have developed such a comprehensive methodology, applying which on the measured plant parameters the actual and

future condition of the reactor may be assessed, and the source term may be estimated before the release actually occurs.

1.2. Timeliness and relevance of the issue

The preparedness for nuclear emergencies received more and more emphasizes, either in Hungary. This may be seen from the more frequently and with wider scale organized nuclear emergency exercises, the primary goal of which is to train the on-site and off-site personnel for being capable to response to a real emergency situation. Special attention is paid to the widest scope (largest number of organizations is involved) exercises, which are organized every 5-6 years (such exercise was held in 1998 and 2004). Their main objective is to practice the management of such nuclear emergencies, when the hypothetical accident occurs in the Paks Nuclear Power Plant. The international exercises play relevant role as well, when the Hungarian experts may be trained for emergency response to an accident occurred outside the Hungarian territory.

As well as during emergency management, so in case of a nuclear or radiological emergency one of the most important tasks is the implementation of protective actions in order to prevent the population from harmful effects. The introduction of the protective actions is most efficient, if they are implemented in due time, i.e. before or just after the beginning of the environmental release. The determination of place, time, scale, form and method of optimized and justified protective actions require analyses and assessments. The first steps of these nuclear and radiological assessments are the evaluation of the actual and future state of the power plant, and estimation of the radioactive source term characterizing the release to the environment. The methodology developed in my PhD study aims at supporting these tasks of experts working in nuclear teams of emergency response organizations.

1.3. Research objectives

1. Development of a source term estimation methodology adapted to the Paks Nuclear Power Plant, which on the ground of limited number of available measured plant parameters and depending on the situation makes the selection of the source term from pre-calculated results possible. Elaboration of the necessary calculations and analyses.

2. Development of a methodology for forecasting the time of occurrence of different fuel-conditions, applying which the time of core uncovery and core melt may be prognosed by

the evaluators on the ground of the available technological parameters. Summarizing and comparing the quick assessment algorithms available in international professional literature, and their adaptation to the Paks Nuclear Power Plant.

3. Overview of the methods used for determination of containment leakage during source term estimation. Review of measurement and evaluation methods used for integral pressure test of the containment. Selection of such method for source term estimation, which reduces the conservatism in source term estimation.

4. Overview of various credible scenario that are significant from source term estimation point of view. Development of a method making their quick identification and assessment possible. Determination of the optimal number of measured plant parameters that are necessary for applying the methodology.

5. Application and further development of status trees of the Critical Safety Function Monitoring System elaborated by the Westinghouse Electric Company as part of the Emergency Operating Procedures supporting the emergency activity of the operators in order to involve them into the procedure of source term estimation.

6. Elaboration of a complex methodology applicable for making diagnosis and prognosis of plant conditions and for source term estimation.

1.4. Research methods

The basis of the research activity is the overview and critical analysis of the available written and electronic, international and Hungarian professional literature, their comparison and adaptation to the Paks Nuclear Power Plant. First of all the public documents of the US Nuclear Regulatory Commission (US NRC) and International Atomic Energy Agency (IAEA), publication of technical and scientific conferences, program descriptions, and documents of EU supported international projects (i.e. SESAME, STERPS, ASTRID) were utilized. The last mentioned three projects were organized with the contribution of the Hungarian Atomic Energy Authority.

The adaptation of the source term estimation procedure was supported by own analyses and calculations and available literature results.

2. SUMMARY

The assessment of the severity and the consequences of an accident occurred at a nuclear power plant should be commenced prior to the actual release in order to implement the most effective and efficient actions for protecting the population and the environment. The so-called radiological source term is one of the most important input parameters of the environmental consequence simulators, which – in the case of an accident potentially entailing release of radioactive materials – means the following information: composition of the release, activities of the released radionuclides, the time when the release starts, the duration and height of the actual or potential release.

The quantitative estimate of the source term may be determined by taking into account the core inventory, the release fraction, the reduction mechanisms and the containment leakage.

The application of the methodology established and presented in my dissertation makes the prognosis of the magnitude of the expected radioactive release and consequently the implementation of the protective actions being commenced and finished prior to the actual release. In the methodology the source term estimation is based on the conditions of the engineering barriers, critical safety functions and plant systems.

The PhD study starts with the formulation of the scientific issue, the research objectives and methods. The **Chapter 1** introduces the relevance of pre-release source term estimation, gives the definition of source term, and summarizes the basis and the steps of source term estimation, and the relevant physical mechanisms, which are assessed in details in the later chapters. It reveals the nuclear safety concepts and systems, and it introduces the terms and definitions which are used in the PhD study. The engineering barriers, the concept of defense in depth, and their connection to emergency management and source term estimation are described in this chapter. Additionally, the physical processes and the most important primary, secondary and safety systems of VVER-440/V-213 reactors that operate at Paks Nuclear Power Plant are compiled briefly. In accordance with the legal background, the structure of the Hungarian Emergency Response System, and the nuclear emergency response activity of the Hungarian Atomic Energy Authority are shown. Special attention is paid to the nuclear team performing plant state assessment and source term estimation, and the radiological team utilizing the source term for determining protective actions. This chapter reveals both the software tools and analyzing codes available at the CERTA crisis center of the Authority, which were used during the elaboration of the PhD study. **Chapter 2**

introduces the application of pre-calculated source-terms. This method requires limited plant information and human-capacity for its application. The results should be used as input parameter for radiological environmental calculations, first of all, in the very early phase of an emergency when only limited plant information is available, and the off-site emergency response organization has not yet reached its total readiness. The potential accidental consequences are grouped under four principal scenario: large break loss of coolant accident, total loss of on-site and off-site power, interface loss of coolant accident, leakage from primary to secondary circuit. The expected occurrence times of critical core-states are determined according to the results of sophisticated codes from the professional literature. Detailed source terms were calculated for the different scenario as the function of spray system availability, release route, flow-rate through the break and containment leakage. The chapter includes the procedure that helps to decide which pre-calculated source term should be chosen in different situations. **Chapter 3** deals with the methods of making plant state diagnosis and prognosis, and it shows the basic principles of the method adapted to the VVER-440/V-213 units. The methodology of plant state assessment for nuclear emergency response purposes is based on the diagnosis and prognosis of the engineering barriers, critical safety functions and systems ensuring the critical safety functions. The links between the engineering barriers, fundamental design criteria and critical safety functions are established. The properties and relevance of the six critical safety functions are analyzed in detail; the roles of the different safety systems ensuring the critical safety functions are studied as well. A test application helps to understand the use of the methodology in a real situation. **Chapter 4** summarizes the detailed assessment procedure of the actual and future state of the engineering barriers (fuel matrix and cladding, primary pressure boundary, confinement). Regarding the first engineering barrier its possible conditions are specified; the various processes, plant parameters and operational limits characterizing the different core conditions are determined. The qualitative evaluation of the first engineering barrier is based on the changing in the value of measured plant parameters of primary coolant activity, confinement dose-rate and activities in the stack. Regarding the second engineering barrier its potential states and failure modes and points are determined. The different failure modes of the primary pressure boundary are analyzed in detail, based on the results a method is developed aiming at recognition and identification of the various accidental scenarios. The models applicable for determining the size of the break and the flow-rate through the break are compiled from the professional literature; they are tested, adapted and developed further to the VVER-440/V-213 reactors. Applying the method for the most relevant scenario identified in the Paks

Nuclear Power Plant the limits within which it works properly are determined. The results of the detailed analyses are revealed in figures. Analyzing the possible states of the third barrier the different leakage routes are specified. Instead of the method used for determining the containment leakage found in the professional literature a new method is suggested in order to reduce the conservatism of the source term. This new method is based on experimental parameters provided by the integrated leakage tests of the containments of the Paks Nuclear Power Plant. Subsequent to the assessment of the plant conditions the reduction methods and factors are briefed. **Chapter 5** summarizes the evaluation method of the actual and future status of the critical safety functions, and the actual and future availability of the systems ensuring these critical safety functions. The Critical Safety Function Monitoring System developed by the Westinghouse Electric Company and adapted to the Paks Nuclear Power Plant is developed further in order to make the rapid assessment of the states of the functions and availabilities of the systems possible during source term estimation.

3. SUMMARIZED CONCLUSIONS

The most important statements that may be concluded from my study are as follows:

1. In case of an emergency occurred at a nuclear power plant the pre-release source term estimation is a complex task, it requires the comprehensive assessment of core state, release rate, reduction mechanisms and containment behavior.

2. The five levels of defense in depth together serve for preventing the environmental effects and mitigating the consequences of a severe accident. All five levels are to be damaged for resulting in unacceptable harmful environmental consequences.

3. In case of an accident or severe accident occurring at a nuclear power plant the most important design requirements for the safety systems are terminating the chain reaction, ensuring the long-term removal of the residual heat of the core, providing confinement of the radioactive materials.

4. If a reactor accident occurred at the Paks Nuclear Power Plant the Hungarian Atomic Energy Authority Emergency Response Organization would have the task, within the Hungarian Nuclear Emergency Response System, of assessing the actual and future conditions of the plant, estimating the source term, and based on the source term and the meteorological forecast developing and suggesting protective actions in order to support the decision makers.

5. In order to support the performance of these tasks the Hungarian Atomic Energy Authority established a crisis center called CERTA (Center for Emergency Response, Training and Analysis), which is equipped with the necessary advanced hardware and software tools.

6. Almost all Western European off-site emergency response organization has elaborated its source term estimation methodology that based on pre-calculated results of detailed analyses. The application of the methodology and its adaptation to the Paks Nuclear Power Plant, due to the differences between the western type and VVER units, required its complex review and further development.

7. The method developed and revealed in my study is applicable for quick, pre-release source term estimation based on limited available information. Furthermore, in later phase

of an emergency it is applicable for comparison with the results of more detailed calculations for judging their level of conservatism.

8. The diagnosis and prognosis of the states of the three engineering barriers aiming at preventing any radioactive release could be made by assessing the actual and future fulfillment of the relating critical safety functions, and the actual and future availability of the systems serving the critical safety functions.

9. Based on the available data of professional literature, experimental results and calculations of sophisticated codes, together with my own analyses made with analysis tools introduced earlier in the study a methodology is developed, applying which the environmental radioactive release after an accident occurring at a VVER-440/V-213 type reactor may be estimated comprehensively, considering all relevant processes, even prior to the actual release.

10. By utilizing the listed plant parameters the qualitative evaluation of the actual and future status of the engineering barriers may be performed.

11. For the efficient implementation of the protective actions one of the most relevant factors during the procedure of source term estimation is the time when the first engineering barrier becomes damaged. In order to forecast this time point the break of the second engineering barrier, its size and the flow-rate through it should be determined, since such a way the not measured water level inside the reactor pressure vessel may be analyzed. Moreover, fast methods using measured plant parameters exist, in the development and testing of which I have participated. According to the results of the performed and revealed analyses neither methods provide accurate results for the whole variety of accidental scenario; therefore I reviewed the applicability of the methods and made a proposal for their application.

12. In accordance with the professional literature the leakage of the containment is considered very conservatively in the current practice of source term estimation. The revealed approach that is based on actual leakage rates measured during integrated leakage test of the containment makes the source term estimation more accurate by between one and half magnitude in the majority of the analyzed accidental scenario.

13. The status trees used in the Critical Safety Function Monitoring System (developed by Westinghouse Electric Company) supporting the operators' activity and strategy in an

accidental situation, considering other identified parameters as well, are applicable for quick assessment of the states of the Critical Safety Functions as it is required by the methodology for pre-release source term estimation.

4. NEW SCIENTIFIC RESULTS

The application of the methodology established and presented in my dissertation makes the prognosis of the magnitude of the expected radioactive release possible, and consequently the implementation of the protective actions being commenced and finished prior to the actual release. In the methodology the source term estimation is based on the conditions of the engineering barriers, critical safety functions and plant systems.

1. I have elaborated the methodology of the pre-calculated source terms for the Paks Nuclear Power Plant. This methodology requiring limited information may be used in the very early phase of an emergency. The InterRAS software, which is developed by the US Nuclear Regulatory Commission and distributed by the IAEA was used for performing the necessary calculations.

2. I have applied and analyzed the methods of break size estimation that are available in professional literature and developed for Western pressurized water reactors to accidents of VVER-440/V-213 type reactors. I have developed new methodologies based on simple mass-balance and duration of emptying the pressurizer for break size estimation.

3. I have compiled and systemized the list of most significant parameters necessary for assessing the facility conditions of the Paks Nuclear Power Plant; I have created the data-sheet to be sent by the plant personnel in case of failure of the on-line data connection between the installation and the off-site emergency response organizations. This data list supports the application of the source term estimation methodology and the fulfillment of the international reporting obligations.

4. In order to decrease the effect of conservatism in determination of suggested protective actions I have proposed a new, more realistic and quick method, which is based on the results of periodic, experimental leak tightness tests of the containments, for evaluating the actual containment leakage.

5. By further developing the status trees of the critical safety function monitoring system developed by the US Westinghouse Company, I have made a proposal for its application during prognosis of plant condition and source term estimation. I have built the proposed approach into my source term estimation methodology.

6. Based on the data from professional literature, experimental experience, and the results of sophisticated codes and own calculations I have developed such a methodology, applying which to accident situations occurred at nuclear power plants with VVER-440/V-213 reactors, the environmental release may be assessed comprehensively, prior to the actual release, by taking into account all relevant mechanisms.

5. RECOMMENDATION, PRACTICAL USE OF RESEARCH RESULTS

The complex methodology elaborated in the PhD study may be used by organizations responsible for making assessments in case of a nuclear emergency occurred at the Paks Nuclear Power Plant or at a foreign, but same type (VVER-440/V-213) nuclear power plants in order to make diagnosis and prognosis of plant conditions and source term estimation. Consequently the application of the methodology is recommended to be applied at the Centre for Emergency Response, Training and Analysis (CERTA) of the Hungarian Atomic Energy Authority, at the Emergency Center of the Hungarian Army, and for the Nuclear Teams of the county Defense Committees around the Paks Nuclear Power Plant, and even around Bohunice and Mohovce.

6. PUBLICATIONS

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3. K.Horváth, K. Herviou, A SESAME-VVER nukleáris baleseti értékelő szoftver alkalmazása az INEX-2 HUN gyakorlat során, Magyar Energetika, 1999/4, Budapest, 1999, 45-48. oldal

4. Horváth Kristóf, 2004. évi nemzeti nukleárisbaleset-elhárítási törzsvezetési gyakorlat, Magyar Energetika, 2005/2, 19-20.oldal

5. Horváth K. Éghajlati paraméterek szerepe az atomerőművek üzemeltetésében, Magyar Energetika, 2005/4. szám, 2005

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11. L. Koblinger, K. Horváth and others Decision support techniques used in Hungary in cases of nuclear emergencies, Proceedings of IRPA Hiroshima, Japan, 2000

12. Horváth K., Zagyvai P. Forrástag összeállítása mérnöki gátakon végbemenő terjedés modellszámításaihoz egy radioaktív hulladéktárolóban, MNT konferencia, Balatonkenese, 1999, Absztrakt gyűjtemény

13. Horváth K., Petőfi G. Nukleáris- vagy radiológiai veszélyhelyzetben használt szoftverek, MNT Konferencia, Balatonkenese, 2000, Absztrakt gyűjtemény

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15. Végh J., Major Cs., Horváth Cs., Hózer Z., Adorján F., Lux I., Horváth K.: Building Up an On-Line Plant Information System for the Emergency Response Centre of the Hungarian Nuclear Safety Directorate, Nuclear Technology (Vol. 139, August 2002, pp. 156-166.)

7. CURRICULUM VITAE

7.1. Education

1997 Technical University of Budapest, Faculty of Natural and Society Sciences, engineering-physicist MSc

1997 Roland Eötvös University of Science, Faculty of Natural Science, physics-teacher MSc

2001 Budapest College of Economy, Faculty of Foreign Trade, foreign trade financial manager BSc

7.2. Professional carrier

1997-2004 Nuclear Safety Inspector, civil servant, Hungarian Atomic Energy Authority

1997-1998 Tutor, Technical University of Budapest, Jenő Wigner Youth Hostel

2004-2005 Section head, CERTA, Hungarian Atomic Energy Authority

2003- Representative of Hungary in EU ECURIE radiological urgent information exchange system

2004- Senior civil servant

2005- Section head, Emergency Preparedness and Training Section, Hungarian Atomic Energy Authority

7.3. Professional-scientific activity

1998- Member of Hungarian Nuclear Society

1998 Participation in preparation and conduction of INEX-2 HUN international nuclear emergency response exercise

1999 Founding member of Young Generation for Nuclear Energetic

2000 Fellowship students of International Atomic Energy Agency at the French IPSN research institute

2000-	Secretary, then member of Hungarian Academy of Science, Sizing Subcommittee
2000	Leader of the Hungarian Delegation in Nuclear Young Generation Network conference in Bratislava
2002-2005	Coordinator of the EU financed project called ASTRID
2004	Participation in preparation, conduction and evaluation of National Nuclear Emergency Response Exercise
2005	Member of the international committee preparing and evaluating the CONVEX-3 (2005) international emergency exercise;
	Member of the Preparatory Committee in Hungary, acknowledged by the Vice-president of the Governmental Co-ordination Committee
2005	Member of the IAEA's OSART review team, Brunswick NPP, USA

7.4. Other knowledge

1989	Basic level, C type Russian language exam
1998	Basic level exam of public administration
1999	Higher level, C type English international language exam
2000	Higher level, C type English ORIGO language exam
2002	Primary circuit auxiliary operator exam, at Paks Nuclear Power Plant
2002	Special exam of public administration
2004	ECDL exam
2005	Basic level, C type German language exam
2005	Overall radiation protection exam

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