# SEVERE ACCIDENTS RISK ASSESSMENT AS A BASIS FOR EMERGENCY PREPAREDNESS

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## ABSTRACT

The paper demonstrates, by example of the Republic of Croatia, the possibilities of implementing risk assessment as basis for nuclear accident emergency preparedness development. Individual risks of severe accidents for citizens of the biggest Croatian population centers, as well as collective risk for entire population have been assessed using the PRONEL method. The assessment covered 90 power reactors located at a distance up to 1.000 km.

The conducted assessment shows the risks for various regions of the Republic of Croatia, and comparison between them. If risk would be taken as basic criterion in nuclear emergency planning, the results of assessment would directly indicate the necessary preparation level for each region. Furthermore, the assessment of risks from individual power plants and power plant types indicates to which facilities the greatest attention should be paid in nuclear accidents preparedness development. Risks from groups of power plants formed in accordance with their respective distance from exposure location shows what kind of tools for determining consequences and protective actions during a nuclear accident should be made available.

## INTRODUCTION

In spite of continuous risk reduction, a completely safe technological facility has still not been constructed, nor will be, according to current findings. Thus, accident can occur at any facility, including the nuclear power plants. Due to a large quantity of radioactive substances, accidents in nuclear plants can cause significant consequences, not only within the plant itself, but also in its immediate and remote surroundings. For that reason, development of emergency response plans to be undertaken in case of an accident started simultaneously with beginning of operation of the first nuclear power plants, with objective of minimizing consequences.

Recently in the Republic of Croatia efforts were made to improve emergency response plans to be undertaken in case of nuclear accident (ENCONET (1997)). Special emphasis was placed on Krsko NPP in Slovenia and Paks NPP in Hungary, these two being the plants nearest to the territory of the Republic of Croatia (OG 157 (1998)). However, one could ask whether planning and preparation would be conducted in the same way if, instead of distance, a more comprehensive criterion would be adopted - risk. The paper demonstrates, by example of the Republic of Croatia, the possibilities for using risk assessment as basis in development of nuclear accident emergency response preparedness.

## SCOPE OF THE ASSESSMENT

In order to demonstrate possibilities of using risk assessment in development of nuclear emergency preparedness, individual risk assessment was conducted for citizens of the four biggest population centers (Zagreb, Osijek, Rijeka and Split), as well as a collective risk assessment for the entire population of the Republic of Croatia (Figure 1). The assessment referred to power reactors located at a distance up to 1.000 km that were in operation during the data collection (IAEA, (1999)). These are 64 power reactors manufactured in West European countries, USA or Canada, and 26 power reactors of "Eastern" design (Figure 2). The first group includes 57 pressurized water reactors (PWR) and 7 boiling water reactors (BWR). The second group is composed of 13 power reactors of VVER-440 V213 type, 6 power reactors of VVER-440 V230 type, 5 power reactors of VVER-1000 V320 type, one power reactor of VVER-1000 V302 type and one power reactor of VVER-1000 V338 type. Within the 1.000 km range there are also one heavy water reactor (Cernavoda NPP) and one fast breeder reactor (Phenix NPP). However, due to restriction of the applied method to light water reactors (see next chapter), risks from these two power reactors have not been assessed.


**Figure 1 – Republic of Croatia and the biggest population centers**

Distances between power reactors included in the assessment and population centers in the Republic of Croatia are 40 km or more. For that reason only nuclear accidents that can cause significant consequences at greater distance, i.e. accidents that include release of larger quantities of radioactive substances have been taken into account. This includes core melt accidents, along with early major containment failure or containment bypass.

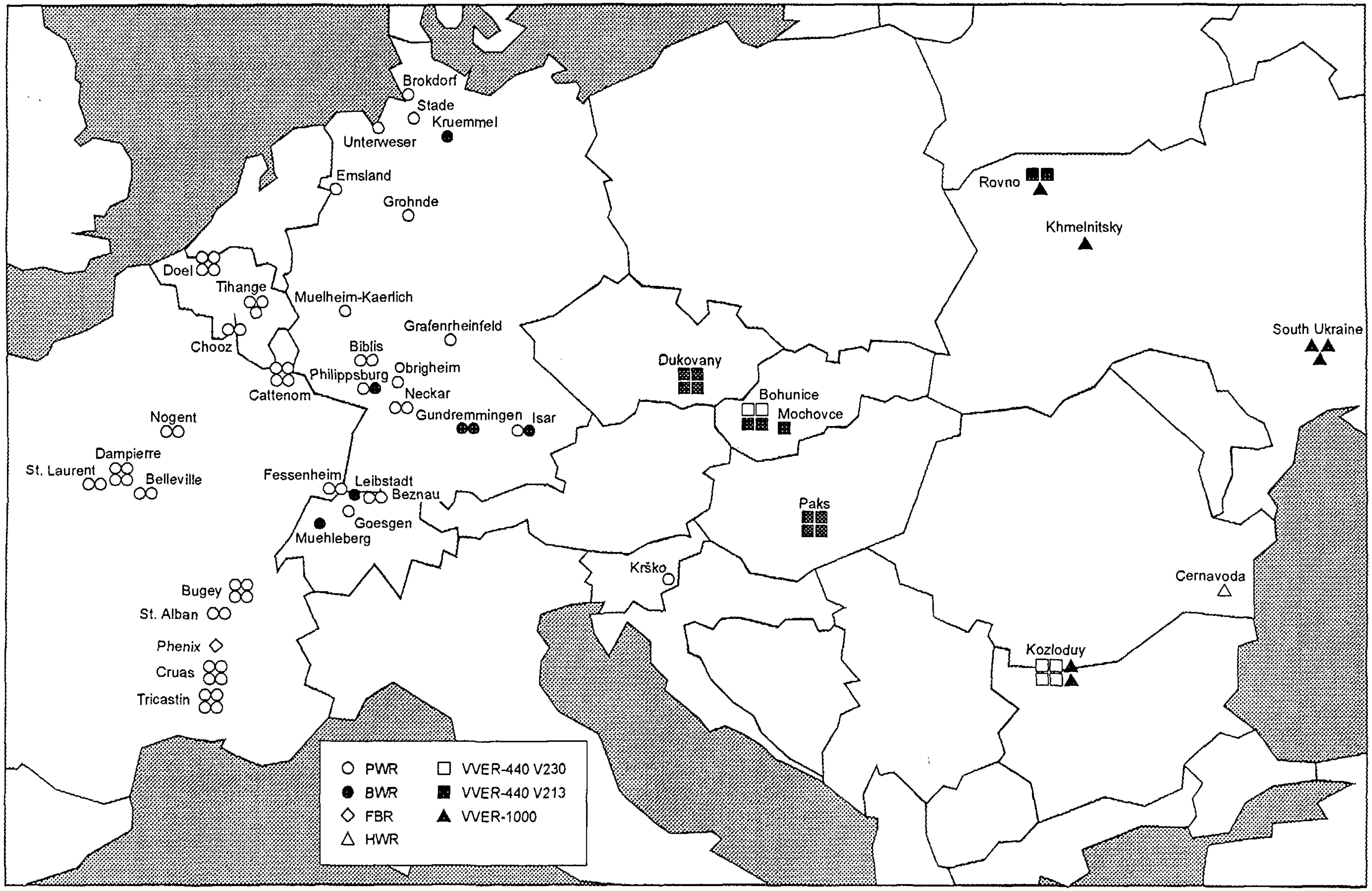


**Figure 2 – Nuclear power plants at distance of up to 1.000 km from the biggest population centers in the Republic of Croatia**

## BRIEF DESCRIPTION OF THE METHOD APPLIED

Human health risk assessment for population of the Republic of Croatia related to nuclear accidents was conducted using a quantitative risk assessment method called PRONEL (Šinka (2000)). PRONEL method features separated assessment of nuclear accident consequences and assessment of its relative frequency. Assessment of consequences, i.e. the received radioactive dose, is composed of three individual analyses: source term analysis, atmospheric dispersion analysis and exposure analysis. Source term analysis is based on the release assessment method developed by the NRC (U.S. Nuclear Regulatory Commission) (NRC (1996)). The method applies to light water reactors, and thus the PRONEL method is applicable exclusively to risk assessments of accidents in reactors of that type. Atmospheric dispersion is analyzed using the so-called Lagrange "puff" model. The PRONEL method exposure analysis takes into account only the effects caused in the early phase of the accident. This ensues from the assumption that, as there is sufficient time, by performing appropriate protective measures the consequences caused in late phase of accident could be significantly reduced. Exposure pathways in the early phase of accident include exposure to direct radiation of the radioactive cloud, inhalation of aerosols, particles and gases coming from the radioactive cloud, and exposure to radiation of radionuclides deposited on the ground.

Frequency assessment procedure in the PRONEL method is based on results of the conducted probability safety analyses (conduct of these analyses is not a part of the method) and on assessment of "probability of unfavorable direction" (probability for the radioactive cloud, formed out of the substances released from the nuclear power plant during the accident, to pass over the selected point of exposure). With assessed consequences and frequency, the risk of nuclear accident is calculated as a mathematical product of two parameters.

## RESULTS

The most significant results of the conducted assessment can be summarized into the following seven points:

1) The collected input data for 90 power reactors showed that the sum core melt frequency amounts to approximately $1{,}3 \cdot 10^{-2}$ /year, while the sum frequency of core melt accidents followed by early major containment failure or containment bypass amounts to approximately $8{,}3 \cdot 10^{-3}$ /year. Thus, if conditions such as they were in time of preparation of the paper would be taken as permanent, a core melt accident could be expected every 77 years, while core melt accident followed by early major containment failure or containment bypass could be expected to happen every 122 years.

2) Citizens of Zagreb, Rijeka and Split would receive the greatest radiation dose in case of an accident in Krsko NPP. Citizens of Osijek, however, would receive the greatest dose if one of the NPP Paks reactors failed. Further, the greatest dose for citizens of Zagreb would be 4 to 15 times higher than the greatest doses received by citizens of the other three cities. The assessed doses are mostly of such amount that they would cause exclusively stochastic effects.

3) Population center with the highest risk is Osijek (Figure 3). Probability for a citizen of Osijek to die because of consequences of accident in the nuclear power plant amounts to $1{,}3 \cdot 10^{-7}$ /year. This probability is almost by half lower for the citizens of Zagreb. Risks for

citizens of Split and Rijeka are almost identical and are about four times lower than risks for the citizens of Osijek. Relatively small differences in assessed risks indicate that all regions of the Republic of Croatia should be given attention in preparedness for nuclear accidents.

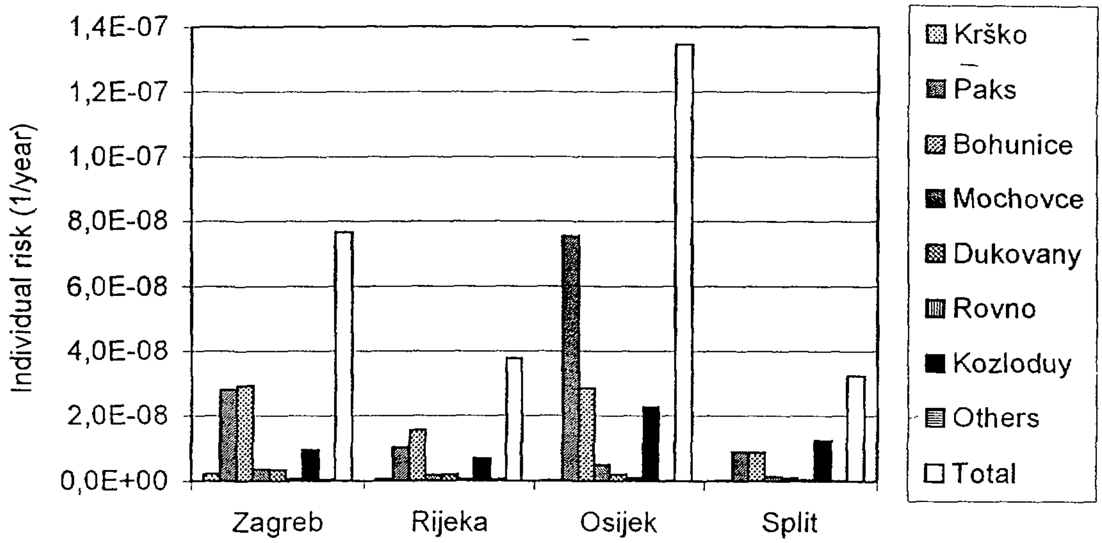


**Figure 3 – Contributions of individual power plants to total individual risks**

4) The three power plants whose contributions to individual and collective risks are notably higher than the rest are Paks NPP, Bohunice NPP and Kozloduy NPP (Figure 3). It ensues that, if risk would be taken as the basic criterion, the greatest attention in emergency preparedness development for the case of a nuclear accident should be paid to these very nuclear power plants. Differences in the way of emergency preparedness development, depending on whether distance or risk are taken as the basic criterion, are clearly observed using the example of the city of Zagreb and Krsko NPP. Namely, the contributions of the Krsko NPP to the total individual risk for the citizens of Zagreb amounts to only approx. 2,5%, although it is the nearest nuclear power plant.

5) If one divides the nuclear power plants into five groups according to distance (<50 km, 50-250 km, 250-500 km, 500-750 km and >750 km), the greatest risk for the citizens of Zagreb and Rijeka would come from the third group, i.e. power plants at a distance of 250-500 km (Figure 4). For the citizens of Osijek, the greatest risk would come from the power plants located at a distance of 50-250 km, while the citizens of Split would be most exposed to risk from the power plants 500-750 km away. Obviously, nuclear emergency preparedness in the Republic of Croatia should include not only short range but also long range assessment tools.

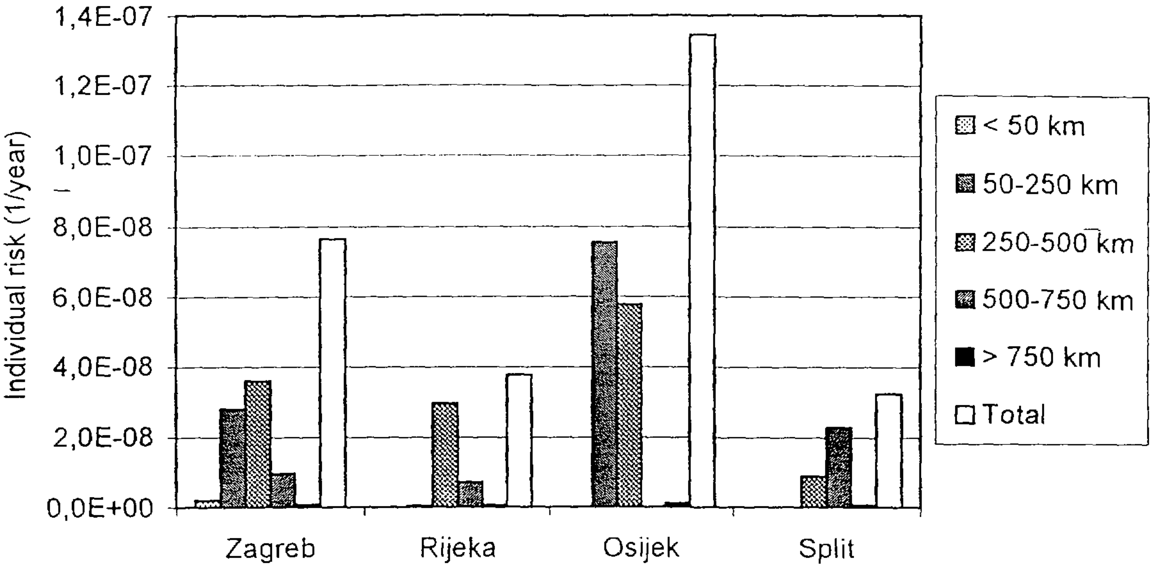


**Figure 4 – Contributions of groups of power plants to total individual risks**

6) The greatest contribution to individual and collective risk is made by power reactors of "Eastern" production, namely those of VVER-440 V230 and VVER–440 V213 types (Figure 5). A sum of contributions of these two reactor types exceeds 97%, which points to necessity to collect as many data as possible on these reactors within emergency preparedness development.

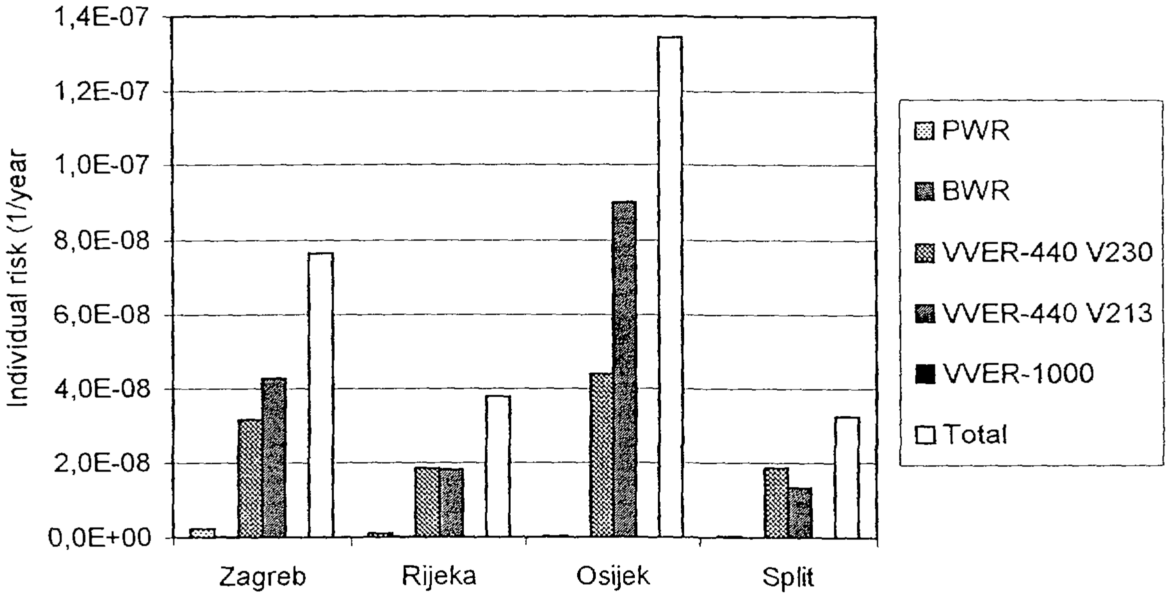


**Figure 5 – Contributions of particular power plant types to total individual risks**

7) The assessed collective risk of nuclear accidents for total population of the Republic of Croatia amounts to 0,35 deaths (or incurable carcinoma) annually. Since annual carcinoma death rate in Croatia amounts to approximately 10.000 people (CNIPH (1995)), the probability that incurable carcinoma that occurs is a consequence of a nuclear accident amounts to $3{,}5 \cdot 10^{-5}$. It is also interesting to compare the collective nuclear accident risk

with total risk of accidents of all types. Some 2.500 people lose their lives in accidents in Croatia annually, so it turns out that contribution of nuclear accidents amounts to $1{,}4\cdot10^{-4}$.

## CONCLUSION

By example of the Republic of Croatia possibilities of implementing risk assessment as basis in nuclear accidents emergency preparedness development have been examined. The results of the assessment conducted point to two important conclusions:

1) When dealing with emergency preparedness development, risk assessment proves to be very useful and widely applicable procedure. In the paper applicability of the procedure has been demonstrated by defining necessary preparedness levels for various regions, identifying facilities that need to be paid special attention to and selecting tools for consequence assessment. However, possibilities of implementing risk assessment are certainly not exhausted.
2) If risk is taken as the basic criterion instead of distance of the nuclear facility, significant changes can arise in the way of emergency preparedness development.

It is necessary to add that the conducted assessment did not include the uncertainty analysis. Uncertainty analysis is generally considered an indispensable part of risk assessment, so its lack makes the assessment somewhat incomplete. This time, however, the lack of uncertainty analysis could be justified by a demonstrational character of the conducted assessment.

## LITERATURE


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