A Brief History of Krško NPP Radiation Impact on Environment

Matjaž Koželj
“Jožef Stefan” Institute
Jamova 39, SI-1000 Ljubljana, Slovenia
Matjaz.Kozelj@ijs.si

ABSTRACT

The paper presents restrictions for radioactivity releases from Krško NPP, which are still valid with minor modification. Radiation monitoring around Krško NPP, which is briefly described, has not changed substantially since late eighties. Compiled data on radioactivity releases in liquid and gaseous discharges are also presented. Available evaluated data on population radiation exposure show different approaches to dose assessment in the past, but still prove that doses have never been even close to the authorised dose limit.

1 INTRODUCTION

The construction of Krško Nuclear Power Plant (Krško NPP) started in year 1975 and was concluded in 1981. The first criticality took place in September 1981 and the first synchronisation with the grid occurred in October 1981. During 1982 numerous test were performed and, finally, in January 1983 Krško NPP started with commercial production. One year later (in January 1984) regular operation of Krško NPP was approved.

Introduction of nuclear energy was a great challenge for involved scientific and technical experts, legislators, and all domestic companies acting either as contractors or subcontractors not only during the construction, but also later, supporting the operation and maintenance of Krško NPP. Beside nuclear safety, one of the most important challenges was how to define legal restrictions regarding radiation influence of Krško NPP to population and environment, and how to establish proper control mechanisms to ensure and verify that the restrictions are followed. Although in former country adopting relevant Law and Rules in the fields of nuclear and radiation safety took almost a decade, the very basic requirements for safe operation of Krško NPP were established and were set early, before the start of operation. Later, the requirements were additionally elaborated, but, as we will see, the original restrictions were not altered up to the present days.

2 LEGAL RESTRICTIONS

First limit for radiation impact of Krško NPP to the environment was already established ten years before the official start of regular operation in the Location Permit issued by National Secretariat for Urbanism of Slovenia in 1974. The Location Permit required that the (effective) dose from the radioactive releases of Krško NPP on the border of the restricted protective zone (500 m from the reactor axis) and beyond shall not exceed 50 µSv per year. Location Permit also required that reference (pre-operational) measurements should be performed and possible consequences of Krško NPP operation (radioactivity releases and distribution) on the surface and underground waters in Krško and Zagreb basins.
estimated and assessed. Due to the lack of national regulations regarding the use of nuclear energy at that time, relevant regulations from the country of origin of installed equipment (i.e. USA), or applicable recommendations from International Atomic Energy Agency should be used where appropriate national regulations were insufficient or nonexistent. And more like curiosity from the position of present times, it was optimistically foreseen that the investors (i.e. Slovenia and Croatia) should find the solution on technology and decide on location of the final repository for the all future radioactive waste from Krško NPP before commissioning the plant.

The limit for effective dose that was established in the Location Permit has never been changed and is also valid at the present time. In 1988 additional requirement was added in connection with the construction of temporary storage for Low and Intermediate Level Radioactive Waste (the storage is still in operation). According to this requirement annual effective dose from external radiation on the Krško NPP fence shall not exceed 200 µSv.

During the construction period of Krško NPP Rules were adopted related to monitoring and limits of contamination in environment and exposure limits for population from different practices. In the Decision regarding the approval of regular operation of Krško NPP (February 1984), additional restrictions regarding liquid effluents from Krško NPP to river Sava were set:

- For all radionuclides except $^3$H, $^{14}$C and dissolved gases: 200 GBq per year and 80 GBq per trimester,
- For $^3$H: 20 TBq per year, 8 TBq per trimester.

Annual limits for activity releases in gaseous discharges were not set explicitly in the Decision. Instead, Krško NPP was required to provide computational models for the dilution of releases during normal operation and dispersion of releases during the potential accident that could serve as a basis for the dose calculation to the public. In response to this requirement Krško NPP has developed models based on the recommendations from the US Nuclear Regulatory Commission that were used for establishing the annual limits for activities in gaseous releases from Krško NPP. The annual limits for activities in gaseous releases were officially confirmed in 1989 and were as follows:

- For $^{131}$I: 18.5 GBq per year,
- For aerosols (radionuclides with $T_{1/2}>8$ d): 18.5 GBq per year,
- For noble gases: annual limit is calculated from the dose limit (50 µSv per year) on the border of the restricted protective zone according to adopted models,
- For $^3$H and $^{14}$C there were no explicit limits for released activities.

These limits were in force until the 2007, when limits for liquid effluents were modified to allow for longer (18 months, previously 12 months) fuel cycle in Krško NPP. Annual limit for the $^3$H release was increased, while the limit for other liquid releases was decreased. The new (and still valid) limits for liquid effluents are:

- For all radionuclides except $^3$H, $^{14}$C and dissolved gases: 100 GBq per year, 40 GBq per trimester,
- For $^3$H: 45 TBq per year.

We can see that the “history” of dose and radioactive release limits for Krško NPP is quite short and, except for the recent adjustment related to the introduction of 18 months fuel cycle, there was no change of limits from the very beginning of Krško NPP operation. The reason is not in the indifference and passivity of the authorities, but in the professional knowledge of involved experts and adoption of internationally approved approach during the initial licensing process and initial operation of the Plant.
3 THE SCOPE OF MONITORING

The Krško NPP must provide the proof that it is complying with the imposed restrictions. Therefore Krško NPP is obliged to measure the emissions of radionuclides and report it the regulatory body, and also to provide independent assessment of effects to environment and population. Monitoring therefore consists of the measurements of the plant releases (measurement of emissions), sampling and measurements in the plant surrounds (measurement of immissions in the environment), evaluation of these measurements, as well as total dose assessment for members of public based on collected data and/or computational models. Objectiveness and validity of results has been ascertained with the involvement of independent and authorised organisations (experts) in the monitoring implementation, evaluation of data and dose assessment.

Requirements for monitoring in environment and emissions reporting have been in force from the very beginning of operation of Krško NPP. The programme of sampling and measurements, which has been verified and approved annually, has been based on generic (and extensive) programme in the relevant rules from 1986 and the new rules from 2007. The main difference between these rules is not in the content of monitoring programme itself, but introduction of the additional requirements related to the quality and reliability of measurements.

Monitoring in the environment covers 12 km circle around plant and also extends 30 km downstream river Sava. It includes:

- external dose measurements with passive and active detectors,
- sampling and measurement of radioactivity in the air (aerosols and iodine),
- sampling and measurement of radioactivity in the river Sava (water, sediments, fish),
- sampling and measurement of soil,
- sampling and measurement of drinking water (wells and water supplies),
- sampling and measurement of atmospheric precipitations and deposits,
- sampling and measurement of food and milk (locally produced).

In Figure 1 sampling locations for monitoring are presented (from [1]). Comparison of this figure with the figure from the report [2] from year 1991 reveals that the number of sampling points has not changed substantially from late eighties, and that sampling positions are not changed for majority of “old” locations.

In addition to sampling, monitoring also includes external dose measurements with passive TL detectors and continuous active detectors (energy compensated GM tubes) for external dose rate measurements. While the active detectors are a part of Early Warning System in Slovenia and were not operational until the late nineties, the network of TL detectors around Krško NPP (57 locations, up to 10 km from the plant) has just slightly been changed from eighties.

In support of monitoring, and also emergency preparedness, one meteorological station is situated inside plant and three in the vicinity of plant. The data from these stations serve for computational modelling required in dose assessment.

All data from monitoring are collected and evaluated through authorised organisations on regular basis. Evaluated data from environment monitoring and data on NPP emissions are used for dose assessment of members of the public in the neighbourhood of NPP. Evaluated monitoring data, as well as results of dose assessment are published on annual basis as a report, which is recently also publicly available through internet site of Krško NPP.
Figure 1: Current map of Krško NPP neighborhood with distribution of places where different samples are regularly taken as a part of Krško NPP monitoring [1]. Position of Krško NPP is marked with arrow.

4 OVERVIEW OF EMMISIONS FROM KRŠKO NPP

As was stated before, for the purpose of monitoring Krško NPP provides data on released activities in all liquid effluents and gaseous discharges from the beginning of operation (first criticality). All releases are continuously measured and data collected. Released activity depends on many factors, but the most important are fuel quality, leaks from primary system, produced power, trips and power excursions, efficiency of liquid and gaseous waste processing, chemistry of primary system, and also implementation of outages, and remediation of possible equipment failures.

4.1 Liquid effluents

The history of annual activity releases in liquid effluents of Krško NPP from 1983 to 2008 is presented in Figure 2. We can see that the annual releases of fission and activation products (Figure 2a) have been steadily decreasing since the first years of operation. But even the highest value (13.4 GBq in 1985) was just 6.7% of annual limit (200 GBq per year until 2007). The values in the years 2008 and 2009 (the last one not presented in the figure) were under 100 MBq (less than 0.1% of valid annual limit (100 GBq per year). The main contributors to annual releases were (and still are) activation products like $^{58}$Co and $^{60}$Co, and fission products $^{134}$Cs and $^{137}$Cs (Figure 2c). Released activity of $^{131}$I (Figure 2b) was always at least ten times lower and, in the last decade, appears in the liquid effluents just occasionally.

While the annual released activity of other radionuclides in liquid effluents has decreased substantially since the beginning of operation, this does not apply to Tritium (Figure 2d). The reason is in direct connection between Tritium production and energy production in NPP. Released activity was always close (40% to 80%) to the valid limit (20
TBq until 2007). In connection with introduction of 18 month fuel cycle, Slovenian Nuclear Safety Administration has raised the limit to 45 TBq.

### 4.2 Gaseous discharges

The history of annually released activities in gaseous discharges of Krško NPP from 1983 to 2009 is presented in Figure 3. The most important radionuclides are noble gases ($^{133}$Xe, $^{133m}$Xe, $^{41}$Ar), which are limited indirectly through effective dose on the NPP fence, and Tritium (no limit). The highest releases of noble gases (Figure 3a) were in mid-nineties (up to 25 TBq), while the current values are around 1 TBq.

Similarly like in liquid effluents, annual release of Tritium in gaseous discharges does not show any decrease (Figure 3b). After the introduction of 18 month fuel cycle annually released activity is around 2.5 TBq. History of releases of $^{14}$C (Figure 3c) on other side, shows initial decrease from the first value 400 GBq (1985) in eighties, but has not substantially changed in the last two decades. Annual release is around 100 GBq.

Annual releases of Iodine (not presented in the Figure 3) have been under 1 MBq since year 2001. In nineties, these values were much higher, up to 2.7 GBq in 1996, which is 15% of limiting value (18.5 GBq per year). In year 1996, to our knowledge, was also the highest release activity of aerosols (20 MBq, 0.1% of limiting value). Annual activity releases of aerosols in the last decade are about MBq or less.

**Figure 2:** Annual activity releases in liquid effluents of Krško NPP for years 1983-2008 (from [3]).
3a. Noble Gases. The release is limited indirectly through limited effective dose (50 µSv per year) on the border of restricted area.

3b. Tritium (\(^3\)H). Annual limit has not been set up.

3c. \(^{14}\)C. Annual limit has not been set up.

Figure 3: Annual activity releases in gaseous discharges of Krško NPP (from [4]).

5 COMPARISON OF EVALUATED DOSES

Data from monitoring on emissions and imissions of radionuclides serve as a starting point for evaluation of doses to general population in the neighbourhood of Krško NPP. This assessment is done by authorised organisation and finally submitted to regulatory body through Krško NPP. We are not going to discuss methods or methodology of dose assessment in the past, but just present the data compiled from available national Annual reports on the radiation and nuclear safety in the Republic Slovenia and available reports on Evaluation of the radiological monitoring of the Krško Nuclear Power Plant prepared by authorised organisations.

Available data on annual doses from gaseous and liquid releases from Krško NPP are presented in Figure 4. The most important exposure pathways are considered: external exposure, inhalation and ingestion for gaseous releases, and ingestion for liquid releases. Total dose is also presented, but we must point out that the total dose is not always realistic term. It is not always possible to simply add doses from different exposure pathways, since the complete dose assessment includes dose estimates for different and distinct critical groups of people.

In Figure 4 we can see that until the year 1994 total annual doses were approximately 2 to 4 µSv per year. The most important contribution was ingestion dose due to liquid effluents. It relates to local fishermen and their families, and the most important radionuclide for this exposure pathway is \(^{137}\)Cs.

From year 1995 to 2001 total doses were from 5 to 15 µSv per year, but the most important contribution comes from external exposure to gaseous releases (up to 11 µSv per year). This is the external exposure to radiation from cloud of noble gases released from the plant. Assessed ingestion dose due to liquid discharges was still high (2 to 6 µSv per year).
From year 2002 to 2009 total doses are (less than) 1 to (less than) 2 µSv per year. The most important contribution is ingestion dose due to the release of $^{14}$C. The estimate takes into account transfer of $^{14}$C from air to local vegetation and food chain. All other pathways contribute much less.

We can also see that estimated doses have never come close to the authorised limit. Even the highest estimated dose (from 1995) represents only 30% of authorised limit.

Figure 4: Annual doses to people living in the neighborhood of Krško NPP. Data from [2]-[12]

*Total dose for years 2002 to 2009 was not acquired from reports; it is just an estimate and should be understood as “less than”.

Figure 5 presents doses of population in the neighbourhood of Krško NPP from exposure to natural sources, general contamination from nuclear tests and Chernobyl releases, and releases of Krško NPP from mid-eighties until 2009. We can see that measured natural background (2440 to 2530 µSv per year) was always main contributor to the dose. In 1986, when Chernobyl accident happened, the contribution of total contamination was 570 µSv (in Ljubljana 720 µSv!), while is the estimated current value is about 10 µSv per year. The highest estimated annual dose from Krško NPP (15.4 µSv in 1995) was still only 0.6% of natural background, while the (overestimated) annual doses from recent years present only 0.04% of natural background and 2% of administrative dose limit.
6 CONCLUSIONS

We have seen that initial limitations imposed on operation of Krško NPP are still valid and, except in the case of liquid discharge of Tritium, there was no need to modify them. Krško NPP successfully operates within these limitations with releases, which are well below the limiting values.

The scope and extent of monitoring has not changed substantially from the mid-eighties, therefore old data are still compatible with recent measurements.

It seems that we can recognise different approaches to dose evaluation in certain periods of monitoring history. Therefore it is not certain that the doses from different periods are directly comparable.

According to the available data, estimated doses to population were always only few percents of the authorised dose limit.

REFERENCES


