NENE 2022
September 12-15
PORTOROŽ
SLOVENIA
31st International Conference Nuclear Energy for New Europe

Effect of sump pH on iodine release from VVER-1000/V-320 during LB LOCA

Adam Kecek [1, 2]
[1] ÚJV Řež, a. s.
Hlavní 130
250 68 Husinec-Řež, The Czech Republic

[2] Department of Nuclear Reactors
Faculty of Nuclear Sciences and Physical Engineering
Czech Technical University in Prague
V Holešovičkách 2
180 00 Prague 8, The Czech Republic
adam.kecek@ujv.cz

Lubomír Denk [1]
[1] ÚJV Řež, a. s.
Hlavní 130
250 68 Husinec-Řež, The Czech Republic
lubomir.denk@ujv.cz

ABSTRACT

Estimation of fission product source term during various loss-of-coolant accidents at nuclear power plants is the final step in the chain of NPPs safety analyses. The number of studied fission products is large, but one of them, thanks to its bioactivity and complex physical and chemical behaviour, stands out. Iodine behaviour within NPPs containments during various conditions has been studied worldwide in numerous research projects during past decades. One of them is the RTF series introduced within the OECD NEA BIP project, which aims at effect of sump pH on iodine revolatilization. The scope of this paper is to validate COCOSYS 2.4v5 code on this experiment and then transfer the knowledge to the analysis of LB LOCA at VVER-1000/V-320, where the effect of variable sump pH on iodine release will be studied. The study will aim at two different initial chemical speciation according to the R.G. 1.183 and R.G. 1.195 respectively.

1 INTRODUCTION

Fission product mass release, namely the iodine, has been studied in numerous national and international R&D programmes. One of them is the R2CA project [1], which aims at the reduction of radiological consequences of design basis accidents (DBA) and design extension conditions (DEC). The project aims at development of new calculation methodologies and updated computer codes to bring more realistic results. Improvement in the field of methodologies can be done by modification of initial and boundary conditions towards more realistic values, which must be supported accordingly, i.e. use of real data from plant operation and validation of applied computational models.

Iodine, thanks to its chemical nature, exhibits complex physical and chemical behaviour dependant on thermal hydraulics as well as radiochemical conditions [2], e.g. sump pH, which influence on the iodine release during LB LOCA is the scope of this paper. The effect of iodine revolatilization from stagnant sump has been studied within the OECD NEA BIP project in the RTF test series. One of the main outcomes is the fact that lower pH leads to higher iodine concentration in the vessel atmosphere [3].

During normal VVER-1000/V-320 operation, only two significant water volumes are in the containment – the spent fuel pool and the containment sump. The pH of these volumes is maintained nearly constant, but when a LB LOCA occurs, ejecting primary coolant may change the sump pH and concentration in containment atmosphere., leading to possibly higher or lower iodine release into the environment.

2 COMPUTATIONAL CODE AND VALIDATION

2.1 COCOSYS Code

In this study, the COCOSYS 2.4v5 will be used for the analysis of the VVER-1000/V-320 iodine mass release. The COCOSYS code is a lumped-parameter code used for analyses of design basis and severe accident propagation in containments of light water reactors as well as for simulation of experiments. The code itself is based on mechanistic models of relevant physical and chemical processes in LWR containments, i.e. thermal hydraulics and fission product transport. [4]

2.2 Validation on RTF P9T1

The RTF test facility consists of a cylindrical main vessel with a total 350 litres volume, which is partially filled with water, cf. Figure 1. In some tests, radiation source was present. The P9T1 experiment used a stainless-steel vessel. The temperature was maintained at 60°C and the dose rate was 0.78 kGy/h. The test started with pH equal to 10, then the pH was reduced in steps to 5 and finally increased to 9. As it was mentioned in the introduction, lower pH leads to higher iodine concentration in the atmosphere. [3]

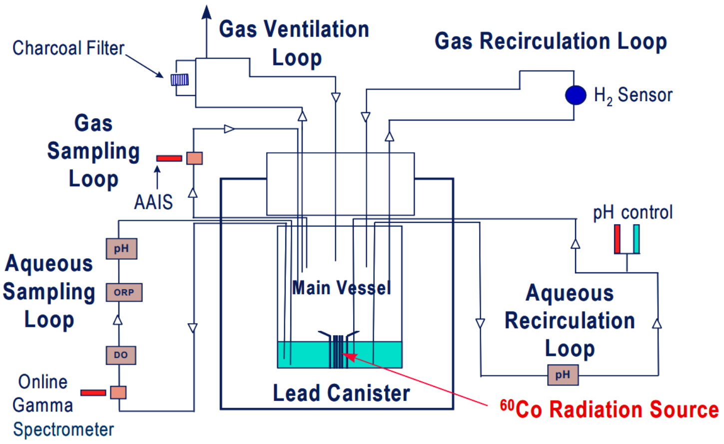

Figure 1 Schematic of the RTF facility and COCOSYS nodalisation [3]

For the validation, a tailored COCOSYS nodalisation was introduced, representing all major volumes as well as the instrumentation (circulation pumps and piping) and surface. The comparison of calculated and measured values can be observed in Figure 2. The trends are in good consonance with the experiment. Slightly lower iodine concentration in the gas phase may be influenced by overestimated iodine adsorption on vessel steel surface.

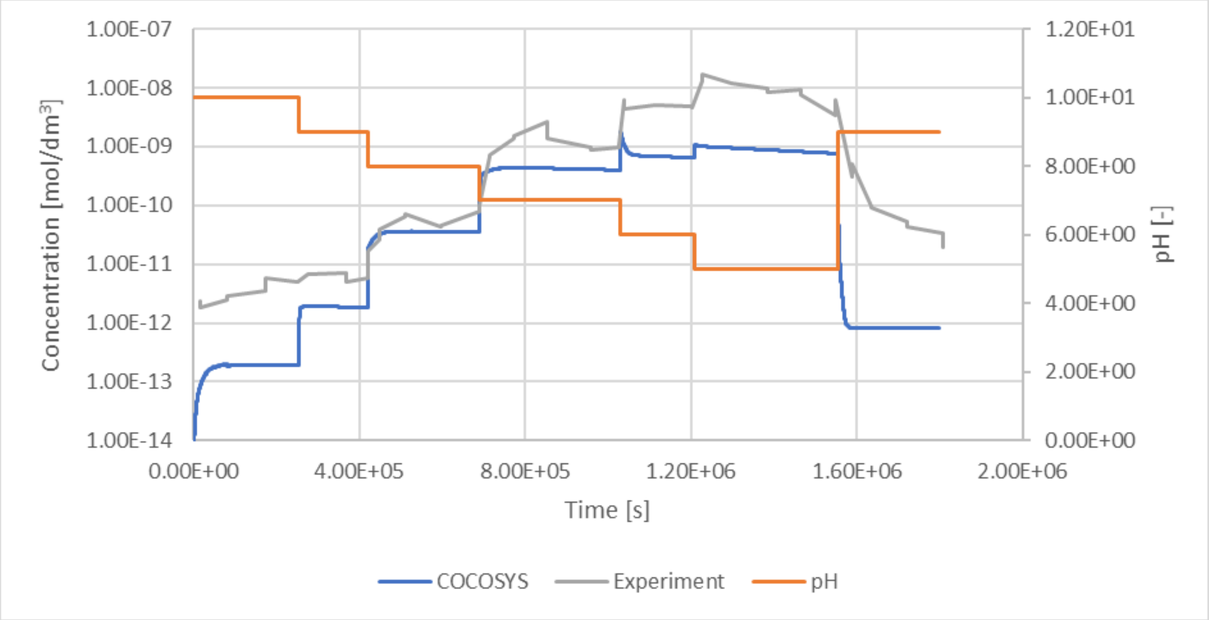

Figure 2 Comparison of the RTF P9T1 experimental data [3] with COCOSYS calculation (concentration of iodine in gas phase)

2.3 VVER-1000/V-320 Containment Model

The containment thermal hydraulic nodalisation follows the geometrical subdivision of the containment volume. The philosophy of the nodalisation is to provide a fast-computational model with realistic approach. This is the reason why some rooms were merged into larger nodes. This merging could be done thanks to large openings between the adjacent rooms.

The dominant volume of the containment model is the reactor hall, GA701. The lower half of the containment constitutes of an inner cylinder surrounded by a cylindrical annular cavity. The inner cylinder accommodates the reactor and other important technological equipment, such as steam generators and main coolant pumps. The reactor cavity is subdivided into two separate volumes, GA501 and G301 representing the upper and the lower part respectively. The spent fuel pool is represented by GA401A2 volume. The rooms which accommodate the steam generators are merged into two large volumes, SGBOX-1 and SGBOX-2. Smaller rooms under the steam generator boxes and the reactor cavity are represented by three volumes, the GA306-1, GA306-2 and GA306-3. Under the containment is a L-shaped containment sump, GA201. The cylindrical annular cavity which surrounds the inner cylinder is divided horizontally into two parts, which are further divided vertically into three parts. This yields to CNT-U1 and CNT-U2 representing the upper part, CNT-M1 and CNT-M2 representing the middle part and finally CNT-L1 and CNT-L2 representing the lower part. The total free volume of the containment is approximately 60 000 m^3. Furthermore, the model contains two large volumes, where BUILDING represents the adjacent buildings and

ENVIRON represents the environment surrounding the power plant. Several small nodes model the spray system piping and ventilation systems.

The model further includes heat structures representing the containment walls, floor, ceiling, and other internal structures. Mass flow between the volumes is achieved by junctions which follow the real situation. A special junction is used to simulate the containment leak to the environment, which properties are set to fit the maximum allowed leakages of the containment.

The containment model is equipped with three separate spray systems. These systems consist of pump, heat exchanger, piping and spray nozzles placed under the reactor hall dome. Delivery and suction ventilation systems maintaining containment underpressure are modelled, where only one of them is filtered.

COCOSYS demands a separate nodalisation for iodine transport, which can be coarser than the thermal hydraulic one. This means that several thermal hydraulic nodes can be merged into one iodine compartment. To do so, several conditions must comply, e.g. merged nodes must be connected via junctions and the TH conditions must be similar in merged nodes. A graphical interpretation of the nodalisation is in Figure 3. The iodine nodalisation further includes information on surface in each compartment. The user can choose between steel, concrete, and epoxy paint both in gas and water (submerged surface) phase.

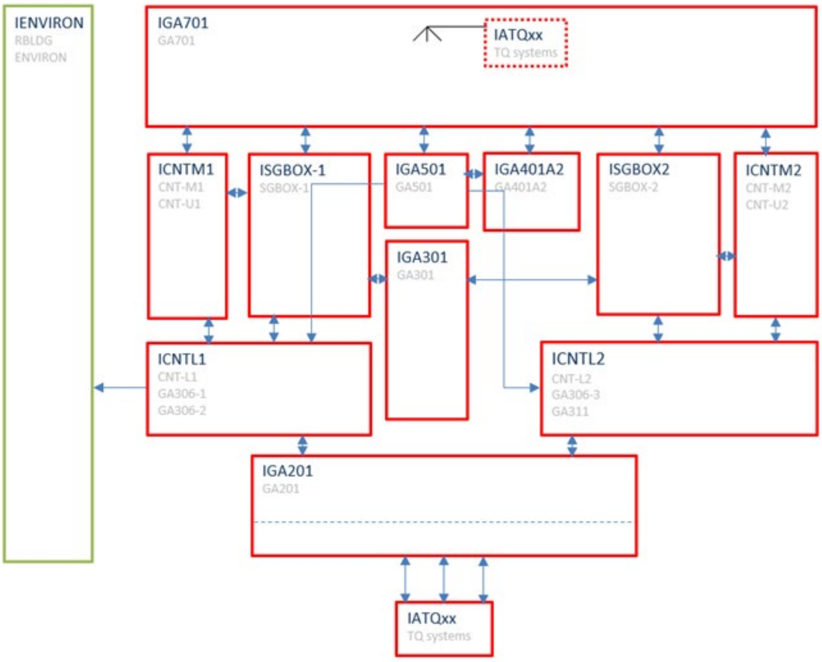

Figure 3 VVER-1000/V-320 containment nodalisation for iodine transport

3 ANALYSED ACCIDENT, INITIAL AND BOUNDARY CONDITIONS

The valid legislative in the Czech Republic demands conservative approach in DBA analyses. On the other hand, realistic approach may be used for DEC-A analyses. [5]

3.1 Primary Circuit and Containment

The mass and energy release were calculated with ATHLET 3.1 computer code. The initiating event is a guillotine rupture of the loop four cold leg close to the reactor vessel with both sided mass release with equivalent diameter 2x850 mm. The initial conditions follow the conservative approach, e. g. increased reactor power (104 % nominal power) and decay heat (+15 %), minimal reactor flowrate, maximal system temperatures and pressures, loss of off-site power at time of the initiating event, slow start of diesel generators – maximum delay of initiation of the safety injection (SI) systems, high and low-pressure injection systems – 1/3 available, hydro accumulators – 2/4 available and no operator action during the event.

The containment initial and boundary conditions were set conservatively towards iodine release, i.e. minimal initial environment pressure and maximal initial environment temperature, containment under pressure, relative humidity and temperature.

3.2 Calculated variants

Typically, the pH of the VVER-1000/V-320 is maintained in the range from 7 to 7.2 [7], [8]. For the calculations, a range from 5 to 10 was chosen to cover the range from the P9T1 experiment as well as to cover conditions with increased and decreased chemical compound concentration. For each of the calculations, the pH was set constant, i.e. no pH calculation based on chemical compound concentration was done by COCOSYS. Furthermore, it was decided to test the sensitivity for two different initial iodine chemical compositions based on the R.G. 1.183 [9] and R.G. 1.195 [10] respectively.

Table 1: Calculated variants

Iodine speciation	pH values	Further information
R.G. 1.183 [9] *95 % CsI, 4.85 % I_2, 0.15 % CH_3I*	5 to 10	Release of iodine to the containment atmosphere only Injection timing 30 – 1800 s after initiating event
R.G. 1.195 [10] *91 % I_2, 5 % CsI, 4 % CH_3I*	5 to 10	Release of iodine to the containment atmosphere only Injection timing 30 – 1800 s after initiating event

4 RESULTS AND DISCUSSION

The comparison is done for the two chemical speciation separately. The variants with chemical speciation based on the R.G. 1.183, i.e. dominant aerosol iodine, revealed highest release for lowest pH, cf. Figure 4. This is in consonance with the expectation based on the RTF results, cf. Figure 2. Significant decrease of the released mass can be observed from pH 6 and higher. From pH 8 the released iodine mass shows lower sensitivity to the changing pH.

Interesting results may be observed for pH 5 to 6, where slight increase of the released iodine mass can be observed in comparison to the reference calculation. This effect is not in consonance with the experiment. The origin of this effect may come from complex containment behaviour, i.e. presence of spray systems, painted surface etc. These factors are not present in the simplified RTF test facility. Further discrepancies in the expected trend can be observed for pH 8 and further.

The range of the results vary between the maximal and minimal value by almost 20 %. It should be noted that the highest sensitivity is close to the typical primary circuit pH range.

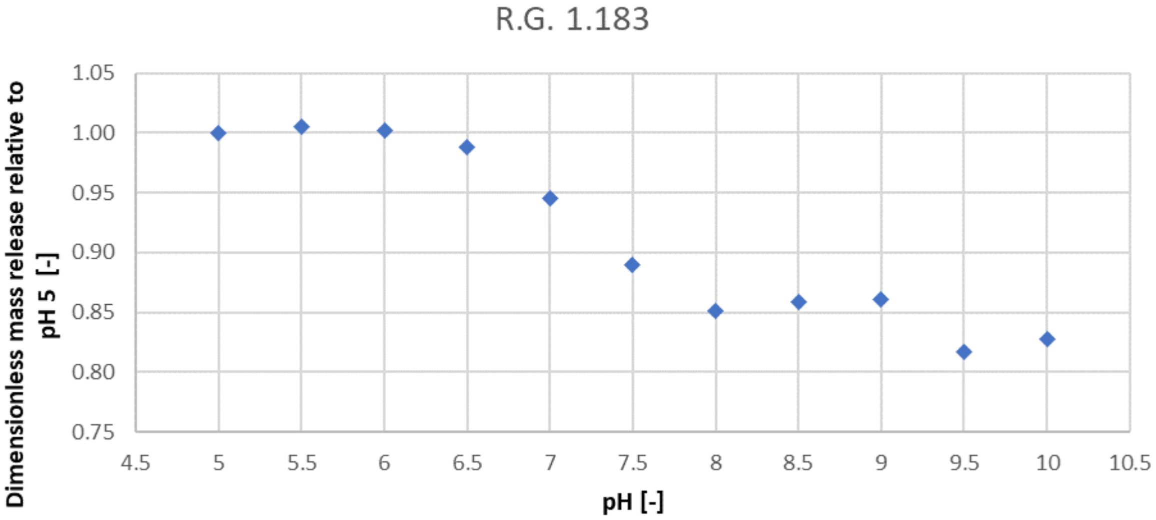

Figure 4 Comparison of iodine mass release relative to calculation with pH 5 (initial iodine speciation according to R.G. 1.183)

The variants with chemical speciation based on the R.G. 1.195, i.e. dominant elemental iodine, confirmed the consonance with the basic assumption, cf. Figure 5. Compared to the previous sets, the decrease of the released iodine mass starts with pH 5.5. The sensitivity of the system is most significant for the pH between 6 and 7. From pH 8, the released iodine mass is nearly pH independent. Unlike the previous variants, the sensitivity follows the basic assumption without any disruption in expected trend. The variation between minimal and maximal iodine mass release is higher, reaching almost 40 % from the reference pH 5 calculation.

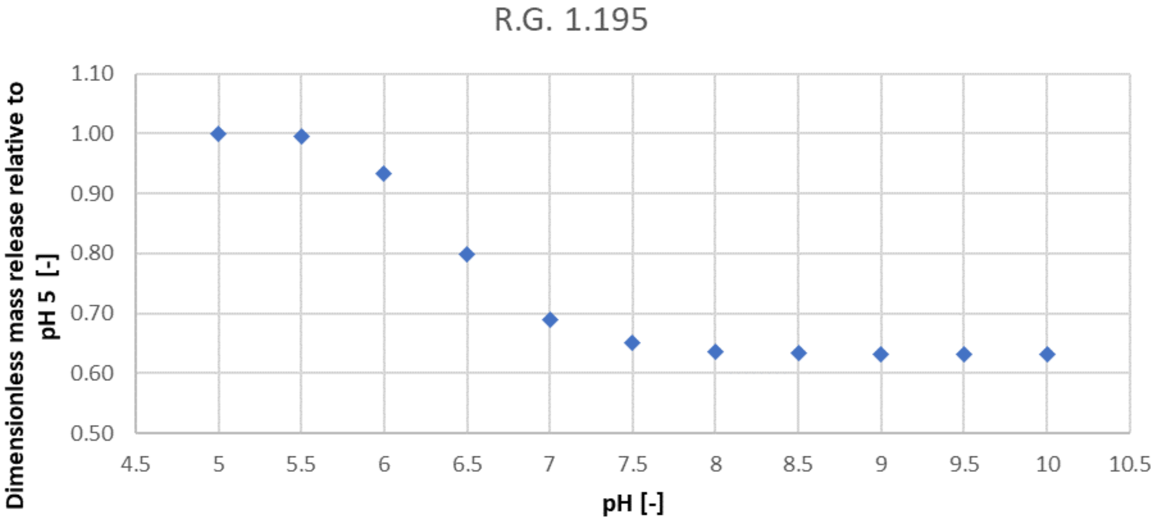

Figure 5 Comparison of iodine mass release relative to calculation with pH 5 (initial iodine speciation according to R.G. 1.195)

5 SUMMARY

The recalculation of the variants proved that the iodine mass release from the containment is influenced by the sump pH value. From the evaluation, it was found that the variation of sump pH has different impact on the iodine mass release for different initial iodine chemical speciation. The variants with dominant elemental iodine exhibit stronger sensitivity to the change of the sump pH.

Furthermore, the conducted study proved that for conservative analyses pH 5 should be used with initial iodine speciation following the R.G. 1.195. For the speciation following the R.G. 1.183, pH 5.5 should be used.

For realistic calculations, further evaluation of pH evolution in the containment sumps should be done, because the sensitivity for both iodine speciation is highest for pH values typical for normal primary circuit operation. This can be done both by standalone containment calculation with appropriate modelling of the mass transfer back to the primary circuit, or with a coupled approach, which is a favourable option.

ACKNOWLEDGMENTS

This work was conducted within the R2CA project.
This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 847656.

REFERENCES

[1] Website r2ca-h2020.eu/

[2] OECD NEA , State of the Art Report on Iodine Chemistry, NEA/CSNI/R(2007)1, Paris (2007)

[3] OECD NEA, International Standard Problem (ISP) No. 41 – Containment Iodine Computer Code Exercise Based on a Radioiodine Test Facility (RTF) Experiment, NEA/CSNI/R(2000)6/VOL1, PARIS (2000)

[4] W. Klein-Heßling, S. Arndt, H. Nowack, C. Spengler, S. Schwarz, D. Eschricht, S. Beck, *COCOSYS V2.4v5 User's Manual*, Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH, Cologne, Germany (2018)

[5] *Bezpečnostní návod BN-JB-2.10 (Rev. 0.0) Deterministické bezpečnostní analýzy událostí abnormálního provozu a základních projektových nehod*, State Office for Nuclear Safety, Prague, Czechia (2020)

[6] Denk, L.: *Metodika výpočtů radiačních následků pro bezpečnostní zprávu*, ÚJV Z5085 T, ÚJV Řež, a. s., 2018

[7] Miklos, M. et al.: *Review of the Primary Coolant Chemistry at NPP Temelín and its Impact on the Fuel Cladding*, Proceedings of the WWER2011 Conference, (2011)

[8] EPRI, *Review of VVER Primary Water Chemistry and the Potential for its Use in PWRs: Potassium Hydroxide and/or Ammonia Based Water Chemistries,* Technical report 1003382, USA (2002)

[9] US NRC, *Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors*, R.G. 1.183, United States Nuclear Regulatory Commission, USA (2000)

[10] US NRC, *Methods and Assumptions for Evaluating Radiological Consequences of Design Basis Accidents at Light-Water Nuclear Power Reactors*, R.G. 1.195, United States Nuclear Regulatory Commission, USA (2003)