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Proizvodnja električne energije predstavlja enega izmed stebrov energetike. K napredku in razvoju tega področja je ogromno prispeval izumitelj Nikola Tesla. V letošnjem letu praznujemo 160. obletnico njegovega rojstva in v ta namen je v Cankarjevem domu v Ljubljani odprta razstava o njegovem delu.

Leta 1895 so po načrtih Nikole Tesle na reki Niagari, natančneje na otoku Goat Island (Kozji otok), zgradili hidroelektrarno. To je bila prva večja elektrarna, ki je proizvajala izmenični električni tok. Električno energijo so pošiljali v 40 km oddaljeno hitro rastoče industrijsko mestece Buffalo v ZDA. Prva hidroelektrarna v Evropi, točneje na Hrvaškem, je bila postavljena tudi po zaslugi Nikole Tesle. Na reki Krki, pod slapom Skradinski buk, so le dva dni po odprtju elektrarne na Niagari pričeli proizvajati električno energijo za 11.5 km oddaljeno mesto Šibenik, do katerega so zgradili daljnovod.

Danes proizvedejo približno 16% svetovne električne energije s pomočjo hidroelektrarn. Vedno večji postaja tudi delež proizvodnje električne energije tudi iz ostalih obnovljivih virov kot na primer izraba sončne energije, energije vetra in geotermalne energije.

Jurij AVSEC
odgovorni urednik revije JET

Dear Readers of the Journal of Energy Technology (JET)

The production of electricity is one of the pillars of energy technology. Nikola Tesla is a key figure in the field. This year, we celebrate the 160th anniversary of his birth; to this end, in Cankarjev dom in Ljubljana an exhibition of his work has been opened.

The hydroelectric power plant on the Niagara River was built according to Tesla's plans in 1895. It was the first major power plant to produce alternating electric current. From Goat Island in the middle of the Niagara River, electricity was sent 40 km to the rapidly growing industrial town of Buffalo, NY, USA. Thanks to Nikola Tesla, the first hydroelectric power plant in Europe was built in what is now the Republic of Croatia. Only two days after the opening of the plant at Niagara, under the Skradinski buk waterfall, 11.5 km from the city of Šibenik, the production of electricity began.

Today, hydroelectric power produces approximately 16% of the world's electricity. Recently, it has been joined by other renewable energy sources, such as solar, wind, and geothermal energy.

Jurij AVSEC
Editor-in-chief of JET

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ANALYSIS OF THE KRŠKO NPP SPENT FUEL STORAGE CRITICALITY SAFETY UNDER HYPOTHETICAL DEGRADED CONDITIONS

ANALIZA ZAGOTOVITVE VARNOSTNE MEJE PRED KRITIČNOSTJO BAZENA ZA IZTROŠENO GORIVO NUKLEARNE ELEKTRARNE KRŠKO PRI HIPOTETIČNIH DEGRADIRANIH POGOJIH

Marjan Kromar[ℜ], Dušan Ćalić[1], Bojan Kurinčič[2]

Keywords: Criticality safety, PWR fuel, pool boiling, optimum moderation, MCNP6, ENDF/B-VII.1

Abstract

An analysis of the Krško NPP's old racks under hypothetical degraded pool conditions has been performed. Pool boiling and the optimum neutron moderation scenario with the absence of soluble boron normally present in the cooling water have been analysed. MCNP neutron transport code version 6.1.0 and the neutron continuous energy cross section ACE library based on the ENDF/B-VII.1 nuclear data files have been used. Four out of four and three out of four cell positions loaded have been considered. Where appropriate, burnup curves were determined.

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Povzetek

V prispevku je predstavljena analiza starih rešetk bazena za iztrošeno gorivo Nuklearne elektrarne Krško ob hipotetičnih degradiranih pogojih bazena. Upoštevano je vretje hladilne vode in primer optimalne nevtronske moderacije ob predpostavki, da ni raztopljenega bora v hladilu. Za preračun transporta nevtronov je uporabljen program MCNP verzija 6.1.0 in ACE knjižnica nevtronskih presekov evaluirana iz ENDF/B-VII.1 podatkov. Analizirani so primeri štiri od štirih in tri od štirih zapolnjenih lokacij v rešetki bazena. Kjer je bilo potrebno, so bile določene omejitvene krivulje izgorelosti.

1 INTRODUCTION

After its use in the reactor, the Krško NPP's nuclear fuel is temporarily stored in the spent fuel storage pool. One of the basic safety functions of a nuclear facility, such as a Spent Fuel Pool (SFP), is to ensure sub-criticality, which is to be fulfilled during all design-basis events. Evaluation of the NEK's old storage racks based on the design basis accident scenarios and fulfilling all legislation requirements and safety standards was performed by Framatome ANP GmbH (FANP), *[1, 2]*. The Krško NPP's pool has been licensed based on this evaluation. However, after the Fukushima accident, there was also an interest in the industry (EU stress tests) to explore beyond design basis accident scenarios under severe or hypothetical degraded storage conditions. Supplemental calculations, related to the hypothetical loss of all neutron poison (soluble boron) in the SFP coolant, as well as for the hypothetical optimum moderation conditions are examined in this paper to establish loading curves for the mitigation of the above hypothetical scenarios.

2 ASSUMPTIONS

2. 1 Calculation Methodology

In the criticality safety calculations, the adequacy of the safety margin, when criticality safety limits have been established through computer-based calculation methods, must be assured. Appropriate bias should be determined from the difference between calculated and experimental results that reflects the accuracy of the calculation methodology. The bias and the uncertainty associated with the bias are used in combination with an additional subcritical margin to establish an upper safety limit. The adequate subcritical margin is considered assured if the calculated results are below the upper safety limit and are within the area of applicability of the validation, *[3]*.

The MCNP code version MCNP 6.1.0, *[4]*, and ENDF/B-VII.1 nuclear data library, *[5]*, were used in all calculations. Since the code and library are different than in FANP, *[1, 2]*, analysis, a validation procedure is needed to determine appropriate bias. In order to validate the MCNP code for criticality safety calculations, several suitable benchmark experiments from the Handbook of Evaluated Criticality Safety Benchmark Experiments, *[6]*, also known as the ICSBEP Handbook, have been calculated, *[7]*:

- LEU-COMP-THERM-020 (LCT020)
- LEU-COMP-THERM-021 (LCT021)
- LEU-COMP-THERM-071 (LCT071)
- LEU-COMP-THERM- 077 (LCT077)
- LEU-COMP-THERM-083 (LCT083)
- KRITZ-LWR-RESR-001
- KRITZ-LWR-RESR-002
- KRITZ-LWR-RESR-003

Benchmark results were evaluated based on the NRC guidance provided in *[3]*. A weighted single-sided lower tolerance limit (K_L) has been determined to be 0.98914.

2. 2 Geometrical and material data

A geometrical model from the original FANP analysis, *[1, 2]*, was adopted. The model takes into account the whole rack, consisting of an arrangement of 27 × 23 storage cells. The radial cross sections of all considered cases are presented in Figures 1–3. The rack is surrounded by a 30-cm layer of water (yellow) and 1 m of concrete (red).

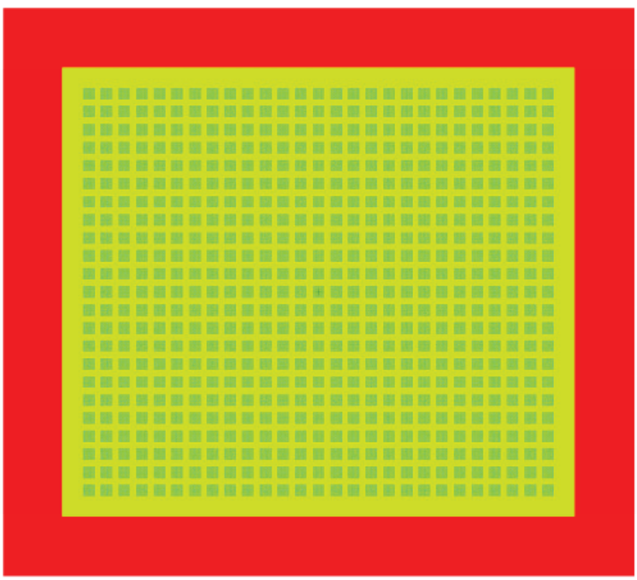

Figure 1: *NPP Krško old storage rack, radial view, 4 out of 4 positions loaded*

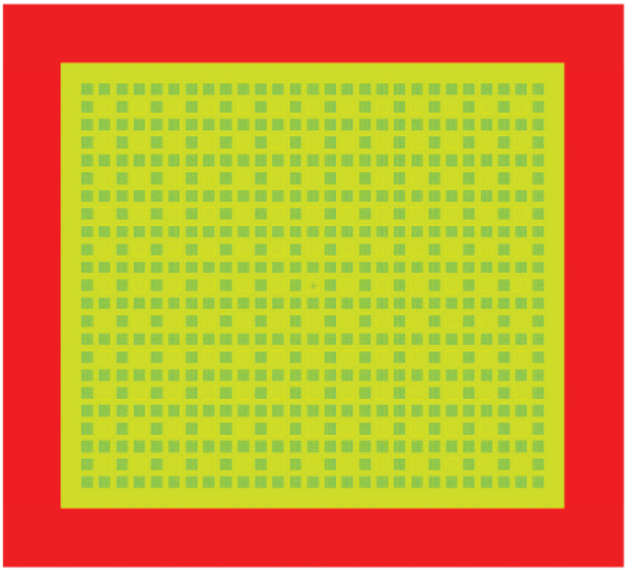

Figure 2: *NPP Krško old storage rack, radial view, 3 out of 4 positions loaded*

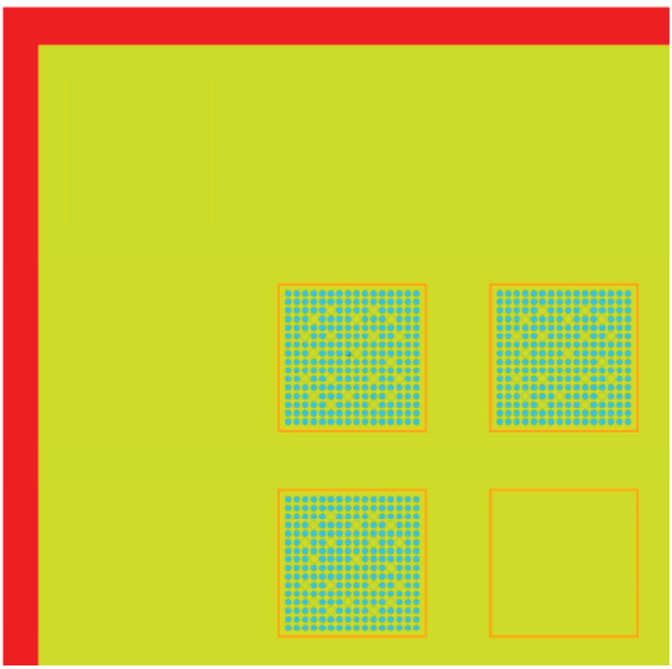

Figure 3: *NPP Krško old storage rack, upper left corner, 3 out of 4 positions loaded*

The entire rack is represented in the axial direction (Figure 4) with an additional reflector consisting of a 30-cm water layer (density 1 g/cm³ in all cases) on the top (blue). The thickness of the water beneath the rack is 15 cm. The bottom concrete thickness is again 1 m.

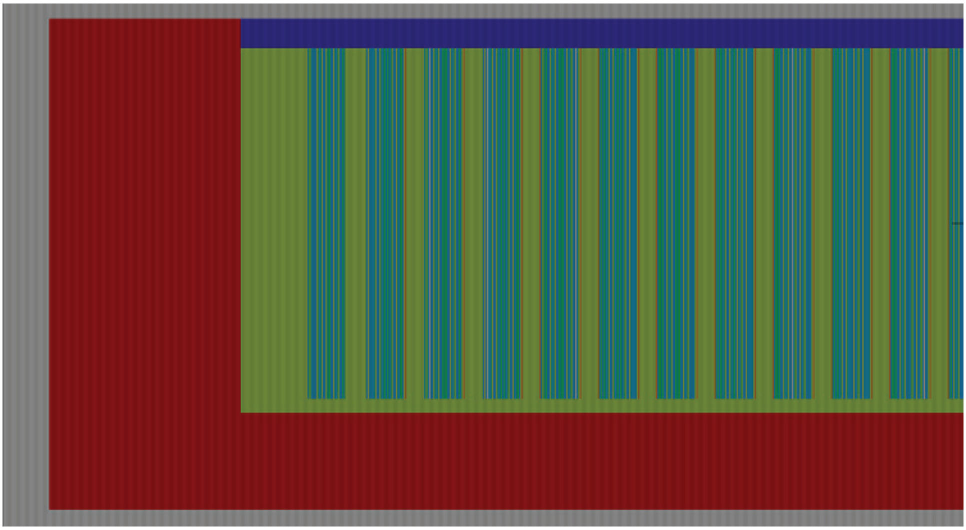

***Figure 4:** NPP Krško old storage rack, axial view, 4 out of 4 positions loaded*

Nominal dimensions of the fuel assembly and rack are used, except for the cell wall thickness, which is taken at a minimal thickness of 0.475 cm. The isotopic composition of materials is taken from original input files used in the FANP analysis.

2. 3 Cross sections' temperature model

The neutron cross section library, *[5]*, is available only at some selected temperatures. The MAKXSF code, *[8]*, was used to take into account Doppler broadening at needed temperatures. Cross-section sets at 80 °C, 100 °C, and 120 °C were generated and used in appropriate pool boiling cases. Linear temperature interpolation of the multiplication factor was carried out to take into account thermal scattering kernel data S(α,β) at the proper temperature in a similar manner as in *[7]*. The following equation is used:

$$f_L = \frac{T_H - T}{T_H - T_L}. \tag{2.1}$$

S(α,β) temperatures T_L and T_H are 20 °C and 127 °C, respectively. The multiplication factor at needed temperature T is determined as a weighted average of the multiplication factors, where weight f_L is used for lower temperature S(α,β) calculation and 1-f_L is used for higher temperature results. SFP temperatures and water densities are listed in Table 1 and are the same as those used in the original FANP analysis.

Table 1: *SFP temperatures and densities*

Temperature [°C]	Density [g/cm³]
20	1
80	0.971798
100	0.958364
120	0.943083

The results are presented in Figures 5-7. For all cases, the highest multiplication factor occurs at 120 °C. It is clear from the figures that the multiplication factors obtained at high S(α,β) temperature are higher than the results at lower temperatures. In addition, since 127 °C is conservative but very close to the desired 120 °C, it is judged to be acceptable to use results at this temperature without further lengthy temperature interpolation for all cases representing 120 °C.

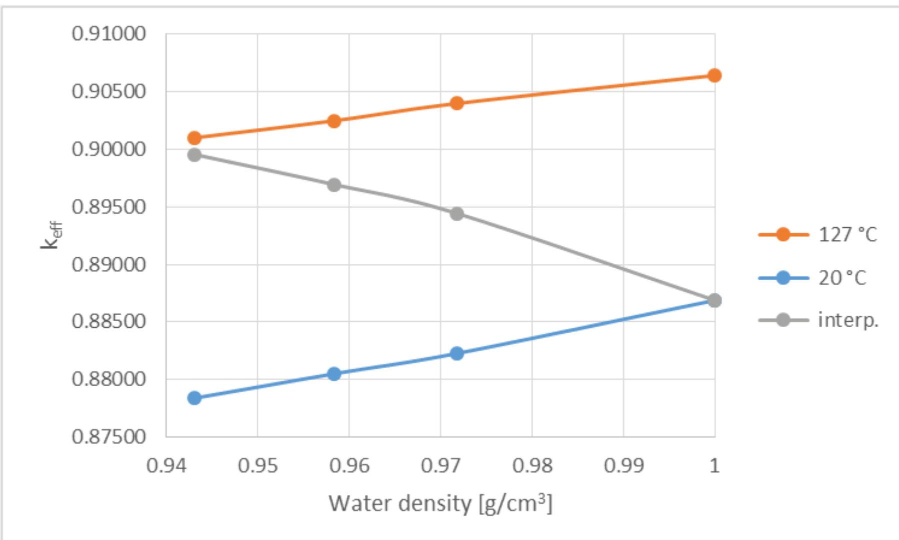

Figure 5: *Interpolation of thermal scattering kernel data, 4 out of 4 positions loaded, 3.5% enrichment*

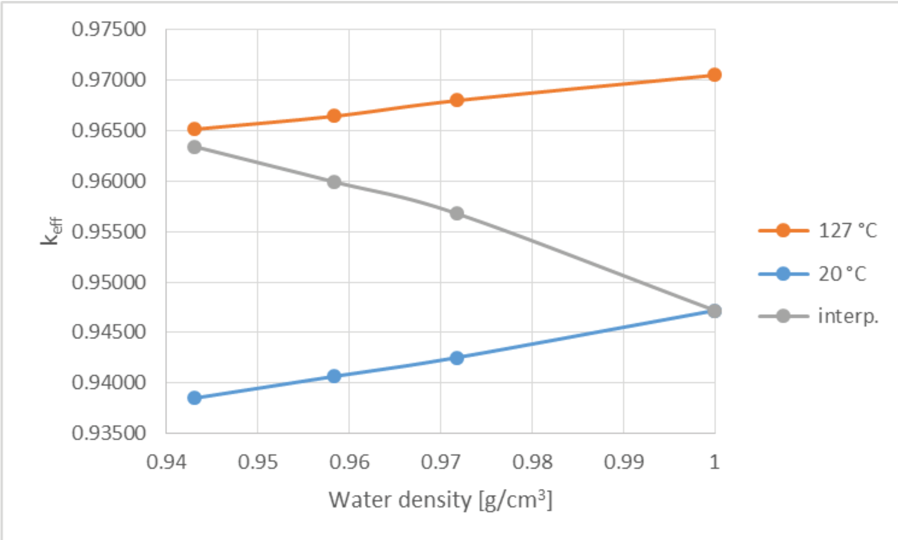

Figure 6: *Interpolation of thermal scattering kernel data, 4 out of 4 positions loaded, 5% enrichment*

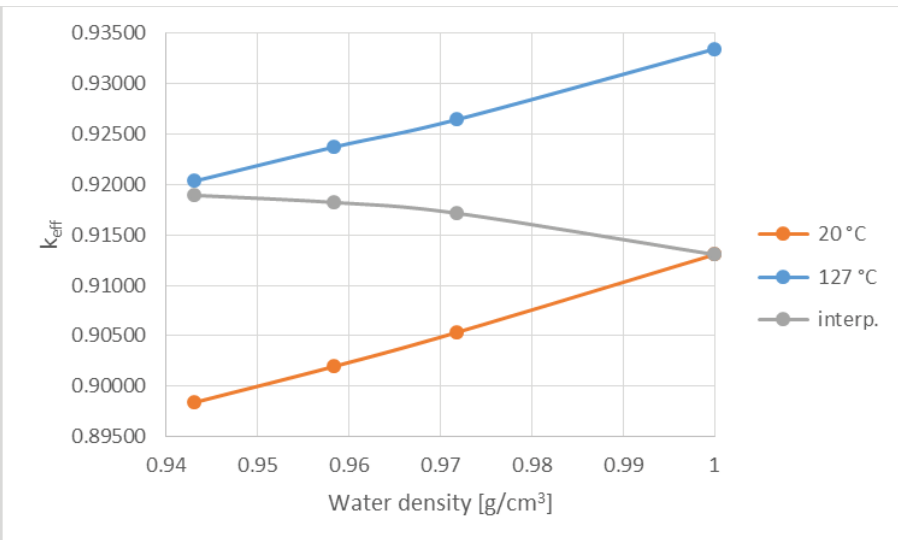

Figure 7: *Interpolation of thermal scattering kernel data, 3 out of 4 positions loaded, 5% enrichment*

3 CRITICALITY SAFETY EVALUATION

A limiting multiplication factor k_{limit} is determined by the following equation:

$$k_{limit} = K_L - \Delta k_m - \Delta k_{man} - \Delta k_{dep} \tag{3.1}$$

where:

K_L weighted single-sided lower tolerance limit of calculational methodology (0.98914),

Δk_m margin arising from legislation requirements (0.05),

Δk_{man} uncertainty arising from specific modeling features as well as manufacturing tolerances concerning dimensions, construction materials, etc.,

Δk_{dep} bias caused by the uncertainties in the depletion calculations.

3. 1 4 out of 4 positions loaded, pool boiling, theoretical coolant density

Taking into account uncertainties Δk_{man} and Δk_{dep} from the original FANP analysis, the limiting multiplication factor has been determined to be k_{limit}=0.91355.

As shown in Figures 5 and 6, a case of 120 °C with a theoretical density of 0.943083 g/cm³ is the limiting case. Calculation results are presented in Table 2. In the last column, the statistical uncertainty of calculations (1σ) is listed.

Table 2: *Effective multiplication factors, 4 out of 4 positions loaded, pool boiling*

Enrichment/Burnup	k_{eff}	
3.5%	**0.90102**	**±0.00007**
4.0%	**0.92626**	**±0.00007**
4.0% 23 MWd/kgU	**0.80770**	**±0.00007**
4.5%	**0.94718**	**±0.00007**
4.5% 29 MWd/kgU	**0.80648**	**±0.00007**
5.0%	**0.96515**	**±0.00008**
5.0% 34 MWd/kgU	**0.80799**	**±0.00007**

The results of the fresh fuel cases are shown in Figure 8. For better readability the limiting multiplication factor line is also drawn. The presented curve is fitted with a parabolic function. Enrichment is determined where the fitting curve +3σ intersects the limiting value. The obtained limiting enrichment is 3.727%. As shown in Table 2, three cases with supplied burnup isotopic composition were also calculated:

- 4.0% 23 MWd/kgU,
- 4.5% 29 MWd/kgU,
- 5.0% 34 MWd/kgU.

To determine the necessary limiting burnup, linear interpolation is used instead of the standard fitting procedure, since only two multiplication factors are available for each particular enrichment. The obtained loading curve is presented in Figure 9. The area above the curve represents the combination of enrichment and burnup suitable for storage in SFP.

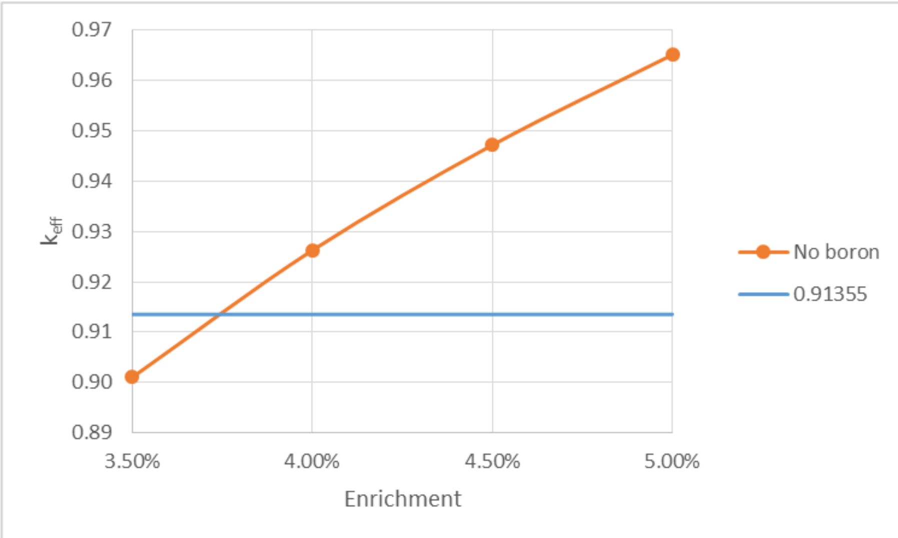

Figure 8: *Effective multiplication factor, 4 out of 4 positions loaded, pool boiling, fresh fuel*

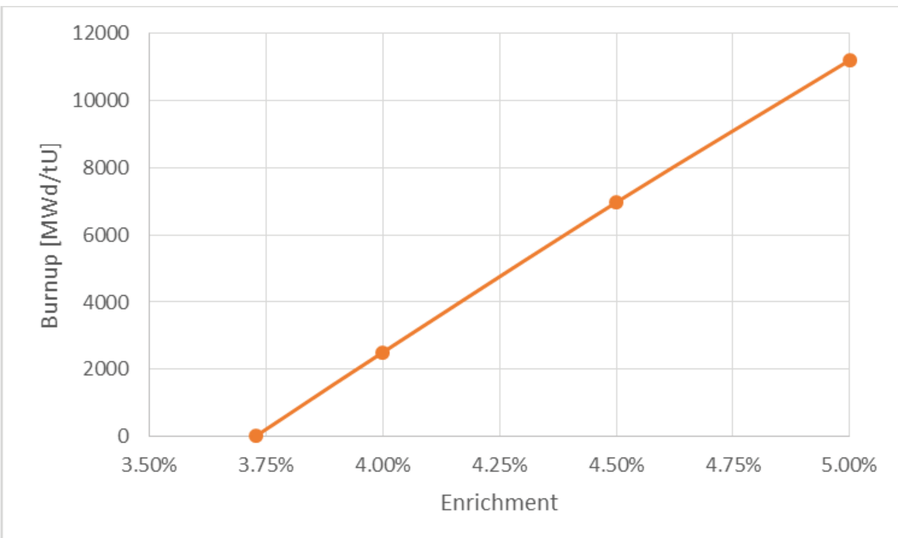

Figure 9: *Loading curve, 4 out of 4 positions loaded, pool boiling*

3.2 4 out of 4 positions loaded, optimum moderation

Taking into account uncertainties Δk_{man} and Δk_{dep} from the original FANP analysis, the limiting multiplication factor has been determined to be k_{limit}=0.92828.

Calculation results are presented in Table 3. For each enrichment, a parabolic fit is applied to determine optimum water density and maximal k_{eff}. The weighting function $1/\sigma^2$ is used. The pooled variance is taken as a final uncertainty.

The results of the fresh fuel cases are shown in Figure 10. For better readability the limiting multiplication factor line is also drawn. The presented curve is fitted with a cubic fit. Enrichment is determined where the fitting curve +3σ intersects the limiting value. The obtained limiting enrichment is 2.372%. As shown in Table 3, the following cases with supplied burnup isotopic composition were also calculated:

- 3.0% 7 MWd/kgU,
- 3.5% 17 MWd/kgU,
- 4.0% 23 MWd/kgU,
- 4.5% 29 MWd/kgU,
- 5.0% 34 MWd/kgU.

To determine the necessary limiting burnup linear interpolation is used instead of the standard fitting procedure, since only two multiplication factors are available for each particular enrichment. Burnup values higher than 20000 MWd/tU are additionally increased to take into account reactivity end effects of the axial burnup shapes. Increase is estimated from the FANP analysis [1] as a linear function having 0 MWd/tU at 20000 MWd/tU and 5000 MWd/tU at 45000 MWd/tU. The obtained loading curve (denoted as “No boron”) is presented in Figure 11. For comparison purposes, the licensed loading curve (denoted as “boron”) from FANP analysis obtained assuming 2000 ppm of boron in the SFP is also shown.

Table 3: *Effective multiplication factors, 4 out of 4 positions loaded, pool boiling*

Enrichment/Burnup	Density	k_{eff}	
2.0%			
	0.19	**0.88220**	**±0.00006**
	0.20	**0.88259**	**±0.00006**
	0.21	**0.88235**	**±0.00006**
	0.22	**0.88162**	**±0.00006**
Max	**0.20146**	**0.88258**	**±0.00006**
2.5%			
	0.19	**0.94082**	**±0.00006**
	0.20	**0.94141**	**±0.00006**
	0.21	**0.94121**	**±0.00006**
	0.22	**0.94066**	**±0.00006**
Max	**0.20381**	**0.94141**	**±0.00009**

2.5% 4 MWd/kgU			
	0.19	**0.91320**	**±0.00006**
	0.20	**0.91388**	**±0.00006**
	0.21	**0.91409**	**±0.00006**
	0.22	**0.91359**	**±0.00006**
Max	**0.20734**	**0.91407**	**±0.00007**
3.0%			
	0.19	**0.98661**	**±0.00006**
	0.20	**0.98711**	**±0.00006**
	0.21	**0.98704**	**±0.00006**
	0.22	**0.98632**	**±0.00006**
Max	**0.20346**	**0.98716**	**±0.00006**
3.0% 7 MWd/kgU			
	0.19	**0.93414**	**±0.00006**
	0.20	**0.93504**	**±0.00006**
	0.21	**0.93530**	**±0.00006**
	0.22	**0.93496**	**±0.00006**
Max	**0.20939**	**0.93531**	**±0.00006**
3.5%			
	0.19	**1.02362**	**±0.00006**
	0.20	**1.02403**	**±0.00007**
	0.21	**1.02380**	**±0.00006**
	0.22	**1.02315**	**±0.00006**
Max	**0.20189**	**1.02400**	**±0.00007**
3.5% 17 MWd/kgU			
	0.20	**0.91200**	**±0.00006**
	0.21	**0.91277**	**±0.00006**
	0.22	**0.91275**	**±0.00006**
	0.23	**0.91223**	**±0.00006**
Max	**0.21604**	**0.91284**	**±0.00008**
4.0%			
	0.19	**1.05424**	**±0.00006**
	0.20	**1.05495**	**±0.00006**
	0.21	**1.05464**	**±0.00006**
	0.22	**1.05384**	**±0.00006**
Max	**0.20300**	**1.0549**	**±0.00010**
4.0% 23 MWd/kgU			
	0.20	**0.91148**	**±0.00006**
	0.21	**0.91227**	**±0.00006**
	0.22	**0.91235**	**±0.00006**
	0.23	**0.91213**	**±0.00006**
Max	**0.21902**	**0.91241**	**±0.00009**

4.5%			
	0.18	**1.07931**	**±0.00006**
	0.19	**1.08067**	**±0.00006**
	0.20	**1.08077**	**±0.00006**
	0.21	**1.08053**	**±0.00006**
Max	**0.19970**	**1.08091**	**±0.00016**
4.5% 29 MWd/kgU			
	0.20	**0.90992**	**±0.00006**
	0.21	**0.91081**	**±0.00006**
	0.22	**0.91107**	**±0.00006**
	0.23	**0.91075**	**±0.00006**
Max	**0.21955**	**0.91108**	**±0.00006**
5.0%			
	0.19	**1.10321**	**±0.00006**
	0.20	**1.10345**	**±0.00006**
	0.21	**1.10335**	**±0.00007**
	0.22	**1.10232**	**±0.00006**
Max	**0.20050**	**1.10353**	**±0.00011**
5.0% 34 MWd/kgU			
	0.20	**0.91234**	**±0.00006**
	0.21	**0.91311**	**±0.00006**
	0.22	**0.91353**	**±0.00006**
	0.23	**0.91320**	**±0.00006**
Max	**0.22045**	**0.91347**	**±0.00009**

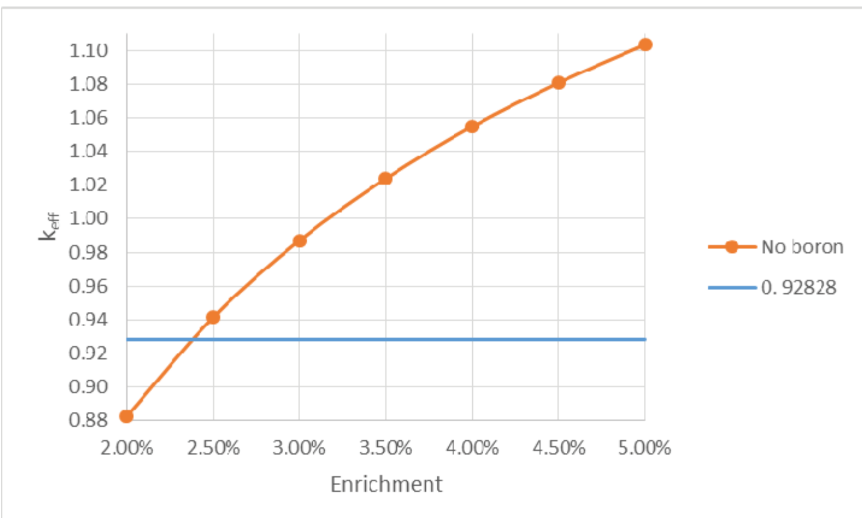

Figure 10: *Effective multiplication factor, 4 out of 4 positions loaded, optimum moderation, fresh fuel*

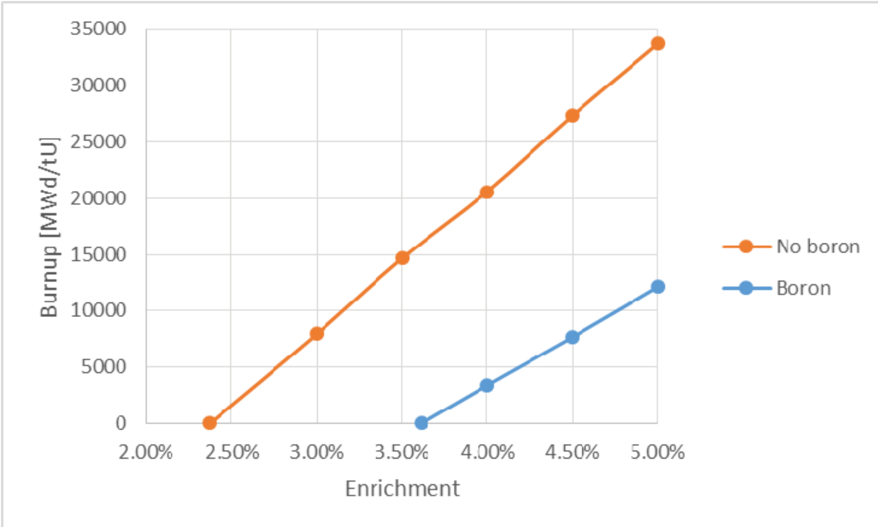

Figure 11: *Loading curve, 4 out of 4 positions loaded, optimum moderation*

3. 3 3 out of 4 positions loaded, pool boiling, theoretical coolant density

Taking into account uncertainties Δk_{man} and Δk_{dep} from the original FANP analysis, the limiting multiplication factor has been determined to be k_{limit}=0. 92742.

The results are presented in Figure 7. The maximal k_{eff}=0.92035±0.00008 occurs at 120 °C and coolant density of 0.943083 g/cm³. It is well below the limiting value. Therefore, the pool remains subcritical under those conditions for the fuel assemblies with the enrichment below 5%.

3. 4 3 out of 4 positions loaded, optimum moderation

Taking into account uncertainties Δk_{man} and Δk_{dep} from the original FANP analysis, the limiting multiplication factor has been determined to be k_{limit}=0.92634.

The results of calculations are presented in Table 4. For each enrichment, parabolic fit is applied to determine optimum water density and maximal k_{eff}. The weighting function $1/\sigma^2$ is used. The pooled variance is taken as the final uncertainty.

The results of the fresh fuel cases are shown in Figure 12. For better readability, the limiting multiplication factor line is also drawn. The presented curve is fitted with a parabolic fit. Enrichment is determined where the fitting curve +3σ intersects the limiting value. The obtained limiting enrichment is 4.247%. As shown in Table 4, two cases with supplied burnup isotopic composition were also calculated:

- 4.5% 29 MWd/kgU,
- 5.0% 34 MWd/kgU.

Since only two multiplication factors are available for each particular enrichment, linear interpolation is used instead of the standard fitting procedure to determine the necessary limiting burnup. The obtained loading curve is presented in Figure 13. Based on the FANP analysis, there are no burnup limitations if at least 2000 ppm of boron is present in the SFP.

Table 4: *Effective multiplication factors, 3 out of 4 positions loaded, optimum moderation*

Enrichment/Burnup	Density	k_{eff}	
3.5%			
	0.10	0.88055	±0.00006
	0.11	0.88291	±0.00006
	0.12	0.88382	±0.00006
	0.13	0.88319	±0.00006
Max	0.12091	0.88381	±0.00006
4.0%			
	0.10	0.91019	±0.00006
	0.11	0.91233	±0.00006
	0.12	0.91298	±0.00006
	0.13	0.91212	±0.00006
Max	0.11037	0.91298	±0.00006
4.5%			
	0.10	0.93604	±0.00006
	0.11	0.93801	±0.00006
	0.12	0.93827	±0.00007
	0.13	0.93705	±0.00006
Max	0.10953	0.93838	±0.00007
4.5% 29 MWd/kgU			
	0.11	0.78828	±0.00006
	0.12	0.78982	±0.00007
	0.13	0.79020	±0.00006
	0.14	0.78942	±0.00006
Max	0.12828	0.79022	±0.00006
5.0%			
	0.10	0.95862	±0.00007
	0.11	0.96041	±0.00007
	0.12	0.96041	±0.00006
	0.13	0.95913	±0.00007
Max	0.11599	0.9606	±0.00011
5.0% 34 MWd/kgU			
	0.11	0.79185	±0.00006
	0.12	0.79328	±0.00006
	0.13	0.79341	±0.00006
	0.14	0.79284	±0.00006
Max	0.12810	0.79352	±0.00011

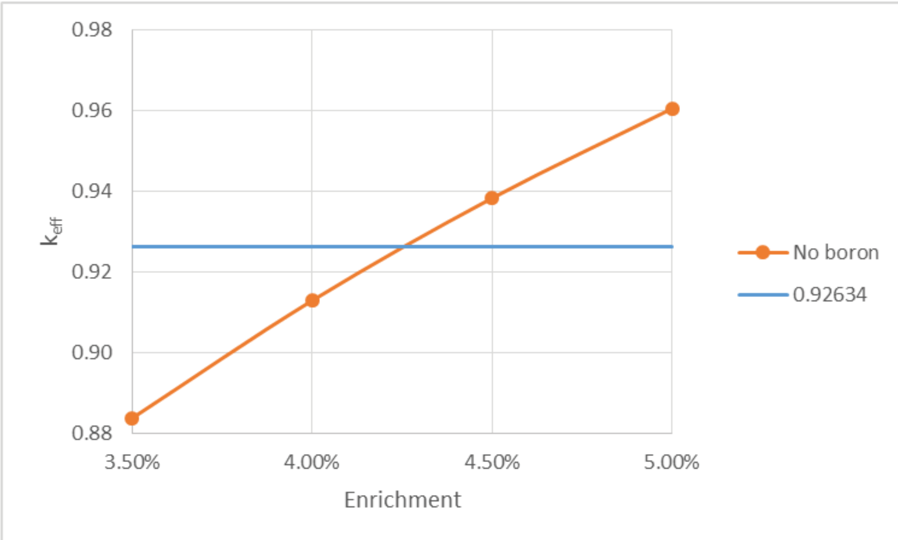

Figure 12: *Effective multiplication factor, 3 out of 4 positions loaded, optimum moderation, fresh fuel*

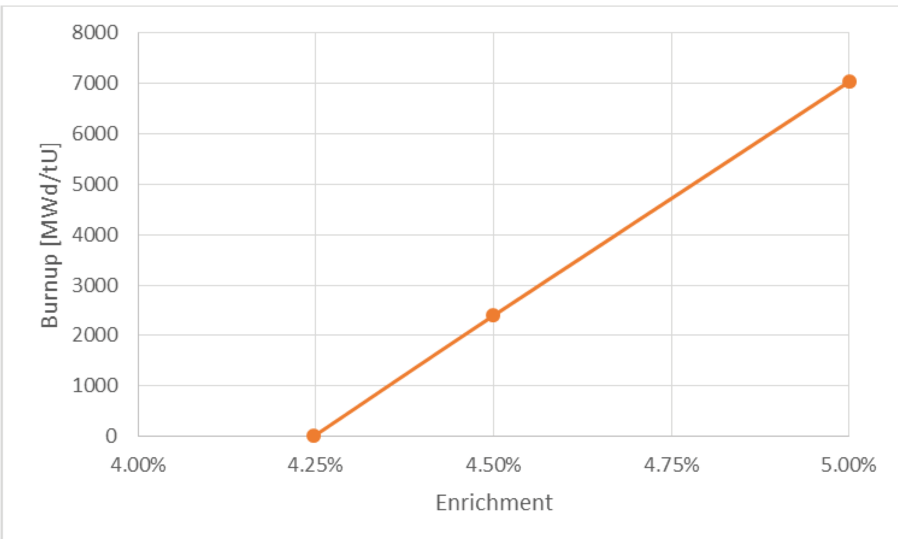

Figure 13: *Loading curve, 3 out of 4 positions loaded, optimum moderation*

4 SUMMARY

NPP Krško old racks have been re-analysed under hypothetical degraded SFP conditions, exploring some hypothetical scenarios beyond the design basis. In addition to the optimum moderation scenario, it was assumed that no soluble boron was present in the SFP coolant. The MCNP stochastic code with a continuous energy neutron library based on the ENDF/B-VII.1 nuclear data files has been used. Cases 3 out of 4 and 4 out of 4 positions loaded with fuel assemblies were considered. Pool boiling and cases with optimum moderation were analysed.

For the abovementioned hypothetical scenarios, this analysis showed that in the 3 out of 4 positions loaded case, fresh fuel assemblies with the enrichment up to 5% were subcritical if the pool was boiling provided that the SFP was covered with water. In the hypothetical optimum moderation scenario, the maximum fresh fuel enrichment was calculated at 4.25%. For higher enrichments, a burnup credit curve was determined. In 4 out of 4 cases, the limiting enrichments were 3.73% for the pool boiling conditions and 2.37% for the optimum moderation scenario. For higher enrichments, burnup credit curves were determined.

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Nomenclature

FANP	Framatome ANP GmbH
NPP	Nuclear Power Plant
PWR	Pressurized Water Reactor
SFP	Spent Fuel Pool
US NRC	United States Nuclear Regulatory Commission

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DESIGN OF A TRAIN ARTICULATION SYSTEM

NAČRTOVANJE IN IZRAČUN PRIKLOPNIKOV VAGONOV

Gordan Grgurić[1], Tihomir Mihalić[ℜ], Andrej Predin[2]

Keywords: train articulation system, rail vehicle, Jacobs bogie, conical bolt, strain, FEM, railcar, articulation coupler, joint

Abstract

A train articulation system is a joint or collection of joints at which something is articulated, or hinged, for bending. This paper deals with the construction of a passenger train's articulation system in which the wagons are connected via Jacobs bogies. The work includes the construction, design, finite element method (FEM) analysis and comparison of the results of strains gathered by FEM and analytical methods. Furthermore, the comparison of the welded type and casted tape of joint is contemplated using permitted strains and the feasibility of a particular construction as criteria.

Povzetek

Vlakovni povezovalni sistem je spoj oziroma skupek spojev, ki omogoča vožnjo vlaka oziroma vagonov v ovinek. Prispevek obravnava konstrukcijo spojnega sistema potniškega vlaka, kjer so vagoni povezani z jacobs bogies (dvoosno podvozje vlaka). Delo vključuje zasnovo, konstrukcijo in analizo z uporabo metode končnih elementov (MKE) ter primerjavo rezultatov deformacij in obremenitev pridobljenih z MKE in analitičnimi metodami. Prav tako je bila narejena primerjava med zvarjenim in ulitim spojem glede na dovoljene obremenitve in izvedljivost določenega spoja.

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1 INTRODUCTION

Jacobs bogies are a type of rail vehicle bogie commonly found on articulated railcars and tramway vehicles. Instead of being underneath a piece of rolling stock, Jacobs bogies are placed between two train sections (Figure 1). The weight of each car is spread on one half of the Jacobs bogie. It is a semi-permanent joint used for the composition of passenger trains, because the joints of freight wagons are expected to enable the possibility of quick assembly and disassembly of the wagon. The advantages of these joints for passenger trains are increased security at derailment as well less weight and lower cost of the composition since bogies are heavy, complex, and expensive structures. The ride is smoother and quieter due to their being fewer bogies in the composition. The disadvantages are a constant connection and the possibility of dismantling the composition only in the workshop. A lower number of bogies means higher axle loads, *[1]*.

Figure 1: *Jacobs bogie*

A train articulation system is a joint or collection of joints at which something is articulated or hinged for bending. The articulation coupler used in a Jacobs bogie (Figure 2) is an element that forms the connection between the bogie and wagon. The joint is functionally composed of a conical stud (Figure 3), which enters its slot on the bogie (Figure 4) and the flange with four screws and the seat attached to the chassis of the first wagon. On the other side of the joint, that is the second wagon, bolts are connected to its chassis (Figure 5). Given that the task structure, strains in the cast, and welded variants of the conical stud and flange are calculated and analysed in this paper. Two methods for calculating strains have been used. Strains in the conical stud are calculated with the conventional analytical method for long, thin rods, which is then modified to better describe the short, thick rod that the conical stud actually is. Then, the entire flange with the conical rod was calculated in FEM.

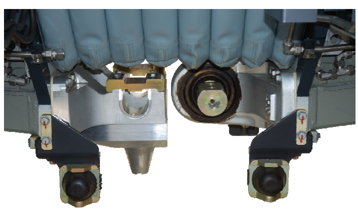

Figure 2: *Articulation coupler of Jacobs bogie*

Figure 3: *Flange with conical stud*

Figure 4: *Slot on the Jacobs bogie where conical stud enters*

Figure 5: *Bolts connected to the chassis of the second wagon of the Jacobs bogie joint*

2 ANALYTICAL METHODS FOR CALCULATING STRAINS IN THE CONICAL STUD OF A JACOBS BOGIE

Analytical, basic methods from the strength of materials field were used. The complex load was considered, composed of bending moment, normal (axial) forces and transverse forces. Furthermore, stress concentration due to changes in the cross-section as an important factor for dynamically loaded structures was also included in the analysis. The terms for stresses, deformations, and displacements are valid with certain assumptions and limitations, which are, according to Alfirević, *[2]*:

1. Height of the rod is small compared to its length; it should be $h/l \leq 0{,}2$ to 0,25 with error expectancy of about 2%
2. A maximum slope of the tangent to the elastic line of $\alpha_{max} \leq 0{,}05$ to 0,1 rad;
3. Stresses should be analysed in the cross sections which are far from the ends of the rod, supports and places where the concentrated load is. Sufficient distance can be considered the height of the rod *h*.

For the conical stud, crucial criteria are the first and third conditions. It is evident from Figure 6 that the proportion of the rod does not meet the criteria. If we look at the cross section C, the value of h/l = 0.744, which is significantly higher than prescribed by the first condition. Regardless of that, calculations were carried out for the purpose of the comparison of the results and the assessment of the usability of the method for the type of tasks.

This work was carried out with the presumption that the joint must have a durable, dynamic strength to withhold force of 100 kN. Furthermore, the force that appears on the joint when the train is moving at the speed of 36 km/h collides with the still, braked wagon was calculated to be 385 kN. Such a high load may not appear even once or can appear several times over the duration of the part's use.

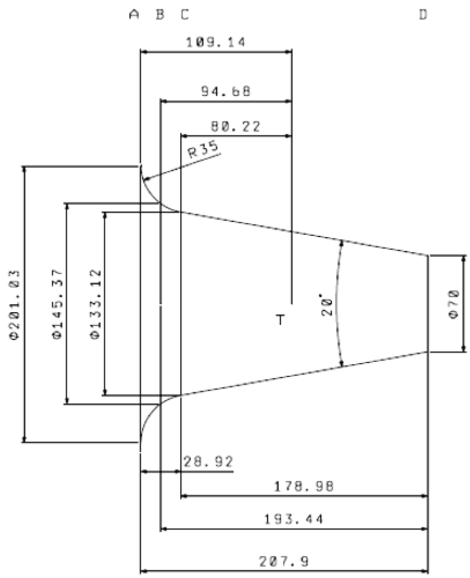

Figure 6: *Conical stud and referred cross-sections A, B, C, and D*

In each cross-section equivalent, stress according to the Huber-Mises-Hencky (HMH) theory and maximal stress were calculated. The following results were obtained:

- Cross-section A: σ_{equ} = 7,296 MPa, σ_{max} = 14,22 MPa
- Cross-section B: σ_{equ} = 13,958 MPa, σ_{max} = 34,423 MPa
- Cross-section C: σ_{equ} = 16,639 MPa, σ_{max} = 35,867 MPa

The highest stress is calculated at Cross-section C, so with it, the increase of stress due to the variable cross-section area was taken into account, according to *Machinery Handbook*, *[3]*. This stress is $\sigma_k = \frac{\sigma_{\max} \cdot K_f}{k_1 \cdot k_2 \cdot k_3} = 60{,}21\ \mathrm{MPa}$

where the coefficients are K_f = 1,175, k_1 = 1, k_2 = 0,7, k_3 = 1.

As stated before, the discussed conical stud is a short, thick rod. This means that the most influential parameter is the ratio of length to height. As much as this ratio is lesser than 3, the type and distribution of stresses start to change and differs significantly from those calculated for long rods. Previously, it was believed that as the rod becomes shorter, the method for long rods when applied to them shows greater strain than is realistic, Young, *[4]*. However, the emergence of numerical methods determined the exact opposite. Stresses increase significantly the lower the ratio of length to height is; this has been proven with experiments, *[4]*, as well as with our results. For this conical stud, the ratio is l/h = 1,344. Young, *[4]*, states that it is possible to calculate the stress using a method for long rods and then increase strains by the coefficient obtained considering the previously mentioned ratio. Thus, a coefficient of 2.1 was used to multiply σ_{max} which yielded σ_k = 75.32 MPa.

3 FEM ANALYSIS OF A CAST CONICAL STUD WITH AN ENTIRE FLANGE

Research of the best suitable boundary conditions was carried out. The finite elements used were of a linear tetrahedral shape. The size of finite elements at the change of the cross-section area and the radius was 10 times smaller than at the rest of the domain. FEM simulations were carried out using Autodesk Simulation Mechanical 2014 software. Furthermore, verification of the FEM model was carried out, and the results are shown in Figure 7.

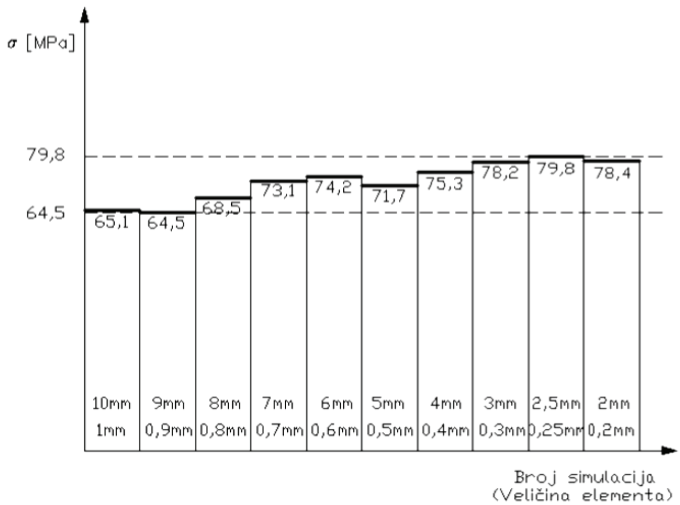

Figure 7: *Verification of the FEM model*

FEM analysis has given strain at the critical cross-section C, σ_{max} = 78.4 MPa, Figure 8, and the maximal displacement was calculated to be 0.197 mm (Figure 10); the joint was loaded with 100 kN.

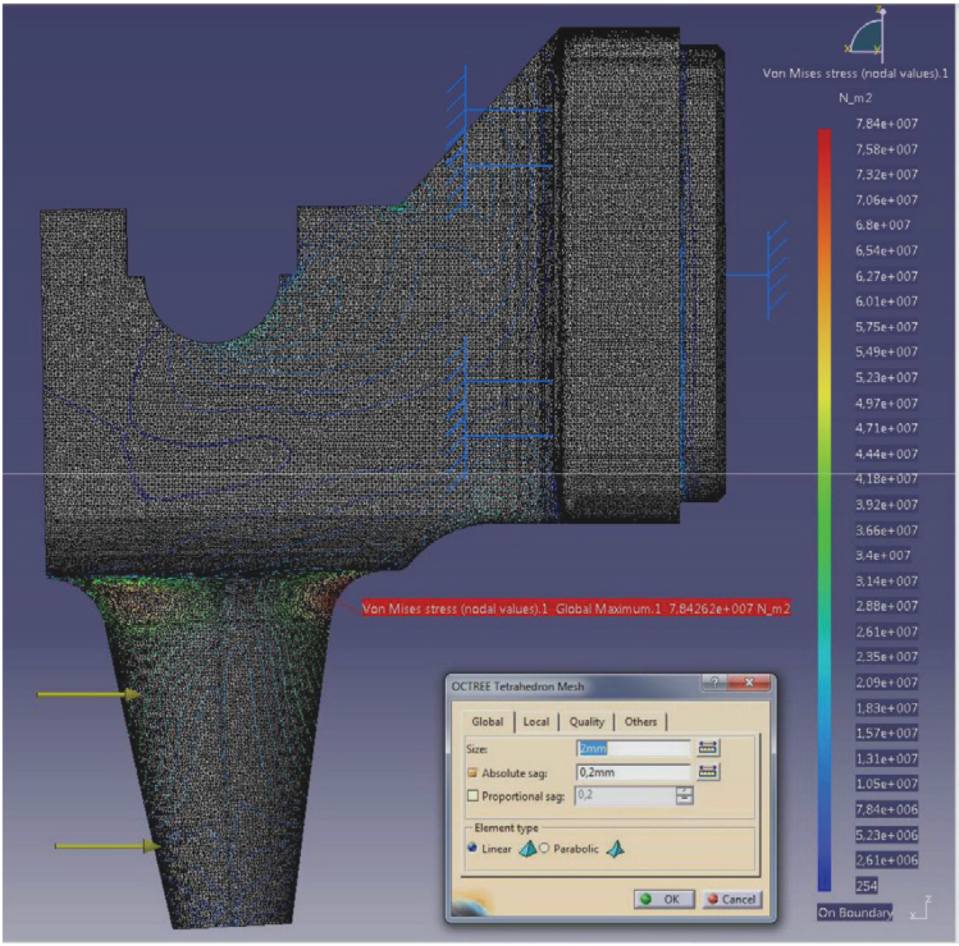

Figure 8: *Load of 100 kN,* σ_{max} = 78,4 MPa

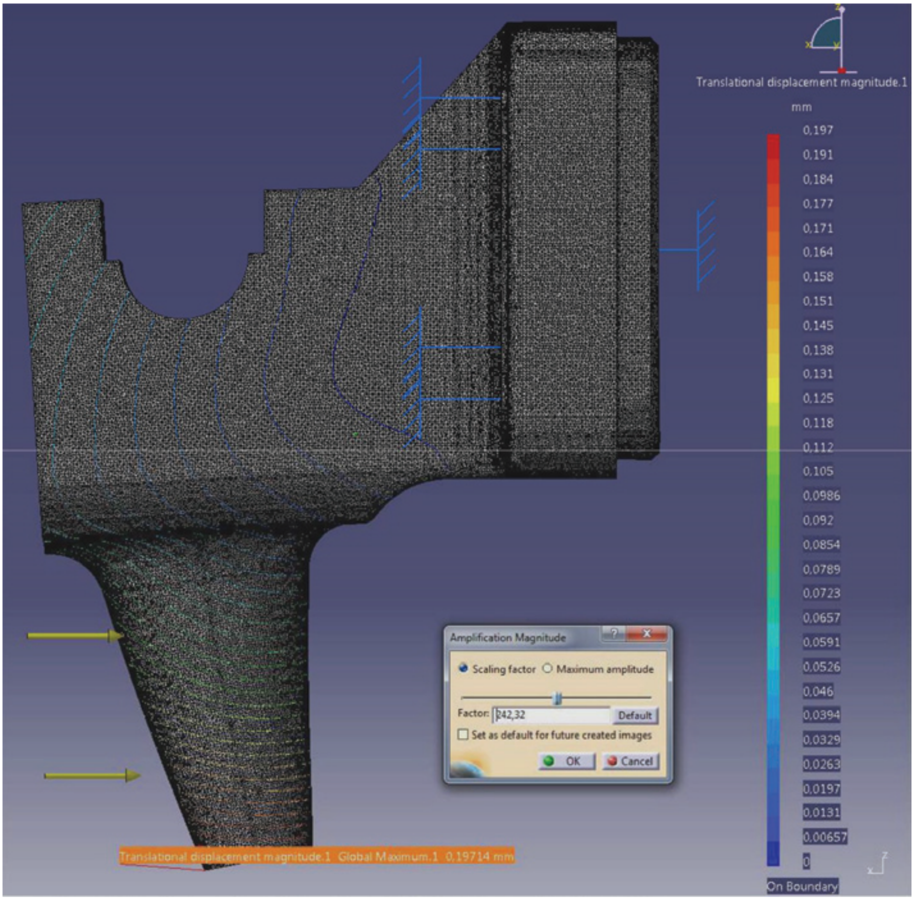

Figure 9: *Load of 100 kN, maximal displacement 0,197 mm*

For the given material R_m = 600–750 MPa while $R_{p0,2}$ = 400 MPa at least, which means that the maximum strain is less than one quarter of the yield point. It is obvious that the criterion of strength with regard to the allowable stress $\sigma_{allowed} = R_{p0,2}/4$ = 100 MPa.

4 FEM ANALYSIS OF A WELDED CONICAL STUD WITH THE ENTIRE FLANGE

An articulation coupler has complex geometry and is a large part. Therefore, the production of a welded joint is a complex and demanding process. It was necessary to verify whether it is possible to make welded joint with the same functional dimensions. Figure 10 shows a welded version of the joint. The model of the joint was made as one body with the welds; in places that are not welded but are in contact, a tiny gap was left. The joint is composed of three parts: a conical stud, a body block, and a flange.

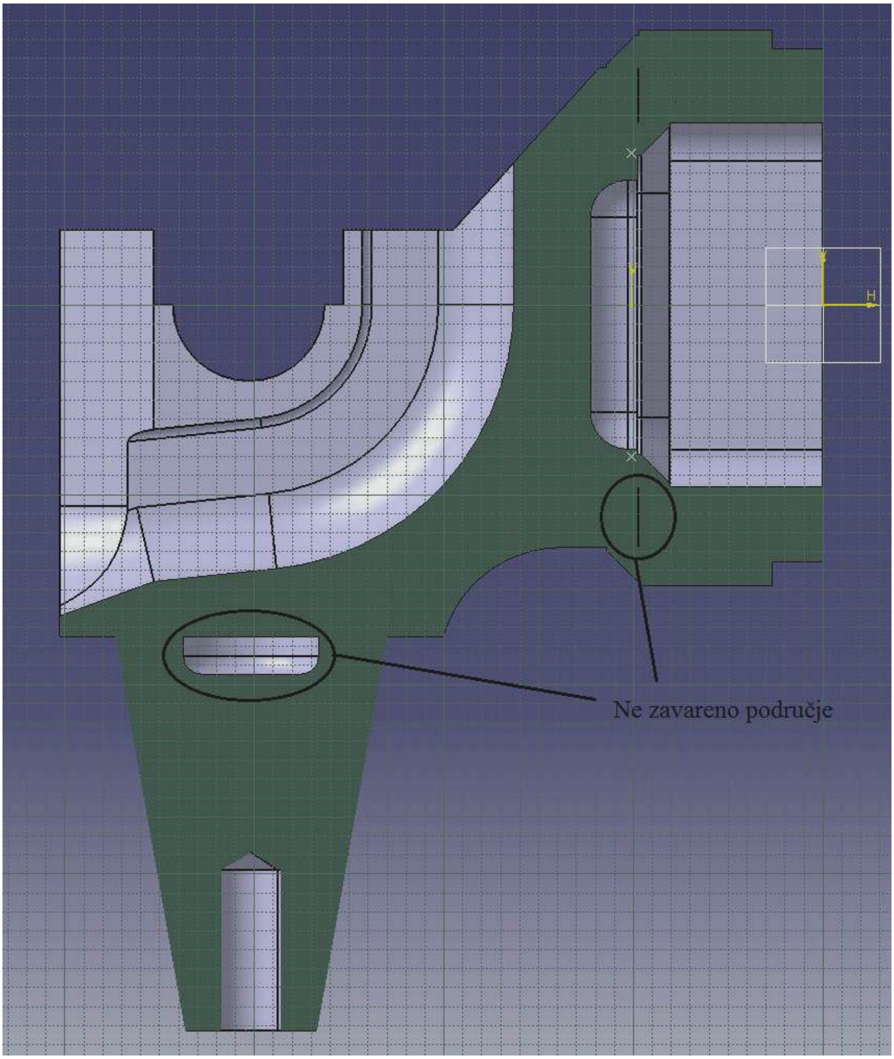

***Figure 10:** Welded version of articulation coupler*

The FEM analysis has determined strain at the critical cross section C, σ_{max} = 142 MPa (Figure 11), while the welded joint was loaded with 100 kN. This analysis has shown that the strain grows and exceeds one third of $R_{p0,2}$. Furthermore, corrosion during exploitation must be taken into consideration, since this is welded construction. It can be concluded that the welded design would not meet the strength criterion without significant changes in the dimensions, which is not possible.

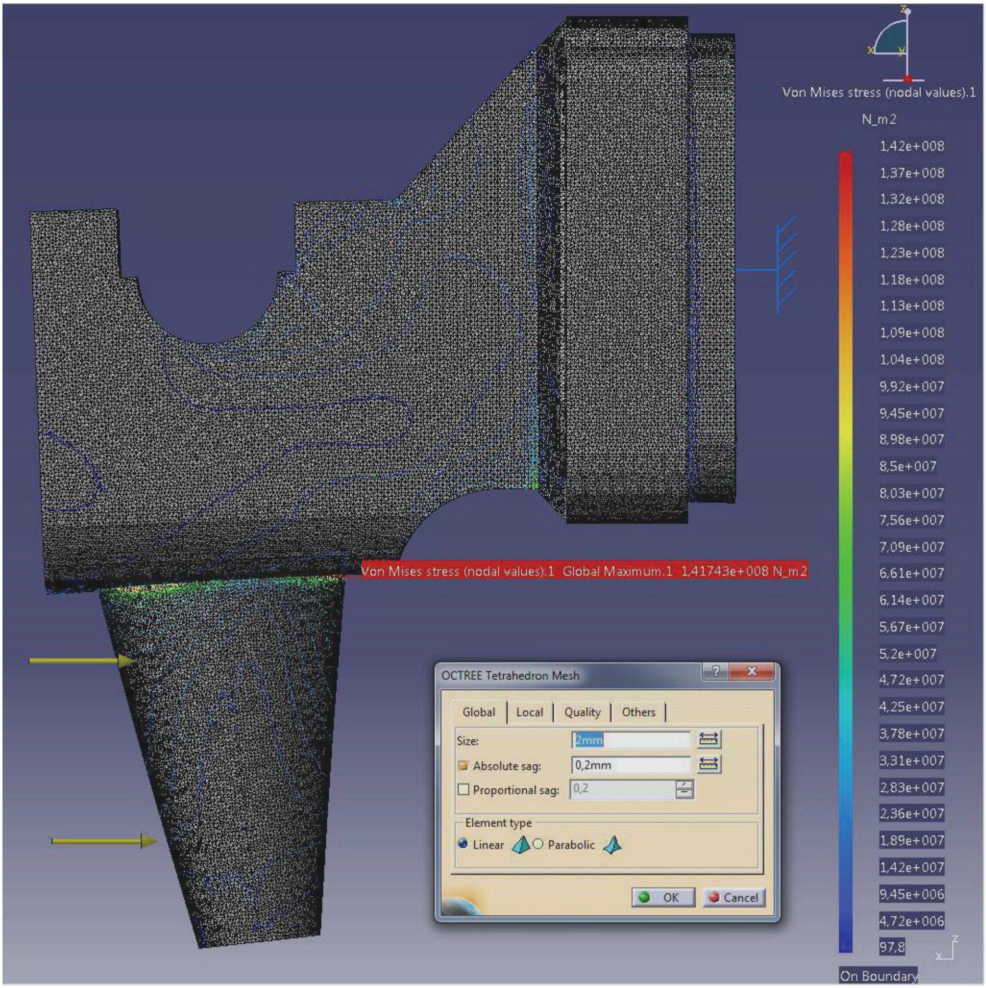

Figure 11: *Load of 100 kN,* σ_{max} = 142 MPa

5 CONCLUSION

This work has proven that the cast construction of an articulation coupler satisfies the strength criterion while welded construction does not. The limiting factor concerning welded constructions is the dimensions of the joint, which are set and cannot be changed.

The usefulness of conventional analytical methods for preliminary calculations has been proven. However, analytical methods show that they cannot precisely calculate and determine the position of the stress on the critical part of the structure because the conical stud does not fit the conditions of the mechanics of materials field for long, thin rods.

In further research, other analytical methods for calculating strains in short, thick rods could be investigated for the purpose of calculating stress in railcar joints.

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Nomenclature

σ_{equ}	Composed stress calculated with HMH theory
σ_{max}	Maximal stress
R_m	Ultimate tensile strength
$R_{p0,2}$	Yield strength
$\sigma_{allowed}$	Allowed stress

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PREPARATION OF NATIONAL PROGRAMME FOR SPENT FUEL AND RADIOACTIVE WASTE MANAGEMENT TAKING INTO ACCOUNT THE POSSIBLE FUTURE EVOLUTION OF ERDO (EUROPEAN REPOSITORY DEVELOPMENT ORGANISATION)

IZZIVI VKLJUČITVE EVOLUCIJE ERDO (EVROPSKA ORGANIZACIJA ZA RAZVOJ SKUPNEGA ODLAGALIŠČA) V PRIPRAVO NACIONALNEGA PROGRAMA RAVNANJA Z RADIOAKTIVNIMI ODPADKI IN IZRABLJENIM GORIVOM

Tomaž Žagar[ℜ], Leon Kegel[1]

Keywords: spent fuel, radioactive waste, ERDO, National Programme, geological disposal facility

Abstract

According to Council Directive 2011/70/Euratom establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste (Waste Directive), each European Union member state shall ensure the implementation of its national programme for the management of spent fuel (SF) and radioactive waste (RW).

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On 1 February 2006, the Parliament of the Republic of Slovenia passed the Resolution on the 2006–2015 National Program for Managing Radioactive Waste and Spent Nuclear Fuel (Official Gazette of the Republic of Slovenia, No. 15/2006), which expired at the end of 2015. In March 2016, the Slovenian government adopted reviewed national programme, which sets out general activities related to SF and RW management for all radiation and nuclear facilities in Slovenia for the next ten years (2016–2025) in the fields of low-level and high-level waste management.

Like some other European countries, Slovenia operates a small nuclear fleet and can be expected to generate relatively small amounts of spent fuel. For such a small program, the financial and human resources required to develop a national geological disposal facility (GDF) may not be feasible or economically practical within the framework of the open and connected markets of European Union. A multinational repository that would accept spent fuel or waste packages from such countries could present a potential solution for disposal challenges. In the European Commission, this idea was recognised some years ago and was developed through two SAPIERR preparatory projects and is now being further promoted through a Working Group on the European Repository Development Organization (ERDO-WG).

This paper presents an approach how to incorporate this multinational/regional developments in the field of SF management in the national programme through a dual-track approach.

Povzetek

Vse države članice Evropske Skupnosti so v skladu z Direktivno Sveta 2011/70/Euratom (poznano pod imenom direktiva o radioaktivnih odpadkih) obvezane implementirati lastne nacionalne programe ravnanja z izrabljenim gorivom (IG) in radioaktivnimi odpadki (RAO). Parlament Republike Slovenije je prvo resolucijo o nacionalnem programu o ravnanju z RAO in IG za obdobje 2006-2015 sprejel že 1. februarja 2006 (skoraj 5 let pred omenjeno direktivo). Veljavnost prve resolucije se z letom 2016 izteka, zato je Vlada RS v marcu 2016 v postopek potrditve poslala novo resolucijo z nacionalnim programom ravnanja z RAO in IG za obdobje 2016-2025.

Pri pripravi strokovnih podlag za novo resolucijo smo se soočali z izzivom, kako v nacionalni program ravnanja z IG vključiti razvoj na področju mednarodnih oziroma regionalnih odlagališč izrabljenega goriva in visoko-radioaktivnih odpadkov. Slovenija ima podobno kot še nekaj evropskih držav, majhen jedrski program, v katerem bodo nastale majhne količine izrabljenega goriva. Za takšne majhne količine IG pa so človeški in finančni viri potrebni za razvoj globokega geološkega odlagališča za odlaganje IG skoraj neodvisni od količine odloženega materiala. Skupno mednarodno ali regionalno odlagališče IG bi za takšne programe pomenilo velike ekonomske, varnostne in praktične prednosti, posebej v luči enotnega in povezanega trga držav Evropske Skupnosti.

Ideja regionalnega odlagališča visoko-radioaktivnih odpadkov in IG je bila prepoznana v okviru projektov SAPIERR in jo sedaj naprej razvija delovna skupina držav članic ERDO-WG; European Repository Development Organization Working Group (delovna skupina za razvoj organizacije evropskega odlagališča).

V prispevku je predstavljen vzporedni pristop k obravnavi razvoja nacionalnega odlagališča in razvoja organizacije skupnega odlagališča v nacionalnem programu ravnanja z RAO in IG.

1 INTRODUCTION

Slovenia has a small nuclear program: it owns one nuclear power plant in co-ownership with Croatia in a 50:50 share located in Krško (Krško NPP), operates one research reactor (TRIGA) and central interim storage facility for radioactive waste from small producers (medicine, industry and research) both at same location Brinje near capital Ljubljana, has one approved location for low and intermediate radioactive waste repository and one closed and remediated uranium mine and mine tailings repository at the Žirovski vrh uranium mine. In Slovenia all spent and fresh nuclear fuel is located only at reactor sites. Irradiated fuel in the Krško NPP is either loaded in the core or stored in spent fuel pool. All irradiated fuel in TRIGA is currently loaded in the reactor itself, *[1][2]*.

Current international and national regulatory and legal frameworks in all European countries require a national programme for managing radioactive waste and spent fuel. The main goal of these programmes is not only to fulfil legal requirements but to ensure safe and efficient management of radioactive waste (RW) and spent fuel (SF). The ultimate goal of radioactive waste management programmes and plans is to provide for the safety of people and the environment at all times, simultaneously to the implementation of long-term, technologically modern and rational infrastructure support to all users of nuclear and radiation technologies.

In Slovenia, the national programme is adopted in the form of a resolution. The resolution proposal is prepared by the competent ministry. After the public consultation process, the resolution will be approved first by the government and later also by the national parliament. Moreover, this procedure is repeated every 10 years.

In its history, Slovenia has adopted several strategic documents related to RW and SF management. In 1996, the first Strategy on SF management was accepted with some general direction regarding how to manage all SF. The strategy for NPP Krško fuel was superseded in 2004 due to the Bilateral Agreement on the status and other legal issues related to the investment, exploitation, and decommissioning of the NEK (Bilateral Agreement between Croatia and Slovenia on NEK). Almost at the same time, Slovenia was also joining the EU. In this process, its legal system was harmonized with EU directives, which resulted in adopted nuclear acts. After this, in 2006, Slovenia approved the Resolution on radioactive waste and SF management for the 2006–2015 period which included all relevant topics for the management of the radioactive waste and spent fuel, from the legislation and identification of different waste streams in Slovenia, to the management of radioactive waste and spent fuel, the decommissioning of nuclear facilities, and the management of naturally occurring radioactive materials, *[2][3].*

In 2016, Slovenia is approving the next revision of the national plan: the Resolution on radioactive waste and spent fuel management for the 2016–2025 period. This document incorporates several relevant changes that influence RW and SF management plans which took place since 2006. It was adopted by the Slovenian government in March 2016 and sent to Slovenian parliament for final approval, *[4].*

2 THE PROPOSED CONCEPTS OF REGIONAL AND INTERNATIONAL COOPERATION REGARDING RADIOACTIVE WASTE MANAGEMENT

The idea of regional and international cooperation regarding RW management is not new and has its roots in the previous century. Over 50 countries currently have spent fuel stored in temporary locations, awaiting reprocessing or disposal. Not all countries have the appropriate geological conditions for such disposal; for many countries with small nuclear programs, the financial and human resources required for the construction and operation of a geological disposal facility are daunting, *[5][6].*

The need for country assistance in arranging their cooperation for shared facilities was widely recognised by the international organisations such as the International Atomic Energy Agency (IAEA), the Nuclear Energy Agency (NEA) within the Organisation for Economic Co-operation and Development and it was recognised recently also within The International Framework For Nuclear Energy Cooperation (IFNEC), *[7].*

In 2003, Dr Mohamed El-Baradei, Director-General of the IAEA told the UN General Assembly that multinational approaches to the management and disposal of spent fuel and radioactive waste should be considered and concluded that "considerable advantages in cost, safety, security and non-proliferation would be gained from international cooperation in these stages of the nuclear fuel cycle", *[6].*

With respect to the implementation of the Waste Directive in the EU, the Member States with advanced programmes can meet the requirements on their own, but those with slower-paced or less-advanced disposal programmes face particular challenges in doing so. By cooperating in a regional grouping, countries could develop a common programme for addressing many of the requirements of the Waste Directive, *[7].*

In Europe, the European Commission (EC), recognizing that less advanced countries need assistance in arranging their cooperation, funded two preparatory projects, SAPIERR I and II, aimed at studying the technical, financial, organisational and legal issues involved in preparing for implementation of shared facilities. Following SAPIERR II, a Working Group on the European Repository Development Organisation (ERDO-WG) was established in 2009. The ad-hoc ERDO-WG was established with support at the government level offered from nine Member States and is operated as a self-funded group. Slovenia is represented in ERDO Working group by the decision of the Ministry competent for energy by ARAO, which has been (from the beginning of the activities) involved in related communication and is providing a public service of radwaste management in Slovenia, *[7].*

3 THE ERDO-WG INITIATIVE

ERDO-WG is a multinational working group that is investigating the feasibility of implementing regional solutions for the safe management and disposal of long-lived RW. The group is studying the feasibility of setting up a European Repository Development Organisation (ERDO) that would implement one or more shared geological repositories in Europe. The secretariat of the group is currently managed by the national waste agency of the Netherlands (COVRA) and by the Arius Association, which covers international cooperation in waste management for the rest of the world, *[8]*.

Important goals of the ERDO-WG are to exchange information, to build up competence and to promote the concept of shared repository development as a complement to the national facilities being developed. ERDO-WG is promoting a volunteer model including a bottom-up approach with stakeholder involvement at all stages. Clearly unsuitable regions for the storage or disposal of RAW are excluded at the start of the selection process for the location, *[8]*.

The benefits of an ERDO to partner countries should be felt at local, national and international level, *[7]*:

Internationally

- increased national visibility and influence in addressing a widely acknowledged issue of global environmental protection and nuclear security
- contributing to Europe-wide investment savings of several billions of euros
- increased influence in European and international agencies dealing with nuclear energy and nuclear safety
- increased influence on suppliers of nuclear technologies and fuels

Nationally

- a clear demonstration of a credible approach to responsible management of national radioactive wastes
- reduced R&D burden
- increased, pooled resources to develop a realistic and timely solution
- significant economic incentives and infrastructure improvements to the host country
- access to wider skills and technology

Locally

- involvement in modern, stakeholder-led approaches to solving environmental problems
- increased influence of local host communities in national environmental decision-making
- substantial economic and infrastructure benefits to the host communities, both today and for many decades to come

The credibility of the shared solution approach is established through the operation as a self-funded group, but experience in recent years has shown that even the modest financial input needed to finance an ERDO-WG secretariat and attendance at group meetings has proven to be an insurmountable obstacle for some Member States. A stable funding regime for the continuing work is required. For this purpose, ERDO-WG prepared a COMS-WD proposal searching for direct partial funding by the EC for coordination work and supporting actions regarding waste directive implementation for less advanced Member States, *[9]*. On that basis, the focus has lately changed from more technical questions to discussion how to encourage further ERDO-WG visibility at the European and national level. ERDO-WG activities should go beyond research and address general shared responsibilities and the need for improved communication with carefully selected target audiences and addressing more political levels including the European Council, the European Energy Forum (EEF) in the European Parliament, EC staff, the Committee of Regions, and national governments and parliaments.

4 IMPLEMENTATION OF NATIONAL PROGRAMME AND COMPLIANCE OF REGIONAL INITIATIVES

According to Article 11 of the Waste Directive, each member state shall ensure implementation of its national programme, including all phases of the management of SF and RW, from generation to disposal. The disposal of RW and SF (if not considered to be a usable resource that can be reprocessed) in another MS or a 3rd country is allowed according to the Article 4 (4). The articles of the Waste Directive do not explicitly allow or prohibit shared responsibility between the Member States in the case of a regional initiative. In the framework of Recital 33, which recognizes a potentially beneficial consideration of some MSs towards the sharing of facilities for SF and RW based on an agreement between the MSs, they are allowed to form a regional initiative concerning these questions. The principle is implemented in Article 12 (k), which accepts agreements with a member state or a 3rd country on the management of SF or RW as part of the national programme, *[7]*.

Member States shall ensure the implementation of their national policies from generation to the disposal of RW; and even after if long-term monitoring of disposal facility is required. Solely regional or international solutions fulfil the requirements of the Waste Directive when *inter alia* an agreement between the exporting member state and country of destination has been signed, and the exporting member state takes reasonable measures to be assured that the disposal facility in the country of destination is authorized for the radioactive waste to be shipped and is operating prior to the shipment. What such reasonable measures are depends on the interpretation. Nevertheless, it is clear that country shall have at least a confirmed location with a building permit for the disposal with clear plans, technical solutions, milestones and public acceptance, *[7].*

However, to cover all the uncertainties and possibility of failure of the regional initiative, the dual-track approach is practically necessary at the moment to gain credibility of the regional initiative.

5 THE DUAL TRACK APPROACH

Experience shows that in every national programme, the route to an operational disposal facility is long and beset with uncertainties, and any specific initiative could end in failure. The same must be acknowledged for a shared disposal facility. Consequently, Member States interested in sharing need to explore national solutions in parallel to supporting a shared solution. This has become known as the "dual-track approach" and, although it is not a specific requirement of the Waste Directive, it is considered to be a necessary feature to underpin the credibility of the ERDO model, *[7]*.

Countries with small amounts of SF and RW and without nuclear power and its associated infrastructure and knowledge base will find it extremely difficult to develop all the components of a necessary disposal facility programme. Economic considerations must also come into play in such cases, even though they cannot override safety requirements or legal obligations. The dual-track approach must thus be able to accommodate participating countries with very different nuclear infrastructures and radioactive waste inventories, *[7]*.

The principles of the dual-track approach in reference to membership of the ERDO can be stated as follows, *[7]*:

- Participating countries should develop, maintain, and promote knowledge and expertise in the safe management of radioactive wastes (requirement of the Waste Directive and the Joint Convention)
- The minimum level of activity required to maintain a continuing national expertise in some aspects of geological disposal, including supporting a minimum level of academic or institutional research.
- Participating countries with wastes from nuclear electricity generation programmes are expected to have an active parallel national disposal programme on their own territory and are expected to operate this programme in an interactive and complementary manner to the ERDO programme.
- All participating countries will thus contribute in varying measure to shared knowledge and will receive the benefit of shared R&D and technology development for all aspects of their national radioactive waste management programmes.

6 NATIONAL RADIOACTIVE WASTE AND SPENT FUEL MANAGEMENT PROGRAMME FOR THE 2016-2025 PERIOD (RENPROG 2016-2025)

The Resolution on the 2006–2015 National Programme for Managing Radioactive Waste and Spent Nuclear Fuel expired at the end of 2015. The process of approval for a new revision is currently underway in Slovenia. Based on several technical inputs and background documents (including technical basis for the revision prepared by ARAO) the competent ministry (Ministry of the Environment and Spatial Planning) prepared a draft Resolution on the 2016–2025 National Programme for Managing Radioactive Waste and Spent Nuclear Fuel (ReNPROG 2016-2025) that successfully passed a public consultation process. The document was approved by the Slovenian government in March 2016 and was sent to Slovenian parliament for final approval.

In ReNPROG 2016-2025, draft various SF and HLW solutions are implemented, which include options for long-term storage and different options for fuel reprocessing and final disposal in a geological repository either national, regional or multinational, *[10]*.

The idea of shared facilities and regional cooperation in waste management for the EU Member States with small or no nuclear programme, including the dual track approach, was implemented in the draft of the document. For long-term spent fuel management, a dual-track strategy has been adopted as a reasonable solution in the present situation. The option of multinational disposal is kept open, and the basic reference scenario for geological disposal has been developed, assuming the disposal of spent fuel in 2065.

First, shared responsibility and the opportunity to safely and sustainably resolve issues related to radioactive waste and spent fuel management together with other countries was implemented in the general policy on management of radioactive waste and spent fuel, in which the principle of international cooperation regarding radioactive waste and spent fuel was included.

This principle states that actions of Slovenia regarding shared responsibility and the opportunity for safe and sustainable solutions related to radioactive waste and spent fuel management should take into account the principles adopted in the Resolution and policy and regional and international agreements. National responsibility for radioactive waste and spent fuel management is considered in parallel with active participation in international, regional efforts to make progress in connection with joint regional programmes on disposal, *[10]*.

The strategy and programme of radioactive waste and spent fuel management for SF and HLW storage and disposal summarize in one part international status of some countries which are introducing long-term storage of SF and HLW. Associated reasons for such a decision include monitoring of international development for the safe and efficient handling of SF and the intention to use advanced methods for processing SF and the benefits due to radioactive decay and the reduction of the residual heat of fuel. During long-term storage, the gathering and refinement of financial assets in the fund shall continue, together with the monitoring of the development of multinational or regional deep geological repositories, *[10]*.

In the end, all SF and HLW management options require a solution in the form of deep geological disposal of SF or HLW. The proposed resolution RENPROG 2016-2025 introduces a proposal for all irradiated and spent fuel owners to evaluate also a possibility of reprocessing and reusing spent fuel as an option that could significantly reduce the volume and radiotoxicity of waste for final disposal, *[11]*. The construction of deep geological disposal (national, regional, or multinational) is a necessary solution regardless of the selected option for storage, processing, and other forms of SF and HLW management, *[11][10]*.

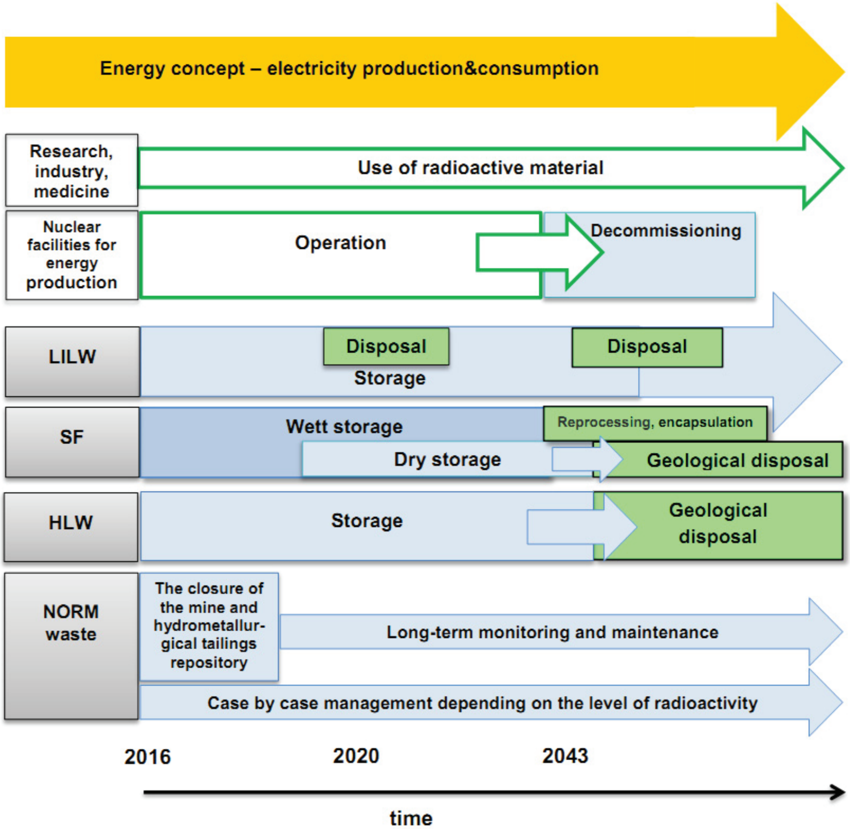

Figure 1*: Schematic representation of the national RW and SF management strategy. The national programme of radioactive waste and spent fuel management is developed as an infrastructure program. RW and SF management strategy correlate to other national programmes and strategies in the fields of economy, research, and energy,* [10].

The reference scenario for a national repository in suitable solid rocks is proposed; however, the possibility of discussion for a multinational repository also remains open with the dual-track strategy approach. Slovenia is a member of the European Repository Development Organisation Working Group (ERDO-WG), which brings together a group of EU countries with the aim of considering the model for the development of shared solutions for the Member States. The main reason for the cooperation and integration in this area is the extremely small nuclear programme in the Republic of Slovenia; with the participation in joint or shared programmes significant positive economic effects can be achieved, *[10]*.

7 CONCLUSIONS

ARAO is a Slovenian waste management organization considering long-term waste management planning including long term SF management strategies. The planning has to consider all relevant aspects, including geological, financial, technical, and human resource factors. Some of these factors are especially limiting for a deep geological facility for Slovenia's very small nuclear program. In this respect, ARAO also considers the progress in international and regional efforts in the field of shared or regional disposal solutions. Slovenia is not alone because many countries operate or will operate small nuclear fleets and can be expected to generate relatively small amounts of spent fuel over the life of their programs. For some of these countries the financial, technical, and human resources limitation may hinder the potential to develop, construct, and operate a GDF. A multinational repository approach that would accept spent fuel or waste packages from such countries could provide a solution for their back-end management and disposal challenges. However, planning a long-term spent fuel policy based only on a yet multinational approach is not a viable solution. For those countries, a dual-track approach to long-term GDF planning option is a potential solution to short term planning needs.

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Nomenclature

ARAO	Slovenian Radioactive Waste Management Organization
COMS-WD	A new proposal for cooperation between the EU Member States responding to the EC Waste Directive
COVRA	National waste agency of the Netherlands
EC	European Commission
EEF	European Energy Forum
ERDO-WG	European Repository Development Organisation Working Group
ERDO	European Repository Development Organisation
GDF	Geological Disposal Facility
HLW	High-Level Waste
IAEA	International Atomic Energy Agency
IFNEC	The International Framework For Nuclear Energy Cooperation
LILW	Low and Intermediate Level Waste
MS	Member States
NEK	Nuklearna Elektrarna Krško
NORM	Naturally Occurring Radioactive Materials
NPP	Nuclear Power Plant
ReNPROG	RESOLUTION on the 2016–2025 National Programme for Managing Radioactive Waste and Spent Nuclear Fuel
RW	Radioactive Waste
R&D	Research&Development
SAPIERR I	Support Action: Pilot Initiative for European Regional Repositories
SNSA	Slovenian Nuclear Safety Authority
SF	Spent Fuel
UN	United Nations

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RRESPONSE OF THE KRŠKO NUCLEAR POWER PLANT COINTAINMENT TO THE LOSS OF COOLANT ACCIDENT IN COMPUTER CODE APROS 6

ODZIV ZADRŽEVALNEGA HRAMA NEK NA NESREČO S PUŠČANJEM PRIMARNEGA HLADILA V RAČUNALNIŠKEM PROGRAMU APROS 6

Jure Jazbinšek[ℜ], Luka Štrubelj[1], Ivica Bašić[2]

Keywords: NEK, model, APROS 6, Containment, LOCA, accident, blowdown, spray, sump

Abstract

Containment is a combination of a steel shell and concrete shield building enclosure, completely surrounding a nuclear reactor, designed to prevent the release of radioactive material in the event of an accident. The NEK (Krško Nuclear Power Plant) reactor containment building nodalization in APROS 6 computer code has been developed based on the plant's available documents and GOTHIC nodalization. The heat structure's data are based on USAR (Updated Safety Analyses Report) Chapter 6 passive heat structures. In all other aspects, realistic calculations based on containment geometry have been performed except for the interior concrete, which has been explicitly calculated.

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An original containment nodalization based on 10 control volumes is proposed, taking into account the containment layout (well-defined physical boundaries and corresponding communication openings) and accident behaviour. The nodalization is suitable for containment thermal-hydraulic modelling according to design basis accidents. In the end, APROS nodalization is prepared based on the same 10-volume nodalization, for which annulus-volume is also included in the model, connecting the reactor building to the environment. The containment model was tested for transient response for conditions, which occur in a Double-Ended Hot Leg Guillotine Break accident.

Povzetek

Zadrževalni hram je zgradba, v kateri so komponente znotraj tlačne meje reaktorskega hladila, ki predstavljajo pregrado pred nenadzorovanim sproščanjem radioaktivnosti v okolje. V programu APROS je na podlagi razpoložljivih dokumentov in nodalizacije programa GOTHIC zmodeliran model zadrževalnega hrama jedrske elektrarne NEK. Podatki za izračune posameznih struktur so povzeti iz dokumenta USAR (posodobljenega varnostenga poročila) - poglavje 6, ki opisuje pasivne toplotne strukture. Model zadrževalnega hrama, ki je sestavljen iz 10 (fizikalno dobro definiranih) povezanih prostorov, je primeren za simulacijo jedrskih nesreč. APROS model zadrževalnega hrama vsebuje tudi vmesni prostor, ki povezuje notranjost zadrževalnega hrama z zunanjim okoljem. Z modelom je bil preverjen odziv modela zadrževalnega hrama na prehodni pojav, ki nastane pri dvojnem giljotinskem zlomu vroče veje reaktorskega hladilnega sistema.

1 INTRODUCTION

Nuklearna Elektrarna Krško (NEK) containment systems consist of a steel shell containment, concrete shield building, penetrations, and directly associated systems such as the containment isolation system, the containment spray system, the containment air recirculation and cooling system, and the combustible gas control system.

The Containment System is designed for all break sizes, up to and including the most severe breaks. Additionally, the containment system is capable of reducing containment pressure to an acceptable value one day following any loss-of-coolant accident. This capability is maintained by the Containment System even assuming the worst possible single active failure affecting the operation of the Emergency Core Cooling System, Containment Spray System, and the reactor containment fan coolers during the injection phase; and the worst possible active or passive single failure during the recirculation phase

Following a postulated rupture of the Reactor Coolant System (RCS), steam and water are released into the Containment System. Initially, the water in the RCS is subcooled at high pressure. When the break occurs, the water passes through the break where a portion flashes to steam at the lower pressure of the containment. These releases continue until the RCS depressurizes to the pressure in the containment (end of blowdown). At that time, the vessel is refilled by water from the accumulators and Safety Injection (SI) pumps. The analysis assumes that the lower plenum is filled with saturated water at the end of blowdown, to maximize steam releases to the containment. Therefore, the water flowing from the accumulators and SI pumps starts to fill the downcomer, causing a driving head across the vessel which forces water into the hot core.

The LOCA analysis calculation model is divided into three phases:

1. blowdown, which includes the period from accident occurrence (when the reactor is at steady state full power operation) to the time when zero break flow is first calculated,
2. refill, which is from the end of blowdown to the time the ECCS fills the vessel lower plenum, and
3. reflood, which begins when water starts moving into the core and continues until the end of the transient.

Nodalization of the NEK reactor containment building model in APROS 6 computer code was developed based on the plant's available documents and available NEK GOTHIC nodalization, *[1]*. The NEK containment system consists of the steel shell containment, concrete shield building (Reactor Building), penetrations and the directly associated systems (Reactor Building Fan Coolers and Containment Spray System) upon which the containment safety functions (confinement of the radioactive fission products during design basis accident and prevent radioactive material releases in the environment) depend. The heat structures' data, except for interior concrete, which is explicitly calculated, are based on USAR Chapter 6 passive heat structures.

APROS nodalization is based on 10 control volumes (well-defined physical boundaries and corresponding communication openings) for simulations of accident behaviour. The nodalization is suitable for the thermal-hydraulic analysis of containment responses during design basis accidents. The interior of the Reactor Building (RB) steel containment shell is modelled with nine volume nodes and one additional node for the annulus, where the annulus-volume is the volume between the RB steel shell containment and concrete building. Heat is transferred from nine connected free volumes located inside the RB steel shell containment towards the annulus-free volume through four connecting (passive) heat structures. The Reactor Building of the Krško Nuclear Power Plant has a cylindrically shaped body, spaced between nearly spherical cups. For nodalization purposes, this Reactor building modelled with nine discrete compartments after a Loss of Coolant Accident (LOCA) can be seen in the nodalization containment scheme, presented in *Figure 1*.

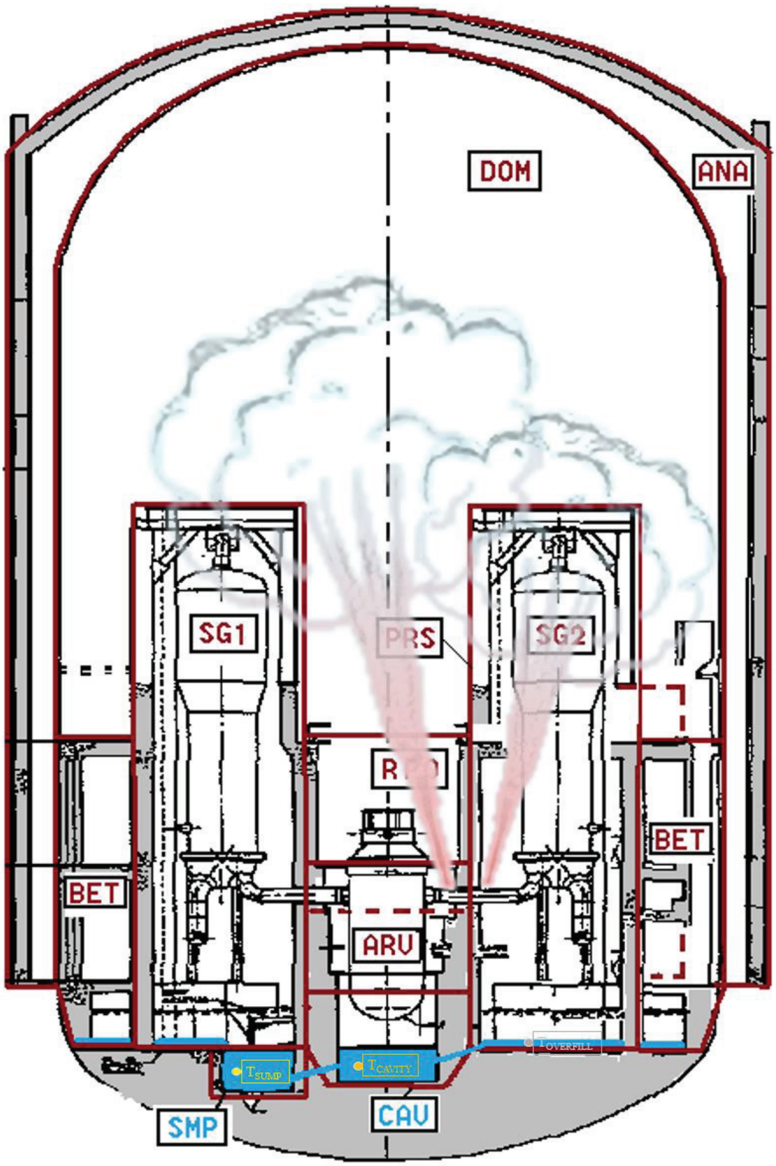

***Figure 1:** Reactor Building Nodalization Scheme of NEK during LOCA*

The containment systems are designed so that for all break sizes, up to and including the Double-Ended Hot Leg (DEHL) guillotine break of a reactor coolant pipe or a main steam line, the peak containment pressure is below the design pressure with an adequate margin. Additionally, the containment systems are capable of reducing containment pressure to an acceptable value one day following any loss-of-coolant accident.

2 APROS MODEL DESCRIPTION

APROS nodalization is based on a nodalization scheme with nine control volumes. The model includes two additional free volumes representing the annulus and the outside environment, which are modelled as two serial connecting volumes. The numbering of APROS Containment compartments is equivalent to GOTHIC nodalization (1-10). The user view of APROS containment nodalization, where connections between free volumes, gas branches, water branches and containment sumps arrangement can be seen as presented in Figure 2.

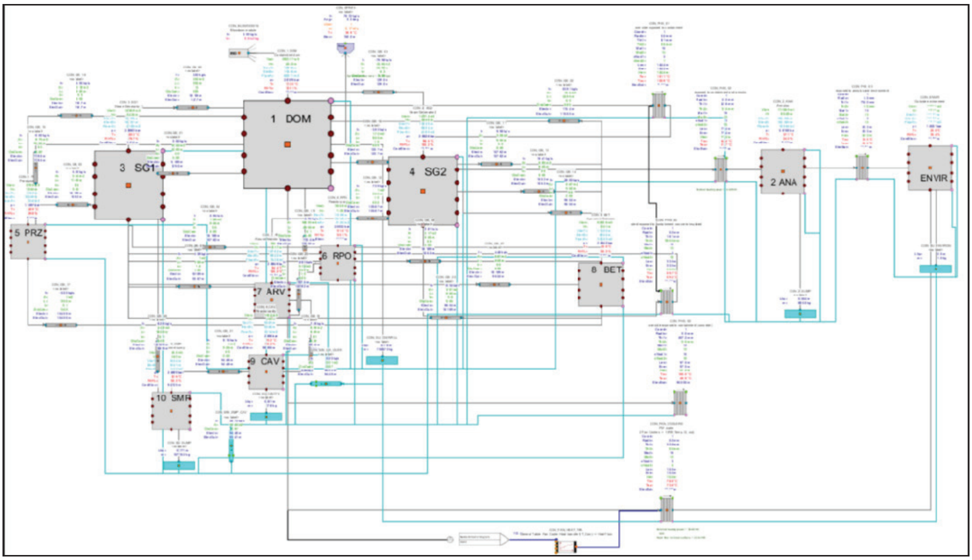

Figure 2: *User view of APROS containment nodalization*

2.1 Nodalization of containment free volumes

All free spaces (compartments) in the containment are modelled with APROS Containment node modules, which include a gas region and a water droplet phase (mist). The atmosphere of each node is assumed to consist of a homogeneous mixture of water vapour and non-condensable gases. The largest and consequentially most important volume in the containment model is module CON_1_DOM, where the majority of measurements of all transient is measured. All effects that are causing transients, such as heat exchangers and spray modules, are connected to the containment dome module.

2.2 Nodalization of containment sumps

The bottom space of the NEK containment is modelled with APROS sump modules, which are basically water pools on the bottom of the reactor building, where the water of the deposited droplets (that has not fallen/ been transferred to another node) is placed. The water sumps are connected to the containment node and allow the heat and mass transfer calculation between the sump surface and node atmosphere.

Every containment node is connected to at least one sump and represents the bottom of a particular free volume with identical geometry. Connections between three water sumps, representing the bottom surface of the RB building are connected to the overflowing configuration.

Gas branches are used in all of the inside connections in the NEK containment model, representing open orifices. If the sump water level reaches the inlet elevation of any gas branch, the gas branch is assumed to be closed.

The water branch is a flow path between the water pools of the adjacent nodes. The sump connection allows the heat and mass transfer calculation between the sump surface and node atmosphere. Only two water branches, which serve as flow paths between three water pools (sump modules), were used in this model of NEK containment.

During the blowdown phase, a large amount of steam is injected into the reactor building, and a large portion of the steam is condensing on the walls and condensate water flows directly into the containment sumps.

2.3 Containment heat structures

Each heat structure module is connected to the desired drain water sump, where atmospheric and/or surface heat transfer is assumed to be the sum of the sensible heat transfer and latent heat transfer from vapour condensation or evaporation. The heat transfer area used for the connections is defined on the basis of the water pool elevation, *[2]*.

In the current version of the APROS NEK containment model, five heat structures were modelled. The amount of input data needed for a more complex heat structure model, as in NEK GOTHIC is high, especially when large numbers of heat structures with numerous nodes are modelled. However, validation showed that the number of heat structures is adequate. The current model was prepared just to evaluate briefly whether APROS is able to predict accurately the containment response to a Double-Ended Hot Leg (DEHL) guillotine break LOCA similar to USAR, *[3]*, and analysis done during the NEK modernization project (SG replacement and power uprate), *[4]*. In both of those studies, the heat structure model is more simplified in comparison to the NEK GOTHIC model, *[1]*.

The heat structure geometry data of APROS 6 heat structures is calculated on the basis of 14 CONTEMPT heat sinks modelled as described in NEK USAR, *[3]*, and SSR-NEK-7.8 (Containment Response to LOCA) documents, *[4]*. The area and masses of the passive heat sinks considered are joined on the basis of heat structure exposure and material.

The heat transfer calculation between the heat structure and the node gas region on the inner surface is calculated with mass diffusion theory for the heat and mass transfer between the structure and gas region based on Ackermann's approximate corrections. In the case of forced convection, the correlation for the average Nusselt number is chosen.

2.4 Containment spray

The heat and mass transfer between the droplets and atmosphere is solved by APROS in detail, for example, droplet interface temperature is separately iterated (using the secant method) due to its strong influence on the combined heat and mass transfer. Furthermore, the drop mean temperature is iterated simultaneously with the surface temperature with Newton's method. Transfer coefficients are corrected by the influence of mass and heat capacity fluxes, *[2]*. Heat conduction within a droplet is modelled using a simplified method. No interactions between spray and fog droplets are modelled. The spray droplets can also fall down (are deposited) from an upper node to the lower one if the proper input connections of the spray modules are activated, *[1]*.

Water mass flow and temperature of water flowing from the containment spray are set in the time-dependent values of the input table of the internal spray system, similar to an analysis performed in the light of the mentioned USAR Section 6, *[3]*.

Since the water for spraying is set to the temperature of the Refuelling Water Storage Tank (RWST), the entire heat capacity of the spray from the RWST temperature to the temperature of the containment atmosphere is available for energy absorption.

2.5 APROS fan cooler heat transfer

The fan cooler heat removal capability is dependent on the containment temperature. The heat removal dependency function of the containment temperature and the component cooling water temperature is provided in NEK USAR, *[3]*, as RBCU Data. The heat transfer of fan coolers in APROS was realized with a boundary condition module, in which the heat transfer of the heat structure is controlled as a function of temperature in the containment dome.

3 APROS MODEL VALIDATION

The APROS containment model was verified and validated based on a comparison of simulated analysis conditions from SSR-NEK-7.8.2, describing Containment Response to LOCA, *[4]*. The analysis peak containment pressures from the postulated double-ended hot leg (DEHL) break were compared between APROS and existing analyses. This peak pressure is a blowdown peak (occurring at the end of initial reactor coolant system blowdown). Both analyses, APROS and SSR-NEK-7.8.2, incorporate the effects of power uprate and steam generator replacement.

3.1 Input data and assumptions

In the APROS containment model, there are three events, (blowdown, fan coolers start, and spray start) that cause thermo-hydraulic transients during simulations. Before the simulation, parameters of containment nodes such as temperatures, humidity, pressures, etc., were set as initial conditions (IC) in the model. The model of containment was not connected to any source of heat losses (dissipation sources such as a reactor or RCS loops) and was set based on the Krško Technical Specifications (TS).

The assumed mass and energy release data during the RCS blowdown phase are from SSR-NEK 7.8.1, *[4]*, which are used as boundary and initiating conditions (not calculated by APROS). The worst peak containment pressure is obtained during the blowdown phase with the double-ended hot leg break. As the long-term containment pressure and the temperature are bound by the double-ended pump suction break with minimum safety injection, only the pump suction break cases require post-reflood calculation, *[4]*.

The input data of the Double-Ended Hot Leg Guillotine (DEHL) Break LOCA is described in SSR-NEK 7.8.1, *[4]*. Mass/energy releases also known as blowdown data start at the beginning of simulation (0 seconds). Energy release during DEHL LOCA is released from two break paths in compartments ARV and SG2. Break path No. 1 discharges from the reactor vessel (ARV) to break point and break path No. 2 discharges from the steam generator (SG2) side to breakpoint (see Figure 1). Data from the DEHL LOCA table used in are presented in Figure 3.

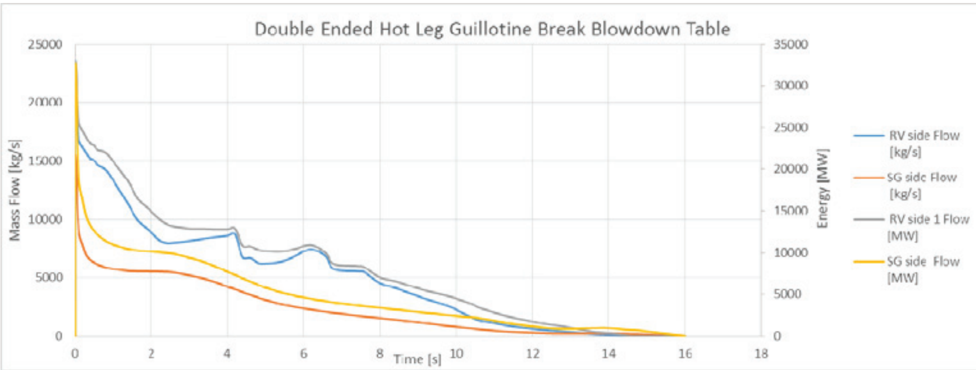

Figure 3: *Visual presentation of blowdown mass/energy releases*

The containment spray (CI system) fill time is 45 seconds (including pump start and diesel generator loading sequencing). The diesel start time is 10 seconds. The total time to spray actuation is 55 seconds assuming the containment HI-3 setpoint is reached prior to the diesel coming up to speed. After the initial DEHL LOCA, the containment fan coolers (RCFC) start 35 seconds after an accident. As explained in section 3.4, the 35-second delay is assumed to be an initial condition for the actuation of RB Fan Coolers in this analysis.

3.2 Initial Conditions

The initial RB pressure assumed is 0.14 kp/cm². The initial RB temperature 48.9°C (120°F) is the maximum Technical Specification value. The RWST maximum temperature is 37°C (98.6°F) and the initial RB relative humidity assumed is 30%. These parameters were entered into all APROS containment nodes, representing free volumes of the reactor building. Initial conditions set for containment annulus is set to 0.8 bars and 30°C, with the RB free volume with four heat structures.

3.3 Containment blowdown pressure simulation

The APROS simulation was run up to 60 seconds, longer than in SSR-NEK, *[4]*. Transients such as RB Fan Coolers start at (at 35 seconds) and containment spray start at 55 seconds. Simulated variables of six vertical containment node volumes, representing the reactor building from the top to the bottom (DOM, SG1, RPO, ARV, SUP and CAV in Figure 2) were monitored. Temperatures in containment volumes vary depending on the node elevation and proximity to sumps, where water that is the result of condensation is gathering and consequentially cooling the nearby volumes.

3.4 RB pressure Results comparison

The Double-Ended Hot Leg (DEHL) LOCA transient results in the maximum calculated containment pressure. This analysis was evaluated only to the end of blowdown since the long-term containment environmental conditions will be controlled by the pump suction breaks.

The APROS Containment model results (blowdown starts at 0 seconds) were compared to results from SSR-NEK, *[4]*. The DEHL LOCA transient from SSR-NEK, *[4]*, was recalculated to absolute values and SI units. Comparisons of APROS simulation results of Containment pressure during DEHL LOCA transient and SSR-NEK, *[4]*, results are presented in Figure 4.

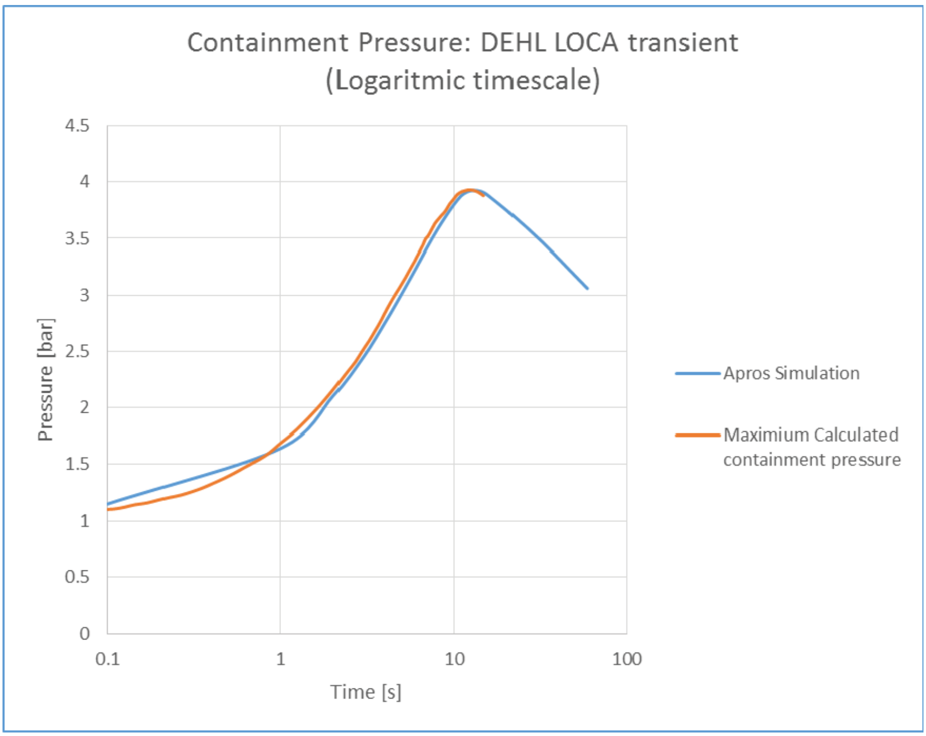

Figure 4: *Comparison of APROS and SSR-NEK results: containment pressure during DEHL LOCA transient*

Good alignment (<0.01%) can be seen between the APROS peak pressure values of the simulated results and the postulated results calculated from SSR-NEK-7.8.2, [4], during the first 15 seconds after the DEHL LOCA transient. Peak pressures in the APROS results occur 13.2 seconds after blowdown is started and in SSR-NEK-7.8.2 after 12.05 seconds, which is only a minor difference.

The results show that the containment peak pressure is below the design pressure with an adequate margin and, therefore, shows that containment can survive the postulated transient. After the peak pressure is attained, the performance of the safeguards systems additionally reduces the containment pressure and temperature.

4 CONCLUSION

Following a postulated rupture (DEHL LOCA) of the Reactor Coolant System (RCS), steam and water are released into the Containment System. Initially, the water in the RCS is subcooled at high pressure. When a break occurs, the water passes through the break where a portion flashes to steam at the lower pressure of the containment. These releases continue until the RCS depressurizes to the pressure in the containment (end of blowdown). The analysis assumes that the lower plenum is filled with saturated water at the end of blowdown, to maximize steam releases to the containment.

Good quantitative and qualitative agreement between APROS simulated results and results from SSR-NEK-7.8.2, *[4]*, during the first 15 seconds after the DEHL LOCA transient were obtained. Simulation of surface temperatures and water volumes in the sumps representing freshly condensed water from a blowdown event, lasting from 0 to 15 seconds, yields realistic results.

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Nomenclature

ANA	Annulus - compartment
APROS	Software for modelling and dynamic simulation of processes and power plants developed by Fortum and VTT.
ARV	space Around Reactor Vessel
BET	Between - compartment (space outside listed volumes)
CAV	Reactor cavity - compartment
DEHL	Double Ended Hot Leg (guillotine break)
DOM	Containment dome - compartment
IC	Initial Conditions (settings in Apros model)
LOCA	Loss of Coolant Accident
NEK	Nuklearna Elektrarna Krško
PRZ	Pressurizer -compartment
RB	Reactor Building
RBCU	Reactor Building Cooling Unit
RCFC	Reactor Containment Fan Coolers
RCS	Reactor Coolant System
RPO	Reactor Pool - compartment
RV	Reactor (pressure) Vessel
RWST	Refuelling Water Storage Tank
SG1	Steam generator 1 - compartment
SG2	Steam generator 2 - compartment
SMP	Containment Sump - compartment
USAR	Updated Safety Analyses Report

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SIMULATION OF COMMISSIONING IN WAREHOUSE

SIMULACIJA KOMISIONIRANJA V SKLADIŠČU

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Keywords: warehouse, commission, visualization, X3D, XML

Abstract

To understand the dynamic behaviour of the systems and verify implemented designs or processes in a particular time frame the use of simulation studies is necessary. Although the amount of time and data used to produce such studies are substantial, the 3D representation of the system produces a fuller understanding of system behaviour. This paper describes the use of 3D animation to visualize workflows in a warehouse using standard techniques within Web browsers or standalone applications. The success of a 3D simulation depends on object behaviour and the level of interaction. Based on an X3D node concept, object-oriented features, and an event-driven approach, the application is well-suited to the virtual environment. XML is used as the interface definition of nodes and the parameters of their behaviour characteristics. Automated nodes and code generation of a dynamic XML Schema simplify the implementation. The study of a specific application enables us to highlight the possibilities of the X3D language to model, to visualize, and to change interactive parameters for actions in the warehouse-commissioning process. Key features of X3D are revealed, and new approaches are proposed to achieve a better realistic behaviour inside the virtual warehouse. The information from simulations in the virtual warehouse is directly usable to optimize performance and further operational planning in the warehouse.

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Povzetek

Za razumevanje obnašanja dinamičnih sistemov in verificiranje kreiranih modelov in procesov v časovnih okvirjih je nujna izvedba simulacijskih študij. Čeprav je količina podatkov in časa potrebnega za pripravo simulacij obsežna, 3D simulacije omogočajo bistveno boljši vpogled in razumevanje delovanja sistema. Članek opisuje uporabo 3D animacij za prikaz delovnega toka v skladišču z uporabo standardnih animacijskih tehnik spletnih brskalnikov ali samostojnih aplikacij. Kakovost 3D aplikacij na spletu je odvisna od obnašanja objekta in stopnjo interakcije, ki jo omogoča. Koncept standarda X3D z vozlišči in objektno usmerjenimi funkcijskimi lastnostmi je dobra osnova za simulacijo v virtualnem okolju. Za vmesnik uporabljamo XML in sistem zapisovanja karakteristik vozlišč s parametri pri čemer uporaba dinamična XML Shema poenostavlja izvajanje kode za avtomatsko generiranje vozlišč in njihovega obnašanja. Raziskava in kreiranje specializirane aplikacije nam omogoča prikazati prednosti X3D modela, za vizualizacijo in pripravo interaktivnih parametrov za spreminjanje funkcij v skladišču med komisioniranjem. Izpostavljene so glavne značilnosti in predlagan nov pristop za doseganje višjega nivoja realističnosti prikaza delovnega toka v virtualnem skladišču. Z simulacijami pridobljene informacije je mogoče neposredno uporabiti za optimiranje procesov v skladišču.

1 INTRODUCTION

The information technology (IT) evolution is currently dominated by the Internet, whose widespread use of technologies and the development of proprietary Web-based 3D formats has resulted in an increased number of 3D-enhanced Web applications. Global and intra-corporate access, platform independence, maintenance minimization, reusability, and interoperability are among the significant aspects and requirements that present challenges for all fields of IT application. The 3D technologies and their availability on consumer platforms are continually growing.

This paper describes the architecture of a new tool addressing the visualization of activities in a warehouse adopting the framework tools developed for sharing of virtual prototypes over the Web with standard programming tools, *[1]*. The framework was further developed for integration of CAD and desktop VR with kinematic mechanism simulation, *[2],* offering wide possibilities of variation via a configuration file in XML format.

The evaluation of activities in a warehouse are time dependent and results in time frame modifications. Consequently, solutions are changed, affecting many parameters. The developed model enables cooperation of a broad set of participants in the process, irrespective of tools used for modelling. This tool gives the opportunity for interactive modifications in configuration from a prescribed set of parameters, including their functionality description. The desktop VR system is used inside a Web browser or as a standalone application visualized with X3D using XML as the interface and configuration data carrier.

In order to share the product or process solutions, a great deal of manual work to transfer the simulation into the virtual environment as a virtual prototype is required. This paper describes the starting research to adopt developed solution for VR assembly and kinematics of models for warehouse activities using the same principle but different parameters, as the goals of the research are different. The architecture of the application addressing the warehouse VP uses standard Web programming tools. The proposed approach enables the cooperation of a broad set of participants in the process, irrespective of tools used for modelling the product.

2 BACKGROUND

3D visualization is becoming increasingly popular for discrete event simulation. However, the 3D visualization of many of the commercial off-the-shelf simulation packages does not reflect the state of the art of the rapidly developing area of computer graphics.

There are several purposes for visualization, which can be categorized as validation, analysis, and marketing, *[3]*. Displaying graphical images of the dynamic behaviour of a model during execution enables the user to discover errors visually. Following the animation of the model as it is running and comparing it with real life operation helps the user to identify discrepancies between the model and the system. Analysis refers to the process of gathering information and drawing conclusions from the simulation. Where statistics can show that a production line is inefficient, visualization can be used to locate the bottlenecks. The third term, marketing, refers to increasing the confidence of people in the provided solution. This means both convincing companies to buy the software and convincing non-engineers of the validity of the result.

Warehouse simulation is the computer-based modelling of a real warehousing system. Simulation enables an organization to analyse and experiment with its warehousing process in a virtual setting, reducing the time and cost requirements associated with physical testing. Storage, docks, conveyors, forklifts and even personnel can quickly be introduced and adjusted within the simulation model, allowing companies the opportunity to determine how to fully utilize their equipment and maximize efficiency. The need for efficiency in industry has never been greater, with personnel, fuel, transportation and material costs continuing to rise. Simulation provides a means of putting a warehouse to the test in a risk-free environment without disturbing the existing warehouse system. It also enables users to determine minimum actual costs without sacrificing the required output.

Regarding object geometry, a variety of excellent modelling and authoring tools and format converters already exist. There are many interesting proprietary Web technologies for building rich 3D content. However, most of them are tailored for specific application domains and limited in producing dynamic 3D scenes. Necessary behaviour extensions are not easily accomplished. Script languages are essentially the only way to achieve applications with complex behaviour. VRML as the standard for 3D graphics on the Web and its successor X3D, *[4]*, offer greater flexibility with inbuilt behaviour related nodes, script nodes, and extensibility mechanisms. X3D is an ISO-ratified open standards file format with run-time architecture to represent and communicate 3D scenes and objects using XML. It provides a system for the storage, retrieval, and playback of real-time graphics content embedded in applications, all within an open architecture. X3D has a rich set of componentized features that can be tailored for use in engineering visualization, training, and simulation.

XML is a public, neutral format that can be used in Web applications with the ability to separate the content and the form of data. XML is an attractive choice as the representation language because the parsers are easy to obtain, and it two specific characteristics : being well suited for data exchange over the Web, and for the creation of user interfaces in various formats. An XML file is a hierarchically structured document in which the objects are denoted by tags containing plain data or additional objects or combinations of both. Attributes are name-value pairs that occur inside tags after the object name. The properly nested objects define the hierarchical structure and may contain references. With a DOM parser, it is possible to read the input file in XML, check formatting and semantic validity, as well as build and present a complex hierarchical object structure with few lines of code.

VP techniques require significant computing power to provide basic requirements, as viewing and interactions with real-time response. The problems of global cooperation over the Web are reduced with more or less specialized viewers surveyed in *[5]*. In order to integrate the virtual world, heterogeneous data sources should be composed. At the data level, this requires converting and processing different data formats. This part of the process is critical and intensive. The process needs to raise the precision of appearance and illustration, to raise presentation performance, and to reduce information loss. It has to be pointed out that virtual models are tessellated models, because only a polygonal representation allows fast rendering in real time. The VP systems use different dataflow for manipulating virtual models in real time and converting data into the VP format is maintained differently from system to system, mainly depending on the application as discussed in *[6]*. In other words, the conversion is not standardized, and proposals do not exist in this direction, since virtual environments functionalities vary severely in applications. Simulation is the process of designing a model of a real system and conducting experiments with this model in order to understand the behaviour of the real system and/or evaluate various strategies for the operation of the system, [7]. Although the simulation experiment can produce a significant amount of data, the visualization of a simulated system provides a fuller understanding of its behaviour. In the visualization, key elements of the system are represented on the screen by dynamically changing positions as the simulation evolves over time

Large companies lack the time, and small companies lack the resources required to implement the technology and automation needed to compete in the marketplace. Desktop non-immersive VR systems features are far from the possibilities of immersive VR technologies, but a key advantage in desktop systems is that standardized computer techniques could be used.

3 SYSTEM ARCHITECTURE

In this research, the focus is on automatic generation of animation of warehouse activities from CAD system modelling into X3D environment for Web-based distributed environment. The main issue is that the process automatically generates simulation for Web services, and no additional knowledge or work is needed to perform simulations. To investigate and evaluate more than one solution, the change of parameters in provided, which is done in a manner that makes the visualization is a straightforward task.

The applications for simulation software managing problems typically present two conflicting issues. Pure simulation applications are user-friendly, but lack flexibility and accuracy. While simulation languages significantly improve model flexibility and accuracy, ease-of-use is sacrificed. By utilizing a simulation language and limiting the problem domain with a user-friendly interface, both fields could achieve great potential. Using templates is limiting the domain of a typical warehouse layout, and the parameters implied by the input data files. These parameters include a wide range of operational functions for all areas of the warehouse. The warehouse XML model implements many possible parameter combinations. The simulation provides the flexibility needed to accurately develop the warehouse model. The interface associated with the software provides for ease-of-use in setting up scenarios and running the model.

The Web-based framework provides a convenient platform for users to view and evaluate a model. A distributed design system can generate design models in an XML-style feature representation to allow a Web-based system to perform viewing and manipulation, leading to two main features:

- Taking advantages of the effective utilizations of the Web and Java technologies makes the system independent of the operating system, scalable and service-oriented. The services located on the Internet provide an accessible way for the evaluation of warehouse activities.
- The configuration file represents an integrator with the definition suitable for X3D presentation.

An XML-style representation has been used to carry out some features for visualization and manipulations in the Web-based system. This format incorporates the characteristics of X3D and features to support Web applications. The XML-based information representation enables the system to be effectively adaptable to meet new developments in the Internet technology. The system and services are based on the Java-Servlet mechanism. With the development of some new Internet integration technologies, such as the Web service, it is necessary to explore new alternatives to integrate the current functions under the new system infrastructure.

All geometrical information, complete warehouse model with the configuration of walls and shelves is extracted from the CAD system with macro programming using the system's programming interface. X3D models generated directly from CAD systems, in general, are composed of many nested, complex and repeated structures. To accelerate the rendering performance of a system, global optimization of polygonal data is necessary. The application was coded to rearrange and optimize the X3D model; the geometry of parts is separated from appearance and additional information, such as view, background and navigation definitions. All data is stored in files. Since the direct translation from CAD systems into X3D models differ significantly, an individual interface is needed for every modelling system. Generally, the modelling systems offer only VRML record and translation from VRML to X3D is necessary. The macro program was coded to perform all needed actions: generate the hierarchical structure in XML, separation of geometry and appearances of parts, combine separated surfaces of the part into a single geometry file including optimization of geometry data. The optimization of the geometry data uses adopted algorithm described in *[8]* based on removing nodes, and performing triangular mesh decimation and undecimation. The optimization of data is necessary caused by the huge amount of data from modelling systems needing to be reduced for working on Internet applications.

The properly nested objects define the hierarchical structure and may contain references. With the DOM parser, it is possible to read the input file in XML, check formatting and semantic validity, built and present a complex hierarchical object structure with few lines of code. The configuration file represents an integrator with the definition suitable for X3D presentation. The semantic of the configuration file is following the X3D specifications and syntax. The basic object is defined, which could be a part, a grouping element or an element enabling multiple choices of objects at the same level. The structure of configuration file is described in *[1]*. A basic approach to recording the geometry specifications and added specifications for dynamic simulations is shown here.

The XML configuration file is built from Excel data sheets, which are commonly used in describing warehouse activities, with all necessary data for parameters to define each simulation scenario. We plan to develop a built-in editor that will allow easy changes of parameters after every simulation run defining the new scenario. For now, the change of time is considered, as are the start time of different activities, manipulation times, moving velocity, etc.

When all the structure is completed, the macro program proceeds to simulation information. The macro appends to the configuration file the object definition of activity data with prescribed parameters with time frames. The macro allows the user to input the number of steps for interpolation of the motion (default value is 10). More steps result in smoother simulation and higher amount of data. The first line example could be seen in Figure 2.

```
Path.1 loLim=0 upLim=25 keynum=10
[1,0,0,0,1,0,0,0,1,0,0,0]
[0.999,-0.039,-0.002,0.039,0.995,0.097,-0.002,-0.097,0.995,-1.743,1.084,-4.287]
[0.997,-0.078,-0.008,0.078,0.978,0.193,-0.008,-0.193,0.981,-3.434,2.646,-8.445]
[0.993,-0.116,-0.017,0.116,0.951,0.286,-0.017,-0.286,0.958,-5.055,4.668,-12.429]
[0.988,-0.153,-0.03,0.153,0.914,0.377,-0.03,-0.377,0.926,-6.587,7.129,-16.196]
[0.981,-0.188,-0.047,0.188,0.866,0.463,-0.047,-0.463,0.885,-8.013,10.002,-19.703]
[0.973,-0.221,-0.067,0.221,0.809,0.544,-0.067,-0.544,0.836,-9.319,13.254,-22.914]
[0.964,-0.252,-0.09,0.252,0.743,0.62,-0.09,-0.62,0.78,-10.489,16.851,-25.792]
[0.953,-0.28,-0.115,0.28,0.669,0.688,-0.115,-0.688,0.716,-11.511,20.753,-28.305]
[0.941,-0.305,-0.144,0.305,0.588,0.749,-0.144,-0.749,0.646,-12.374,24.918,-30.427]
[0.929,-0.326,-0.174,0.326,0.5,0.802,-0.174,-0.802,0.571,-13.069,29.299,-32.135]
```

Figure 1: *Example of the file with interpolation data*

```
<TimeSensor DEF='TS_Path_1' cycleInterval='10' loop='false'/>
<PositionInterpolator DEF='PIvrti_1' key='0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1'
 keyValue='0 0 0,-1.743 1.084 -4.287,-3.434 2.646 -8.445, -5.055 4.668 -12.429,-6.587 7.129 -16.196, -8.013 10.002 -19.703, -9.319
13.254 -22.914,-10.489 16.851 -25.792,-11.511 20.753 -28.305, -12.374 24.918 -30.427,-13.069 29.299 -32.135'/>
<ROUTE fromNode='TS_Path_1' fromField='touchTime' toNode='Mech1Cmd1' toField='startTime'/>
<ROUTE fromNode='Mech1Cmd1' fromField='fraction_changed' toNode='PIvrti_1' toField='set_fraction'/>
<ROUTE fromNode='PIvrti_1' fromField='value_changed' toNode='vrti_1' toField='translation'/>
```

Figure 2: *Generated interpolators and route definitions from Figure 1*

Finally, the configuration file is finished and, at the end of the main object, the routing definitions are included.

These preparations were firstly done manually with much tedious and time-consuming work, but when all objects and scripts are prepared, the task is not so complicated if the configuration file structure is obeyed. To increase the efficiency of data preparation, the editor will be developed to manipulate parameters in configuration file more interactively. The extended database consists of geometry, simulation definitions, and the configuration file that keeps the structure of the product with attributes.

All the data are organized in files: geometry description, sensors, routing definitions, scripting nodes, interpolation data and material appearances with colours, textures, sounds, etc. The objects are represented by attribute pairs; the attribute name refers to the purpose, and the attribute value refers to the name of the file, which contains appropriate description to be included.

The simulation run is triggered by a start button to start the simulation in the browser window. During the simulation run, a full 3D animation of the warehouse scenario is shown from different viewing angles. This application provides input capabilities for setting up a number of customer scenarios and provides 3D graphical output for each. Because the application is developed to handle input parameter combinations simultaneously , the user does not need to edit or compile the model code. Scenarios can quickly be set up and run to get comparative results and see what would likely happen in the real warehouse. When the simulation has completed running the defined scenario and the scenario is positively evaluated the XML file could be used to update the Excel data sheet. The scenario is presented in Figure 3 as snapshots.

4 CONCLUSIONS

The previous decade has seen the increasing use of computer technology for prototyping engineering designs and processes before manufacture or deployment. Providing the means of representing these systems as software programs enable multiple simulations to be run based on various inputs to the system. This methodology represents opportunities for the simulation engineer, such as the ability to vary system parameters or environmental inputs to reflect possible scenarios, and to do so exhaustively. Early verification through simulations minimizes the risk inherent in the design process by reducing the probability of discovering errors late in the development process. In engineering, the visualization of processes are of crucial importance. The use of simulation studies to better understand the dynamic behaviour of a system under investigation is at the core of verifying models early in the development process. Despite the amount of data that such studies produce, a 3D representation of the system creates a fuller understanding of system behaviour. The costs involved in virtual prototyping are inherently lower than doing a similar test on real objects. As an alternative for 2D simulations, more computer techniques are incorporated for visualizing and testing the functionality of the objects in the 3D world. Usage of standard Web-based technologies leads to easier, effective and more general applications suitable for small and medium-sized companies with limited resources in that field of research. Our approach is showing how Web application could be used to transfer models with structural and behaviour features directly to Web environment for evaluation. The use of single XML file covering the various configurations is found to be very suitable for versatile downstream applications.

Future work is focused on implementing the possibility for the user to add alternative partial solutions directly into the model, as fully defined sub-objects on a remote location. We will further investigate the possibilities to optimize the loading time in order to share the behavioural simulation via Web without the tedious extra work of preparing virtual prototypes for a particular solution.

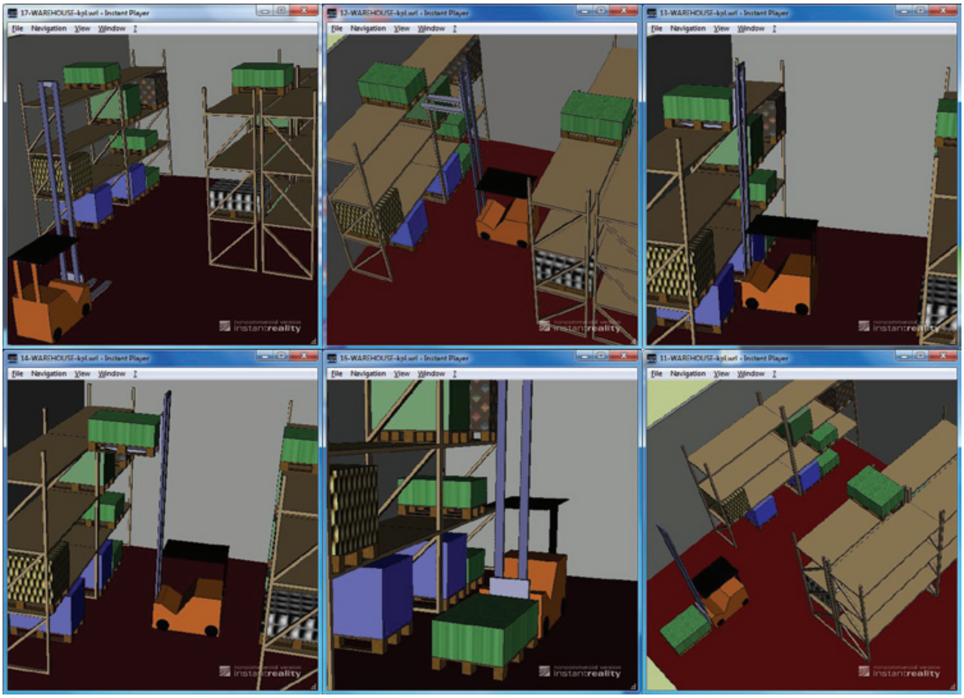

Figure 3: *Snapshots of simulation in warehouse*

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References

[1] **N. Surname:** Title, Publisher or Journal Title, Vol., Iss., p.p., Year of Publication

Examples:

[2] **J. Usenik:** Mathematical model of the power supply system control, Journal of Energy Technology, Vol. 2, Iss. 3, p.p. 29 – 46, 2009

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Nomenclature

(Symbols)	(Symbol meaning)
t	time

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