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DRAFT - EVALUATION OF THE CONSERVATISM OF NPP SAFETY ANALYSIS DOSE CALCULATIONS AS TYPICAL FOR LICENSING PURPOSES

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ABSTRACT

Providing a reliable upper limit of radiological consequences to the plant personnel and the general public is typically the aim of a safety evaluation for anticipated operational occurrences or design basis accidents, as presented in a safety analysis report. A typical tool for dispersion calculation and dose evaluation is MACCS2.

In the present analysis four types of calculations are presented: a first calculation, typical for licensing analysis, with the MACCS2 computer code. In a second step conservative assumptions e.g. ground release even if a stack release would be realistic, are dropped. In a third step calculation two is repeated with RODOS, a code (online decision making tool) used to predict the radiological consequences of an accidental release of activity. The step three calculation still contains all the conservative assumptions that are built in the MACCS2 code. In a last step these assumptions are removed, and a "best estimate" calculation on the dose to the public is performed. The whole analysis (step one to four) is repeated for different source terms (noble gases only, tritium dominated, primary system water ...) and for different weather conditions.

Two main conclusions can be drawn. The first by comparing step two (MACCS2) and step three (RODOS). Here the boundary conditions of the calculations are set to be as similar to each other as possible. The paper shows that despite the fact that MACCS2 uses a Gaussian plume model, while RODOS uses a puff model for dispersion calculation, doses of the same order of magnitude are calculated. For the second conclusion the step one (MACCS2, conservative) and step four (RODOS, best estimate) calculations are compared, it is shown that although the margin of conservatism varies considerably from case to case, the results differ at least one order of magnitude.

ABBREVIATIONS AND NOMENCLATURE

MACCS	MELCOR Accident Consequence Code System
RODOS	Real-time On-line Decision Support system
RG	Regulatory Guide
TEDE	Total Effective Dose Equivalent
χ/Q	Air concentration [Bq/m3] / source term release rate [Bq/s]
ATMOS	Atmospheric transport and deposition
EARLY	Emergency phase calculations
QUICKPRO	Quick prognosis module
ATSTEP	Atmospheric dispersion, deposition, gamma radiation and doses
PHWR	Pressurized Heavy Water Reactor
CNA	Central Nuclear Atucha

1. INTRODUCTION

The process of licensing may vary from country to country. Regarding to assessment of radiological consequences though basically conservative approaches are chosen, as introduced e.g. in [1].

The models used for these purposes are static models, mostly based on the Gaussian plume model, which was introduced in US licensing in [2]. It assumes a release that is continuous, constant, and of sufficient duration to establish a representative mean concentration. The results are not time dependent and take into account horizontal and vertical broadening of a radioactive plume, but no longitudinal change. Gauss models require low computation power and are used e.g. in the codes ARCON, PAVAN and MACCS.

Newer atmospheric dispersion models assume time dependence of the plume (dynamic models). Thereby changes in the weather conditions during and after the release can be modeled (e.g. real time or prognostic weather data from a meteorological service can be used). In these models releases are usually handled as puffs of pollutants released at every selected timestep.

The target of this paper is to evaluate differences of the codes MACCS2, which uses a Gaussian plume model, and RODOS6, which uses a puff model, and their resulting doses. Especially MACCS2 is used for licensing applications, while RODOS6 aims to give a realistic prognosis of the consequences of a radioactive release. By comparing the results of the two codes, while using the same boundary and initial conditions, one can evaluate the conservatisms of typical regulatory procedures.

2. MODELS AND CALCULATION ASSUMPTIONS

The MACCS2 manual [3] states that MACCS2 is a code for estimating the health and economic consequences of severe accidents. It consists of three modules, which calculate atmospheric transport and deposition under time-variant meteorology, short- and long-term mitigative actions and exposure pathways, deterministic and stochastic health effects, and economic costs.

For the purpose of evaluating the TEDE only two modules are needed.

The ATMOS-module (atmospheric transport and deposition) utilizes the Gaussian plume model to determine χ/Q values, based on an input of the source term, release characteristics and deposition behaviour

The χ/Q values are employed by the EARLY-module (emergency phase dose calculations) to calculate doses, accounting for dose conversion factors, sheltering factors and breathing rates.

RODOS is a Real-time On-line Decision Support system for off-site emergency management in case of a radiological release. Models and data bases can be customised to different site and plant characteristics and to the geographical, climatic and environmental variations. RODOS performs its calculation either with incoming online meteorological data and prognosticated meteorological fields or user defined meteorological information. All input and output of RODOS is provided via a graphical user interface.

The calculations for this paper were performed with QUICKPRO. This RODOS module allows for calculations with limited input parameters without the need of geographical data. QUICKPRO utilizes the Gaussian puff model ATSTEP, which was designed for calculation up to distances of 50km [4]. Within this model time-integrated elongated puffs are released at each timestep (10, 30 or 60 min). The puffs are transported in inhomogeneous, variable windfields and – other than in standard Gauss models – allow for longitudinal diffusion. The calculations results are applied to a user defined grid with a minimum possible resolution of 100m x 100m for one grid cell. Radioactive decay, the build-up of daughter nuclides, wet and dry deposition are always accounted for, if applicable.

With the two programs four different calculations were performed – 2 with MACCS2 and 2 with RODOS – and the total equivalent dose was determined. This was repeated for 4 source terms and 3 different weather conditions. Due to the necessity of changing the grid size in RODOS for distances bigger than 17 km, a total of 72 calculations were done.

2.1 Calculation types

A) MACCS2 – A

This calculation represents the most conservative calculation and contains boundary conditions as typically used in licensing procedures. These comprise e.g. a ground release (even though the release is might not be at ground level), no depletion of the radioactive plume through deposition. Furthermore no credit for building wake effects was given.

B) MACCS2 – B

The second calculation targets for a more realistic calculation, so two conservative assumptions were dropped. Firstly the point of release was elevated to a stack at a height of 40m. Secondly deposition was turned on. Deposition velocities of 0.005 m/s for tritiated water vapour, and 0.01 m/s for aerosols, assuming unfiltered releases, were selected [5].

C) RODOS – C

The first RODOS calculation was aiming to keep the boundary conditions as close as possible to the second MACCS2 calculation (B). For that reason initial conditions, containing an elevated release at 40m and deposition, were chosen the same. Deposition velocities are hard-coded within the RODOS program and can therefore not be influenced. By comparing calculations B and C, the difference stemming from the different code models can be seen.

D) RODOS – D

This calculation contains the most realistic assumptions. Additionally to the RODOS – C assumptions more information on the point of release were supplied. A stack flux of $70m^3/s$, a stack diameter of $10m^2$ and building wake were implemented. Furthermore a different distribution of the molecules containing tritium, and a more realistic distribution of iodine in elemental, organic, and aerosol has been assumed (see 2.2).

2.2 Source terms

To provide comparability for different isotope compositions four different source terms typical for a PHWR were selected. The choice was based on accident scenarios from the CNA2 Final Safety Analysis Report and comprises two releases from the auxiliary systems, one from the fuel pool and one consisting of primary side water. The nuclides of relevance were selected according to [6].

1) Noble Gases

A source term consisting only of noble gases is expected to occur due to leakage from the gaseous waste removal system. A selection of Krypton and Xenon isotopes was made resulting in a release of 6.1×10^{14} Bq altogether.

2) Tritium

Due to its importance in heavy water reactors a tritium source term was handled separately. A Tritium release of 10^{15} Bq was assumed, which corresponds to the activity content of 100kg of liquid contained in the Tritium removal system. For the RODOS calculations 10^{15} Bq of tritiated water was released in calculation C and 9.9×10^{14} Bq tritiated water plus 10^{13} Bq of T_2 for calculation D.

3) Primary side water

The primary side water source term consists of Co, Kr, Sr, Y, Zr, I, Xe and Cs isotopes contained in 10 m³ of primary side water. Due to the dominance of tritium in the reactor coolant it was omitted from this source term and is handled separately.

The iodine fractions were chosen as 4.85% elemental, .15% organic and 95% aerosol according to [1]. For RODOS calculation D this composition was changed to 2.8% elemental, 0.4% organic and 96.8% aerosol [7].

4) Fuel Handling Accident

The last source term covers a typical fuel handling accident and is composed of krypton, xenon and iodine isotopes. As recommended in [1] the iodine fractions were chosen to be 57% elemental and 43% organic for all calculations.

2.3 Meteorological Conditions

In the MACCS2 code there is no change in wind direction and speed intended. Therefore – to provide comparability of results – three fixed weather conditions were used for the calculations. Based on a wind direction of 180° and no precipitation for the entire calculation time span, only the wind speed and the Pasquill stability class were changed as follows:

I	Windspeed 0.5m/s, Stability F
II	Windspeed 1.0m/s, Stability D
III	Windspeed 5.0m/s, Stability C

2.4 Initial Conditions and other assumptions

Aside from source term and weather several other assumptions were made to achieve comparable results. In some cases an exact compliance is impossible due to code restrictions (also noted in the following list).

Distances

There were 4 distances chosen for the calculations: 1km, 10km, 20km and 50km. While the MACCS2 text output allows direct readout, the RODOS results were determined by hand from the graphical results. There was always the same grid element at the respective distance used.

Calculation duration

All MACCS2 results represent 24 hour dose contributions. RODOS calculations were performed for 24 hours for low wind speeds. To optimize calculation time high windspeed calculations were only done for 6 hours, neglecting groundshine for the remaining hours up to one day. This seems viable due to the low contribution of groundshine to the total dose (max. 2%).

Release duration

Release duration of one hour was used for all calculations.

Dispersion parameters

In MACCS2 the Briggs Open Country tables were used for calculation, whereas the Mol-SCK-CEN parameters were used in RODOS.

Plume heat

No thermal heat content was assumed to be present in any source term or calculation. Therefore plume rise was not considered

Wake

As stated before no wake was accounted for in calculations A – C. Nevertheless a minimum wake size exists in both programs; 0.1m x 0.1m in MACCS2 and 1m x 1m in RODOS.

Breathing rates

All MACCS results were calculated for a breathing rate of 3.5E-4 m³/s, whereas the RODOS breathing rates are hard-coded within the program.

3. RESULTS

The 72 calculations resulted in 174 dose values, which can be found in Table 1. At a speed of 0.5 m/s a plume would travel 43 km. Therefore although the static model would provide results at 50km, no results are presented.

A graphical presentation of the most relevant results – the difference between the conservative MACCS and realistic RODOS calculation – is provided in Figures 1 to 4. The red

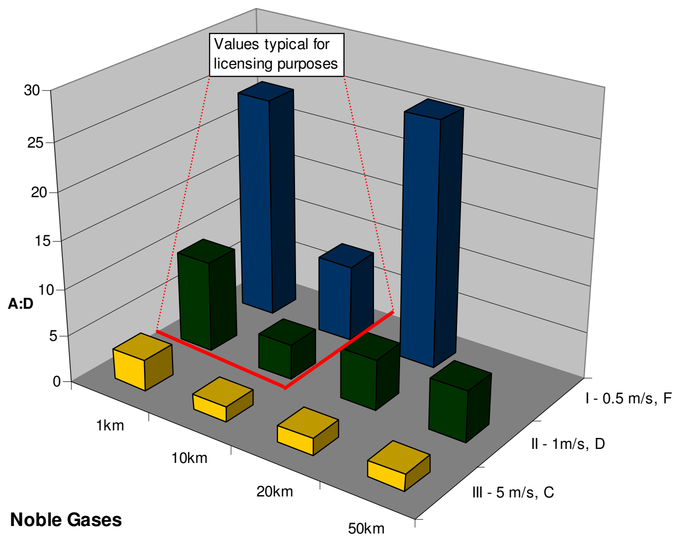

Fig. 1: Comparison of conservative and realistic results for noble gases

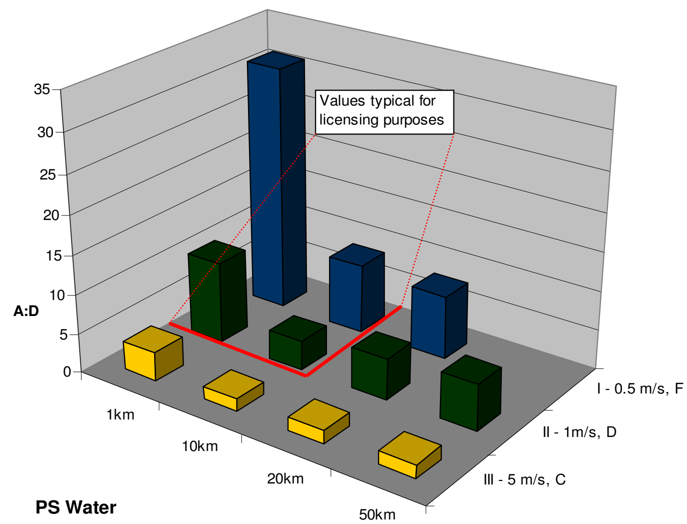

Fig. 3: Comparison of conservative and realistic results for a release of primary side water

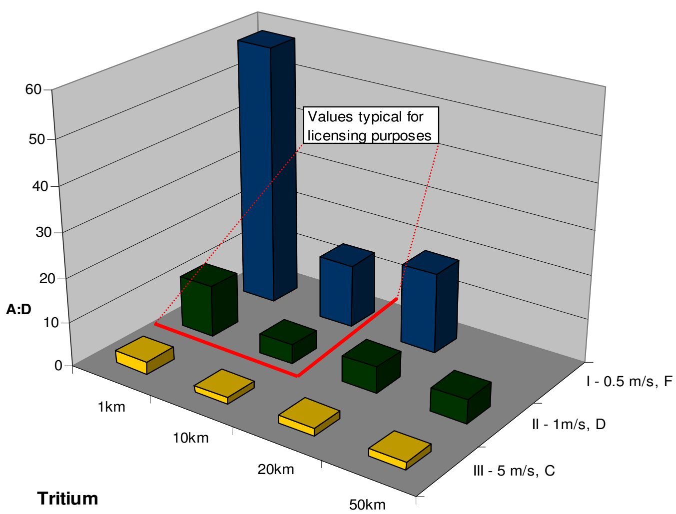

Fig. 2: Comparison of conservative and realistic results for tritium

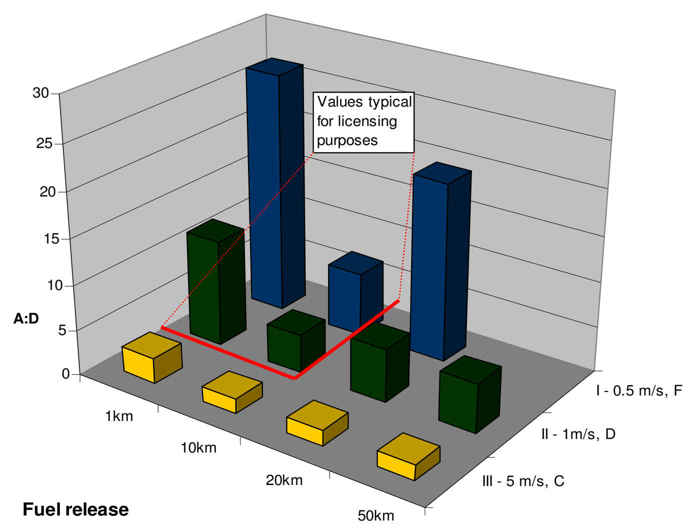

Fig. 4: Comparison of conservative and realistic results for a release due to a fuel handling accident

lines in the back outline the values as they are typically used in licensing procedures; low wind speeds and distances up to 10 km.

4. CONCLUSIONS

Overall observations

As a general trend it can be observed, that the results converge for higher wind speeds and increasing distances. For a windspeed of 5 m/s and a distance grater than 10 km the results for all the source terms can be found within a factor 2.

The lower boundary wind speed of 0.5 m/s on the other hand always shows the highest differences in results.

MACCS2 result comparison

The comparison of MACCS calculations A and B shows that the conservative results almost always ranges over more realistic one, especially at conditions, that are relevant for licensing purposes. Only at high windspeeds and larger differences the elevated release might result in slightly higher doses.

Dose contribution from tritium shows the highest decrease through release elevation and deposition. A factor of almost 200 between calculation A and B at 0.5m/s wind speed, results in the only MACCS dose lying below a RODOS dose.

RODOS result comparison

The results of the two RODOS calculations always lie within a factor 2 of each other. While the dose reduction through wake is clearly visible at short range, this turns at higher distances resulting in slightly higher doses for calculation D.

Comparison of MACCS B and RODOS C

The results MACCS B and RODOS C correspond surprisingly well, always lying well within an order of magnitude, mostly within a factor of 2.

This comparison shows that doses in RODOS decrease faster with increasing distance. This effect is especially strong for source terms containing a big amount of noble gases, which seem to be handled quite differently in respect to their dose contribution within the two Programs. Consistent with the approximation of results at higher windspeeds, the effect is stronger for lower windspeeds. The effect results in a decrease of ratios of the results at the beginning, followed by an increase for after 10 km.

Comparison of conservative MACCS A and realistic RODOS D results

This comparison shows considerable differences for the resulting doses in the licensing domain. For low windspeeds the difference is at least a factor 23 (with a maximum of a factor 60 for tritium) at 1km and consistently larger than a factor 7 at 10km.

The effect of ratios first decreasing and then increasing again, as mentioned before, can also be observed and can be identified in the figures.

The analysis shows that for simple constant weather conditions a Gaussian plume model and a puff model, applied for the ranges they are thought for, produce comparable results (the B-C comparison). This confirms that the models work as expected.

The A-D comparison, the comparison between a calculation which would be typical for licensing, and a calculation that produces the most realistic results, shows that there are significant differences (of a factor 7-60). This shows that a typical licensing calculation adds a confident margin to a resilient upper bound

REFERENCES

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[2] RG 1.4 - Assumptions used for Evaluating The Potential Radiological Consequences of a Loss of Coolant Accident For Pressurized Water Reactors, USNRC, 1974

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[5] DOE-EH- 4.2.1.4 - “MACCS2 Computer Code Application Guidance for Documented Safety Analysis”, DoE June 2004

[6] NUREG/CR-4467 / SAND85-2575 – “Relative Importance of Individual Elements to Reactor Accident Consequences Assuming Equal Release Fractions”, 1986

[7] NUREG/CR-5732, “Iodine Chemical Forms in LWR Severe Accidents”, USNRC, 1992

Table 1: Calculation results [Sv]

Source Term	Weather	Calculation	1km	10km	20km	50km
1 - NG	I	A-MACCS	5.78E-04	4.45E-05	1.92E-05	
		B-MACCS	1.40E-04	2.22E-05	1.07E-05	
		C-RODOS	5.18E-05	5.93E-06	8.20E-07	
		D-RODOS	2.45E-05	5.45E-06	7.35E-07	
		B:C/A:D	**2.70/23.59**	**3.74/8.17**	**13.05/26.12**	
	II	A-MACCS	1.12E-04	5.82E-06	1.99E-06	4.74E-07
		B-MACCS	4.86E-05	5.18E-06	1.87E-06	4.59E-07
		C-RODOS	2.71E-05	1.48E-06	3.46E-07	8.05E-08
		D-RODOS	1.16E-05	1.57E-06	3.73E-07	8.77E-08
		B:C/A:D	**1.79/9.66**	**3.50/3.71**	**5.40/5.34**	**5.70/5.40**
	III	A-MACCS	1.22E-05	4.29E-07	1.66E-07	6.37E-08
		B-MACCS	8.08E-06	4.16E-07	1.63E-07	6.32E-08
		C-RODOS	4.79E-06	2.54E-07	8.90E-08	3.42E-08
		D-RODOS	3.69E-06	2.63E-07	9.24E-08	3.57E-08
		B:C/A:D	**1.69/3.31**	**1.64/1.63**	**1.83/1.80**	**1.85/1.78**
2 - T	I	A-MACCS	7.49E-03	2.92E-04	6.30E-05	
		B-MACCS	3.93E-05	7.46E-05	1.26E-05	
		C-RODOS	2.72E-04	2.26E-05	3.51E-06	
		D-RODOS	1.28E-04	2.05E-05	3.47E-06	
		B:C/A:D	**0.14/58.52**	**3.30/14.24**	**3.59/18.16**	
	II	A-MACCS	6.51E-04	2.18E-05	9.12E-06	3.05E-06
		B-MACCS	3.65E-04	1.46E-05	5.01E-06	1.11E-06
		C-RODOS	1.52E-04	4.71E-06	1.36E-06	4.91E-07
		D-RODOS	5.56E-05	5.12E-06	1.56E-06	5.66E-07
		B:C/A:D	**2.40/11.71**	**3.10/4.26**	**3.68/5.85**	**2.26/5.39**
	III	A-MACCS	4.97E-05	1.05E-06	4.27E-07	2.02E-07
		B-MACCS	4.23E-05	1.01E-06	4.05E-07	1.87E-07
		C-RODOS	2.28E-05	6.40E-07	2.39E-07	1.13E-07
		D-RODOS	1.76E-05	6.58E-07	2.48E-07	1.20E-07
		B:C/A:D	**1.86/2.28**	**1.58/1.60**	**1.69/1.72**	**1.65/1.68**
3 - PS	I	A-MACCS	1.84E-05	7.52E-07	7.01E-08	
		B-MACCS	2.67E-06	2.69E-07	5.35E-08	
		C-RODOS	1.19E-06	8.72E-08	7.74E-09	
		D-RODOS	5.88E-07	8.54E-08	8.58E-09	
		B:C/A:D	**2.24/31.29**	**3.08/8.81**	**6.91/8.17**	
	II	A-MACCS	2.81E-06	1.07E-07	2.98E-08	4.60E-09
		B-MACCS	1.42E-06	8.85E-08	2.28E-08	2.03E-09
		C-RODOS	6.44E-07	2.72E-08	5.45E-09	7.55E-10
		D-RODOS	2.70E-07	2.87E-08	5.71E-09	7.79E-10
		B:C/A:D	**2.20/10.41**	**3.25/3.73**	**4.18/5.22**	**2.69/5.91**
	III	A-MACCS	2.91E-07	9.09E-09	3.36E-09	1.13E-09
		B-MACCS	2.16E-07	9.08E-09	3.38E-09	1.14E-09
		C-RODOS	1.13E-07	5.41E-09	1.83E-09	6.34E-10
		D-RODOS	7.91E-08	5.57E-09	1.90E-09	6.54E-10
		B:C/A:D	**1.91/3.68**	**1.68/1.63**	**1.85/1.77**	**1.80/1.73**
4 - Fuel	I	A-MACCS	9.89E-03	3.96E-04	1.31E-04	
		B-MACCS	1.34E-03	1.37E-04	2.96E-05	
		C-RODOS	6.89E-04	5.85E-05	6.57E-06	
		D-RODOS	3.71E-04	5.67E-05	6.66E-06	
		B:C/A:D	**1.94/26.66**	**2.34/6.98**	**4.51/19.67**	
	II	A-MACCS	1.47E-03	5.47E-05	1.55E-05	2.61E-06
		B-MACCS	7.77E-04	4.50E-05	1.16E-05	1.21E-06
		C-RODOS	3.70E-04	1.68E-05	3.61E-06	6.86E-07
		D-RODOS	1.53E-04	1.79E-05	3.82E-06	7.40E-07
		B:C/A:D	**2.10/9.61**	**2.68/3.06**	**3.21/4.06**	**1.76/3.53**
	III	A-MACCS	1.50E-04	4.63E-06	1.71E-06	5.78E-07
		B-MACCS	1.16E-04	4.70E-06	1.74E-06	5.89E-07
		C-RODOS	6.17E-05	2.95E-06	1.06E-06	3.80E-07
		D-RODOS	4.79E-05	3.07E-06	1.11E-06	4.06E-07
		B:C/A:D	**1.88/3.13**	**1.59/1.51**	**1.64/1.54**	**1.55/1.42**