Appendix O
REFLECTION

The scope and objectives refer to reflection. Both IRSN and EMS have studied and reported influences of different reflecting materials, alone or in combination. There are also many ICSBEP Handbook benchmarks with different reflectors.

The EMS results [30, 95] have been obtained for all fissionable nuclides. The purpose was to find the most efficient reflector combination for each nuclide. The combinations were water alone, steel alone, lead alone, 1.5 cm water plus lead and 1.5 cm water plus steel. In addition, natural uranium alone and 3 cm water plus natural uranium replacing the reflector material were calculated (natural uranium in this application is a fissile material, not a reflector). It was found that a thin layer of water, usually together with steel but sometimes with lead, reduced the minimum critical values for fissile nuclides. For non-fissile nuclides, only steel or only lead were more efficient. It was also found that lead became a better reflector than steel for large units and for arrays while steel was more efficient for small units. This was also found in an independent study by IRSN.

The IRSN results [41] for hydrated nitrates are directly of interest for this study since they cover some of the fissionable materials and the same reference parameters as the study. The corresponding reference values are also included in [59]. IRSN found a similar optimum as EMS for a water-layer of about 1.5 cm between the fissile material and a lead reflector, figures A.38 and A.39 in [41]. There are benchmarks based on critical experiments that can be used to verify the combined effect of a thin water layer between fissile material and lead.

The influence of concrete and lead on the reference parameters are shown in Tables O1 and O2. Note that the composition of concrete can vary a lot.

The values are not interpolated; the nearest calculation value was selected. In particular for spheres (mass and volume parameters), the interpolation may be difficult. The Rombough equation [96] is very useful for interpolation of these parameters, see Appendix Q.

The general importance of considering other reflector materials than water is evident from preliminary IRSN and EMS evaluations. The effect of moderation in the reflector (concrete) can be seen for the non-moderated systems. In these cases concrete is a better reflector than lead. However, the combination of a thin water layer and lead, as discussed in some IRSN and EMS reports and has been familiar to criticality safety specialists at least for 40 years, would give even smaller critical parameter values. This is different than the combination of lead and outside water reflection often used in France.

Table O1. CRISTAL – UNH with different reflector materials

CRISTAL – Reference values for different reflector materials						
System	Isotopes	Mass (kg)	Volume (l)	Cylinder (cm)	Slab (cm)	Conc. (g/l)
UNH + 20 cm water	100	0.81	6.54	14.88	5.4	12
	20	5.92	16.03	20.92	9.18	65
	5	75.38	80.48	37.82	20.04	137
	4	144.2	134.92	45.18	24.98	415
	3	464.9	365.5	64.62	37.4	624
UNH+ 60 cm concrete	100	0.71	5.77	13.1	2.7	
	20	5.17	13.82	18.58	5.74	
	5	64.09	67.38	34.04	15.08	
	4	122.69	113.23	41.2	19.58	
	3	399.88	312.15	59.56	31.42	
UNH + 25 cm Pb + 20 cm water	100	0.58	5.09	11.98	2.3	
	20	4.17	11.56	16.54	4.14	
	5	49.97	53.25	29.64	10.46	
	4	95.37	88.61	35.88	13.8	
	3	313.2	244.1	52.28	23.32	

Table O2. CRISTAL – PuNH with different reflector materials

CRISTAL – Reference values for different reflector materials						
System	Isotopes	Mass (kg)	Volume (l)	Cylinder (cm)	Slab (cm)	Conc (g/l)
PuNH + 20 cm water	100/0/0/0	0.51	7.57	15.66	5.84	7.2
	95/5/0/0	0.63	10.74	17.94	7.24	7.8
	80/10/10/0	0.71	12.06	18.74	7.7	8.07
	90/10/0/0	0.77	13.29	19.46	8.18	8.47
	80/15/5/0	0.89	15.24	20.48	8.83	9.1
	71/17/11/1	0.92	15.6	20.66	8.9	9.2
PuNH+ 60 cm concrete	100/0/0/0	0.45	6.42	13.6	2.96	
	71/17/11/1	0.78	13	18.02	5.16	
PuNH + 25 cm Pb 20 cm H_2O	100/0/0/0	0.36	5.6	12.32	2.35	
	71/17/11/1	0.62	10.73	15.9	3.68	