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ATMOSPHERIC DISPERSION MODELING OF BASIS-DESIGN ACCIDENT (LOCA) AND RADIOACTIVE DOSE ASSESSMENT OF TWO PROPOSED SITES FOR NUCLEAR POWER PLANT IN TUNISIA

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Abstract— The demand for energy is constantly increasing and nuclear power remains an important option for many countries to provide energy for development and fight climate change. In Tunisia, two sites are preselected for Nuclear Power Plant (NPP) implantation: Marsa-Dhouiba site in the far north of the country and Skhira site in the South-East. Estimating of health effects on humans (population and workers) following the accidental release of radioactive gaseous materials into the air from a Nuclear Power Plant is essential for the safety and environmental analyses that are needed for reactor licensing. So, the early offsite consequences of severe accident should be assessed before construction of proposed NPP for many purposes, such as site evaluation of NPP, evaluation of the exclusion area and low population zone. Also, the emergency plan must be evaluated to define the mitigation actions. These actions may be represented by sheltering, evacuation, distribution of stable iodine tablets and/or relocation and where these actions should take place after the nuclear accident especially in the downwind sectors to decrease the consequences of accident. The hypothetical scenario considered in this paper is a design-basis accident, loss of coolant accident. The RASCAL code was applied to evaluate the health effects and define the protective actions in the event of a nuclear accident for both sites. The health effects can be treated as two important dosimetric parameters: the total effective dose equivalent (TEDE) around the reactor sites and the thyroid commitment dose equivalent (TCDE). After making an analysis of meteorological parameters for both sites, atmospheric

dispersion modeling is made for each of the four seasons and finally recommendations for immediate protective actions are discussed.

Keywords— Nuclear accidents, Evacuation, Sheltering, Nuclear power plants, Protective action recommendations, LOCA

I. INTRODUCTION

In Tunisia, two sites, shown in Figure 1, are preselected for Nuclear Power Plant (NPP) implantation: Marsa-Dhouiba site in the far north of the country (N3716, E0929) and Skhira site in the South-East (N3415, E1003) in Gabes Gulf. The meteorological data of both sites are taken from stations established in-situ at an altitude of 24 m above sea level and recorded different meteorological conditions.





Fig. 1. Geographic localisation of the two preselected tunisian sites

The Marsa Dhouiba site, located in Kef Abbed region (Bizerte government), is connected to the Mediterranean Sea. The land is vegetative, with a loamy soil. Its climate is mild, damp and temperature average is 22.8 °C. Kef Abbed is a small isolated village on sea frequented by some local fishermen rarely visited and characterized by small population dispersed not more than 1000. The capital Tunis is located about 60 Km from this site in a straight line in the South-East direction.

The Skhira site (Sfax government), located in Gabes gulf, and is also connected to the Mediterranean Sea. The study area is subject to two opposite types of climate action: climate Saharan dry and hot in the southwest and the Mediterranean climate, relatively wet. According to the Tunisian's census of 2014, the Skhira site is a municipality of 34,673 habitants in 2014. The capital Tunis is located about 280 Km from this site in a straight line in the North direction. Table 1 below describes the meteorological stations and the environments of both sites.

Table 1. Meteorological stations position and environments

Site	Lat (°, ')	Long (°, ')	Position	Distance km wind direction	Soil	Vegetation	Aridity
Marsa Dhouiba	3716	0929	Coast	0.450 km NO	light	Fallow + forest	humid
Skhira	3415	1003	Large lowland	1.2 Km/E	medium	Fallow + olive	arid

In the present work, an accidental release scenario will be considered and simulated using RASCAL code. The software use Gaussian Plume Models (GPM) to describe the atmospheric dispersion of radioactive material. In general, GPM is widely used in literature and has been successfully applied to many dispersion problems (Bamdad and Hosseini, 2016; Denglong and Zaoxiao, 2016; Benamrane and Boustras, 2015; Pirouzmand et al. 2015; Timothy, 2013).

Hypothetical accidents release radionuclides are based upon literature review and particularly on NRC's technical reports [US NRC 10 C.F.R. Part 52, "Early Site Permits; Standard Design Certifications; and Combined Licenses for Nuclear Power Plants,"], a typical design-basis Loss Of Coolant Accident (LOCA) is simulated using RASCAL code.

The accidental scenario assumes that the core is maintained uncovered for a period of time (120 mn) leading a significant released activity. The accidental atmospheric dispersion will be modeled by RASCAL software. The results concern primarily two major dosimetric parameters: the Total Effective Dose Equivalent (TEDE) and the Thyroid Commitment Dose Equivalent (TCDE). TEDE and TCDE will be compared to

dose's threshold to be able to undertake the appropriate protections actions recommended by the U.S. Environmental Protection Agency (U.S. EPA, 2013).

II. ATMOSPHERIC DISPERSION MODELING FOLLOWING AN ACCIDENT

We focus on studying atmospheric dispersion following a postulated loss of coolant accident (LOCA) and we assume that nuclear plant's emergency core cooling system (ECCS) no longer exists. The LOCA could be also defined as an uncovered core events accident. This specific accident will be treated with RASCAL software.

In the following sections, we will introduce two main results obtained from RASCAL which are: the Total Effective Dose Equivalent (TEDE) including all possible doses for external and internal exposures received and the Thyroid Committed Dose Equivalent (TCDE). TEDE and TCDE will be, therefore, compared to EPA's limits. In fact during an incident with an uncontrolled source of radiation, protection of the public from unnecessary exposure to radiation may require some form of intervention that will disrupt normal living. Such intervention is termed a protective action (U.S. EPA, 2013). Among protective actions: evacuating an area; sheltering-in-place within a building or protective structure; administering potassium iodide (KI) as a supplemental action; acquiring an alternate source of drinking water; interdiction of food/milk. The following table lists the thresholds for each of these actions (U.S. EPA, 2013).

Table -2 Recommended protective actions for the Early Phase of a Radiological Incident

Actions	Dose thresholds [mSv]	Comments
Sheltering	10	The total dose by external exposure and the committed effective dose for internal exposure during 4 days
Evacuation	50	
Potassium Iodine (KI) admission	50 received on thyroid child by exposure to Iodine	After the approval of a medical team

The Food and Drug Administration (FDA) updated its guidance on the use of KI as a thyroid blocking agent during radiological emergencies in 2001 (U.S.FDA, 2001, 2002). FDA based these dose recommendations on a review of the thyroid cancer data from the Chernobyl reactor accident of April 1986 and the experience of Poland in administering KI following the Chernobyl release (FDA, 2001). FDA recommends the following:

Children 0-18 years of age: Administer KI when the projected radiation dose to the thyroid from exposure to radioiodine is 5 rem (50 mSv) or greater.

Pregnant and lactating women: Administer KI when the projected radiation dose to the thyroid from exposure to radioiodine is 5 rem (50 mSv) or greater.



Adults up to 40 years of age: Administer KI when the projected radiation dose to the thyroid from exposure to radioiodine is 10 rem (100 mSv) or greater.
 Adults over 40 years of age: Administer KI when the projected radiation dose to the thyroid from exposure to radioiodine is over 500 rem in order to prevent hypothyroidism.

II.1. RASCAL description

RASCAL (Radiological Assessment System for Consequence Analysis) is currently used by NRC's emergency operations center for making dose projections for atmospheric releases during radiological emergencies (McGuire et al. 2007). The code is widely used in several recent scientific work of radiological assessment (Bo et al. 2016; Rossi et al. 2014; Benamrane et al. 2013; Muswema et al. 2014, Schmidt, and Ivanov 2012). RASCAL 3.0.5 uses Gaussian models to describe the atmospheric dispersion of radioactive and chemical effluents from nuclear facilities. In the calculation, RASCAL flip between two models: (i) the straight-line Gaussian plume model (Equation 1) used near the release point where travel times are short and plume depletion associated with dry deposition is small and (ii) the Lagrangian-trajectory Gaussian puff model (Equation 2) used at longer distances where temporal or spatial variations in meteorological conditions and depletion of the plume due to dry deposition may be significant.
 RASCAL was chosen to model the accidental atmospheric dispersion, and to compare between the two sites of nuclear safety point of view and finally recommend possible convenient radiological emergencies such as define evacuation and sheltering zones.

II.1.1 Straight-Line Gaussian Plume Models

Puff models represent plumes as a series of puffs. Concentrations at a point in the plume are calculated by adding the concentrations at the point associated with all puffs in the vicinity of the point. The simplified version of the straight-line Gaussian model used in RASCAL is given by:

$$X(x,y,z) / Q' = FyFz / 2\pi u \sigma_y \sigma_z \quad (1)$$

where
 X = average concentration, Q' = release rate, FyFz = lateral and vertical exponential terms, x = downwind distance at which X, σ_x , σ_y and σ_z are evaluated, u = wind speed and t = time.

II.1.2 Gaussian Puff Model

In a Cartesian coordinate system with x and y axes in a horizontal plane and z in the vertical, the normalized concentration in the vicinity of the puff are:

$$X(x,y,z) / Q = (1 / (2\pi)^{3/2} \sigma_x \sigma_y \sigma_z) \exp[-0.5((x-x_0)/\sigma_x)^2] \exp[-0.5((y-y_0)/\sigma_y)^2] \exp[-0.5((z-z_0)/\sigma_z)^2] \quad (2)$$

II.2. Description of Inputs and Scenario of release

First, we define the location of the Nuclear Power Plant based on latitude and longitude of Table 1. Based on maximum allowed capacity of electrical network, Tunisian electrical utility (STEG) recommends a pressurized water reactor with an effective electric power which should not exceed 1000 MWe. Based on these recommendations we have considered that following reactor parameters:

Table -3 Reactor parameters introduced in RASCAL calculations

Reactor power	3300 MW(t)
Average fuel burn-up	22000 MWD / MTU
Containment type	PWR Dry Ambient
Containment volume	2.50E+06 ft ³
Assemblies in core	200
Stream generator type	U-Tube

II.2.1 Straight-Line Gaussian Plume Models

If we specify how long the core is uncovered, RASCAL will estimate how much core damage will occur. Table 4 was taken from Table 3.13 in NUREG-1465 (Soffer et al. 1995.) For example, if a PWR core is uncovered for 15 or 30 minutes, the estimated damage is 50% or 100% cladding failure, respectively.

Table 4. PWR Event Timings and Fraction of Core Activity Inventory Released

Nuclide group	PWR core inventory release fraction*		
	Cladding failure (gap release phase) (0.5 hr)	Core melt phase (in-vessel phase) (1.3 hr)	Post-vessel melt-through phase (ex-vessel phase) (2.0 hr)
Noble gases (Kr, Xe)	0.05	0.95	0
Halogens (I, Br)	0.05	0.35	0.25
Alkali metals (Cs, Rb)	0.05	0.25	0.35
Tellurium group (Te, Sb, Se)	0	0.05	0.25
Barium, strontium (Ba, Sr)	0	0.02	0.1
Noble metals (Ru, Rh, Pd, Mo, Tc, Co)	0	0.0025	0.0025
Cerium group (Ce, Pu, Np)	0	0.0005	0.005
Lanthanides (La, Zr, Nd, Eu, Nb, Pm, Pr, Sm, Y, Cm, Am)	0	0.0002	0.005

*Reference: (Table 3.13 de NUREG-1465 (Soffer et al. 1995)
 To assess the source terms, we choose "time core is uncovered" option in RASCAL to quantify it. A 30m height

containment bypass is used as a release pathway in the calculations. 30 meters is approximately the containment height. At the beginning of the accident, a reactor shutdown occurs and simultaneously the core becomes totally uncovered by loss of coolant and remains uncovered for two hours (120 minutes) which corresponds to a post-vessel melt through phase as mentioned above in third column of Table 4.

II.2.2 Models Meteorological data introduced

Taking into account the analysis of meteorological parameters for both sites, we consider the following meteorological data in our simulations as indicated in Table 5.

Table 5. Activity Inputs used in RASCAL simulations

Site	Season	Prevailing Direction	Wind speed [m/s]	Relative Humidity [%]	Stability class
Marsa-Dhouiba	Autumn	120°	6	70	D
	Winter	270°	6	80	D
	Springer	270°	6	75	D
	Summer	270°	7	60	B
Skhira	Autumn	360°	6	65	C
	Winter	250°	8	60	C
	Springer	90°	8	60	D
	Summer	90°	8	60	C

III. RESULTS AND DISCUSSION

Results are given for each of four seasons where a day was chosen from each season to conduct simulation and in which the accident occurs represents well the meteorological data averaged over the season. Finally the simulation was carried for worst release. Cumulative TEDE and TCDE are given for 30 hours after the beginning of the release which is a sufficient period to undertake protective actions.

III.1. Atmospheric dispersion during winter

III.1.1 TEDE

During winter, the TEDE obtained in Marsa-Dhouiba site is higher than that of Skhira site (Figure 2 and Table 6). This is reflected by the impact area of dose exceeding 50 mSv and 10 mSv for Marsa-Dhouiba and Skhira, respectively. Whereas, the impact area of TEDE exceeding 0.01 mSv is three times higher in Skhira site than in Marsa Dhouiba site but this finding is not so important because all the green area doesn't represent any danger. Table 6 gives the main numerical results.

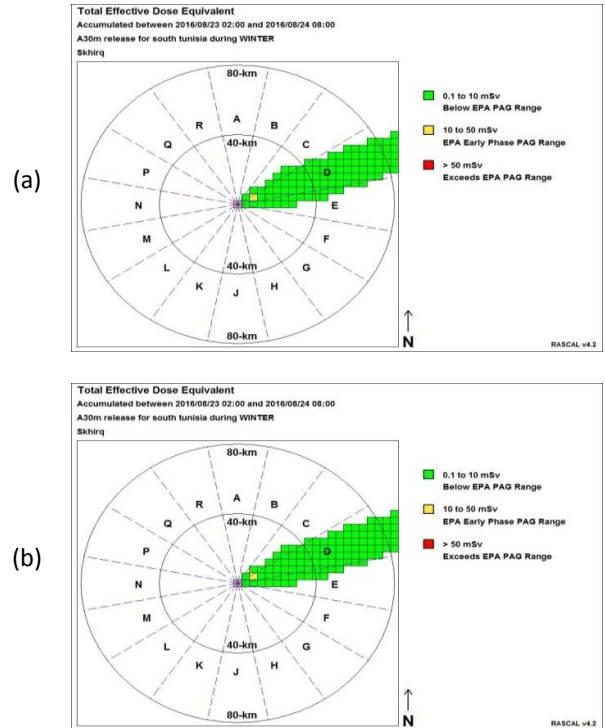


Fig. 2. Schematization of Simulated TEDE obtained during winter season (a) Marsa-Dhouiba site (Met. Stab class, D) (b) Skhira site (Met. Stab class, C)

Table 6. RASCAL's TEDE outputs obtained during winter for both sites

Site	Maximum dose [Sv] (Distance [m])	Threshold TEDE >	Impact area [km ²]	Maximum distance reached [km] (values [mSv])	Recommended immediate protective actions
North site	2.36 (800)	50 mSv	48.6	11.27 (70.1)	Evacuation to 11.27 km
		10 mSv	97.1	20.0 (11.2)	Sheltering to 20.0 km
		0.01 mSv	987.4	80 (1.39)	Safe area from 20 km
South site	8.61 10-01 (800)	50 mSv	0.7	8.0 (50.2)	Evacuation to 8.0 km
		10 mSv	32.4	16 (16.3)	Sheltering to 16 km
		0.01mSv	2379.6	80 (0.4)	Safe area from 16 km

III.1.2 Thyroid commitment dose equivalent

The spread of the TCDE is similar to that of TEDE but with smaller impacted areas. Wherever, we notice in Figure 3.a the presence of a yellow zone which corresponds to areas within which TDC is included between 50 and 250 mSv while for Skhira site there are only safety areas (green zone). Table 7 gives the outputs obtained during winter for both sites.

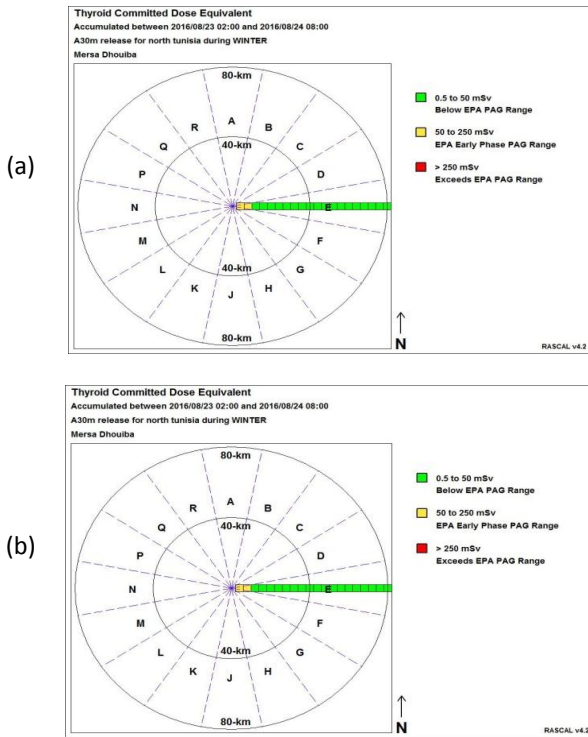


Fig. 3. Schematization Thyroid Commitment Dose obtained during winter season (a) Marsa-Dhouiba site (Met. Stab class, D) (b) Skhira site (Met. Stab class, C)

Table 7. RASCAL's TCDE outputs obtained during winter for both sites

Site	Maximum dose [Sv] (Distance [m])	Threshold TCDE >	Impact area [km ²]	Maximum distance reached [km] (values [mSv])	Recommended immediate protective actions
North site (Prevailing Direction = 270°)	5.35 (800)	250 mSv	0.20	3.22 (83.9)	KI admission for adults up to 40 years for under 3.22 km
		50 mSv	32.4	8.40 (55.6)	KI admission for children, pregnant and lactating woman for under 8.4 km
		0.05 mSv	809.4	80.00 (0.52)	Safe area from 8.4 km
South site (Prevailing Direction = 250°)	1.37 (800)	250 mSv	0.00	1.61 (346.00)	KI admission for adults up to 40 years for under 1.61 km
		50 mSv	0.20	3.22 (83.90)	Sheltering to 16 km
		0.05mSv	1861.6	74.00 (0.39)	Safe area from 16 km

During autumn season, the TEDE obtained in Skhira site is higher than that of Marsa-Dhouiba site (Figure 4 and Table 8). This is reflected by the impact area of dose exceeding respectively 50 mSv, 10 mSv and 0.01 mSv.

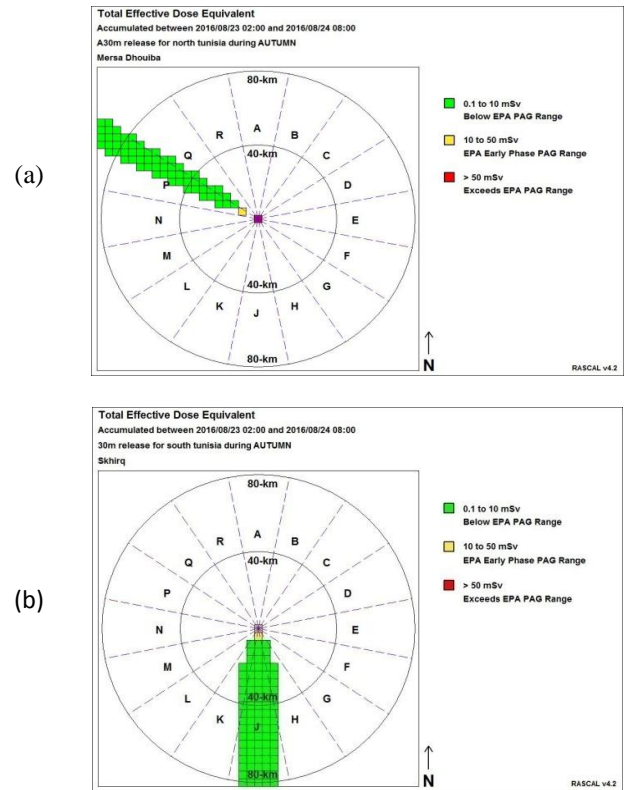


Fig. 4. Schematization of Simulated TEDE obtained during autumn season (a) Marsa-Dhouiba site (Met. Stab class, D) (b) Skhira site (Met. Stab class, C)

Table 8. RASCAL's TEDE outputs obtained during autumn for both sites

Site	Maximum dose [Sv] (Distance [m])	Threshold TEDE >	Impact area [km ²]	Maximum distance reached [km] (values [mSv])	Recommended immediate protective actions
North site	1.18 (800)	50 mSv	16.2	4.83 (71.2)	Evacuation to 4.83 km
		10 mSv	32.4	8.0 (17.6)	Sheltering to 8.0 km
		0.01 mSv	1262.1	80 (0.52)	Safe area from 8 km
South site	0.496 (800)	50 mSv	0.00	2.41 (77.0)	Evacuation to 2.41 km
		10 mSv	32.4	4.48 (15.2)	Sheltering to 4.48 km
		0.01mSv	1958.7	80 (1.04)	Safe area from 4.48 km

III.2. Atmospheric dispersion during autumn

III.2.1 TEDE

III.2.2 Thyroid Commitment Dose

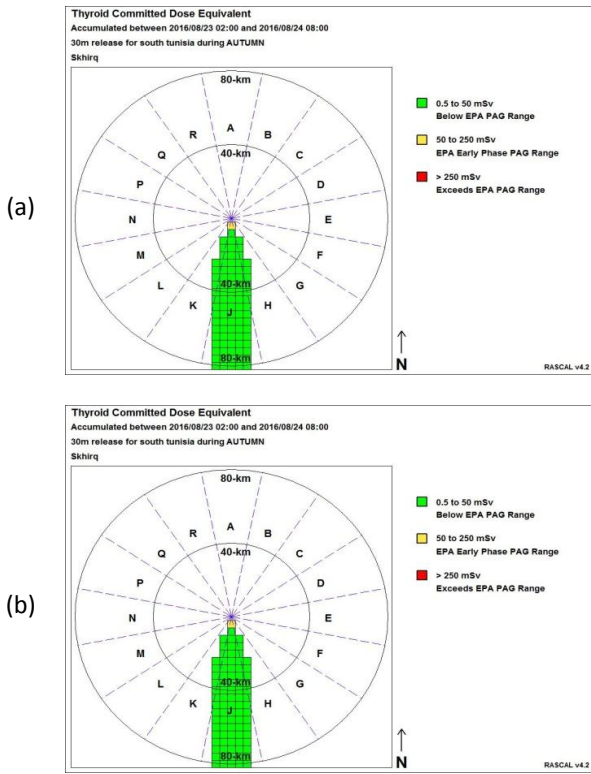


Fig. 5. Schematization Thyroid Commitment Dose obtained during autumn season (a) Marsa-Dhouiba site (Met. Stab class, D) (b) Skhira site (Met. Stab class, C)

Table 9. RASCAL's TCDE outputs obtained during autumn for both sites

Site	Maximum dose [Sv] (Distance [m])	Threshold TCDE >	Impact area [km ²]	Maximum distance reached [km] (values [mSv])	Recommended immediate protective actions
North site (Prevailing Direction = 120°)	5.51 (800)	250 mSv	0.10	3.22 (419.00)	KI admission for adults up to 40 years for under 3.20 km
		50 mSv	0.40	8.04 (74.50)	KI admission for children, pregnant and lactating woman for under 8.04 km
		0.05 mSv	1052.2	80.00 (1.83)	Safe area from 8.4 km
South site (Prevailing Direction = 360°)	1.78 (800)	250 mSv	0.00	1.61 (468.00)	KI admission for adults up to 40 years for under 1.61 km
		50 mSv	0.30	8.40 (53.30)	KI admission for children, pregnant and lactating woman for under 8.40 km
		0.05mSv	1910.4	80.00 (3.55)	Safe area from 8.4km

III.3. Atmospheric dispersion during springer

III.3.1 TEDE

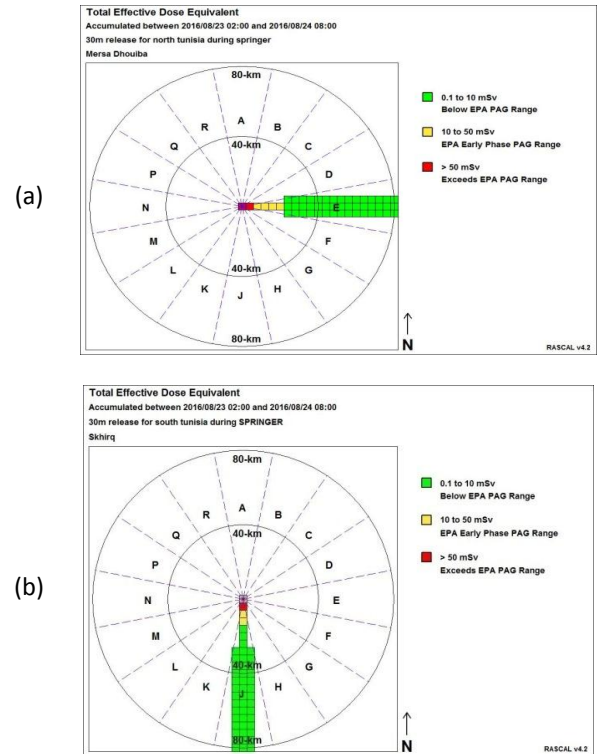


Fig. 6. Schematization of Simulated TEDE obtained during springer season (a) Marsa-Dhouiba site (Met. Stab class, D) (b) Skhira site (Met. Stab class, C)

Table 10. RASCAL's TEDE outputs obtained during springer for both sites

Site	Maximum dose [Sv] (Distance [m])	Threshold TEDE >	Impact area [km ²]	Maximum distance reached [km] (values [mSv])	Recommended immediate protective actions
North site	1.19 (800)	50 mSv	0.20	4.80 (71.80)	Evacuation to 4.8 km
		10 mSv	1.30	20.00 (10.60)	Sheltering to 20 km
		0.01 mSv	4.10	80.00 (2.74)	Safe area from 20 km
South site	1.02 (800)	50 mSv	0.20	4.83 (59.2)	Evacuation to 4.83 km
		10 mSv	0.40	8.00 (17.2)	Sheltering to 8 km
		0.01mSv	987.40	80.00 (1.68)	Safe area from 8 km

During springer, the TEDE obtained in both sites is almost without any significant effect. Whereas, the impact area of TEDE exceeding 0.01 mSv is three times higher in Skhira site than in Marsa Dhouiba site but this finding is not so important because all the green area doesn't represent any danger.

III.3.2 Thyroid Commitment Dose

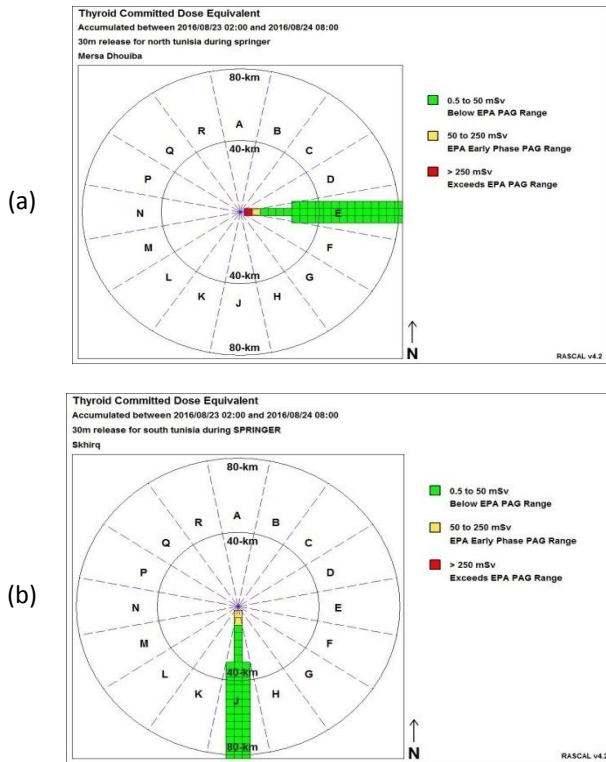


Fig. 7. Schematization Thyroid Commitment Dose obtained during springer season (a) Marsa-Dhouiba site (Met. Stab class, D) (b) Skhira site (Met. Stab class, C)

Table 11. RASCAL's TCDE outputs obtained during autumn for both sites

Site	Maximum dose [Sv] (Distance [m])	Threshold TCDE >	Impact area [km ²]	Maximum distance reached [km] (values [mSv])	Recommended immediate protective actions
North site (Prevailing Direction = 270°)	5.55 (800)	250 mSv	16.20	4.00 (271.00)	KI admission for adults up to 40 years for under 4 km
		50 mSv	32.40	8.00 (73.90)	KI admission for children, pregnant and lactating woman for under 8 km
		0.05 mSv	874.10	80.00 (9.12)	Safe area from 8 km
South site (Prevailing Direction = 360°)	4.89 (800)	250 mSv	0.10	3.22 (352.00)	KI admission for adults up to 40 years for under 3.22 km
		50 mSv	0.40	8.00 (59.90)	KI admission for children, pregnant and lactating woman for under 8 km
		0.05mSv	841.70	80.00 (4.98)	Safe area from 8 km

III.4. Atmospheric dispersion during summer

III.4.1 TEDE

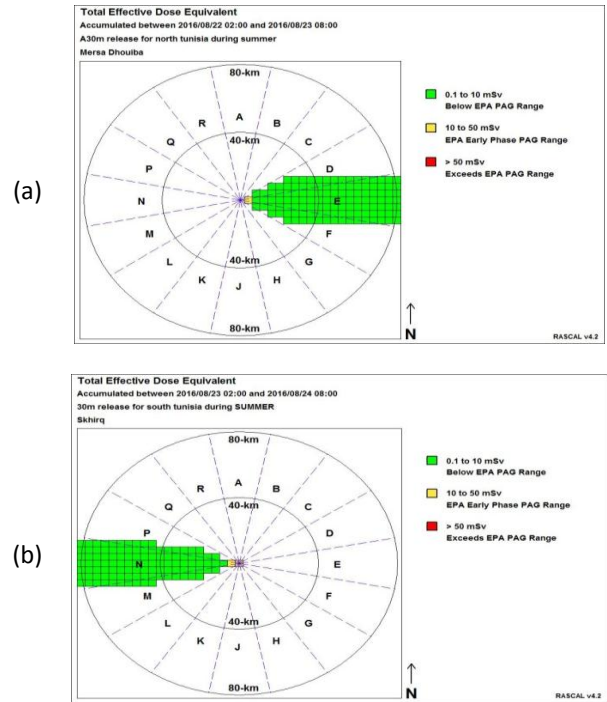


Fig. 8. Schematization of Simulated TEDE obtained during summer season (a) Marsa-Dhouiba site (Met. Stab class, D) (b) Skhira site (Met. Stab class, C)

Table 12. RASCAL's TEDE outputs obtained during summer for both sites

Site	Maximum dose [Sv] (Distance [m])	Threshold TEDE >	Impact area [km ²]	Maximum distance reached [km] (values [mSv])	Recommended immediate protective actions
North site	0.266 (800)	50 mSv	0.00	1.61 (77.60)	Evacuation to 1.61 km
		10 mSv	0.30	3.22 (15.10)	Sheltering to 3.22 km
		0.01 mSv	2784.2	80.00 (0.70)	Safe area from 3.22 km
South site	0.392 (800)	50 mSv	0.10	2.41 (59.1)	Evacuation to 2.41 km
		10 mSv	0.40	4.83 (11.7)	Sheltering to 4.83 km
		0.01mSv	2282.4	80.00 (0.80)	Safe area from 4.83 km

Also, in summer, the TEDE obtained in both sites is almost without any significant effect. Whereas, the impact area of TEDE exceeding 0.01 mSv is three times higher in Marsa-Dhouiba site than in Skhira site but this finding is not so important because all the green area doesn't represent any danger.

III.4.2 Thyroid Commitment Dose

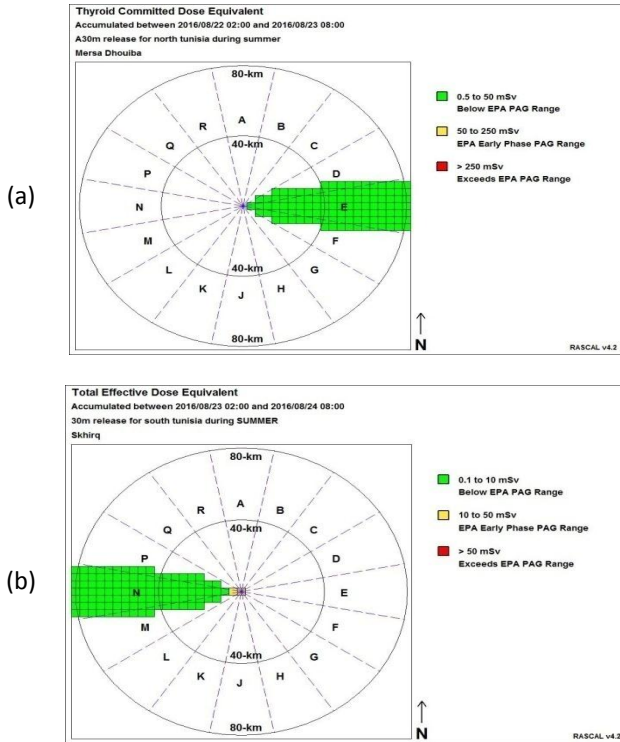


Fig. 9. Schematization Thyroid Commitment Dose obtained during summer season (a) Marsa-Dhouiba site (Met. Stab class, D) (b) Skhira site (Met. Stab class, C)

Table 13. RASCAL's TCDE outputs obtained during autumn for both sites

Site	Maximum dose [Sv] (Distance [m])	Threshold TCDE >	Impact area [km ²]	Maximum distance reached [km] (values [mSv])	Recommended immediate protective actions
North site (Prevailing Direction = 270°)	0.839 (800)	250 mSv	0.0	0.80 (839.00)	KI admission for adults up to 40 years for under 800 km
		50 mSv	0.2	3.22 (54.20)	KI admission for children, pregnant and lactating woman for under 3.22 km
		0.05 mSv	2622.4	80.00 (2.25)	Safe area from 3.22 km
South site (Prevailing Direction = 90°)	1.40 (800)	250 mSv	469.4	1.61 (363.00)	KI admission for adults up to 40 years for under 1.61 km
		50 mSv	598.9	3.22 (92.20)	KI admission for children, pregnant and lactating woman for under 3.22 km
		0.05mSv	825.6	80.00 (2.46)	Safe area from 3.22 km

III.5. Worst scenario of release

We are interesting in study the worst possible scenario of release, in terms of meteorological conditions, leading to the highest activity in the air. So, we assume a calm winds whose wind speed is 1 m/s and a very stable atmosphere (F stability class). The relative humidity is also considered higher (90%), where these meteorological conditions lead to worst dispersion conditions, (Figure 10 and Table 14).

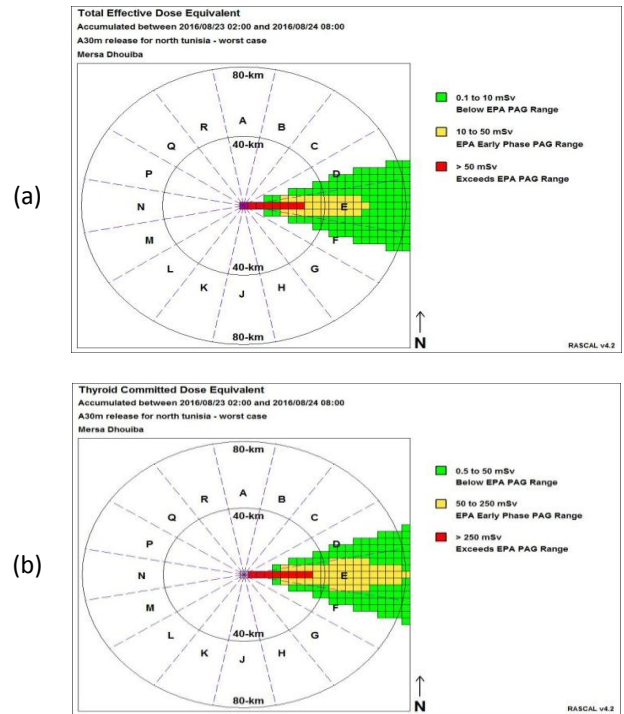


Fig. 10 Schematization of Simulated doses obtained during worst dispersion conditions for (a) TEDE (b) TCDE

Table 14. RASCAL's dose outputs obtained for the worst release case

Dose	Threshold	Maximum dose [Sv] (Distance [m])	Impact area [km ²]	Maximum distance reached [km] (values [mSv])	Recommended immediate protective actions
TEDE ^	50 mSv	2.60 (800)	978.40	28 (52.80)	Evacuation to 28 km
	10 mSv		1796.80	60 (10.80)	Sheltering to 60 km
	0.01 mSv		2638.60	80.00 (5.37)	Safe area from 60 km
TCDE ^	250 mSv	11.10 (800)	48.60	8.00 (336)	8 km (336 mSv)
	10 mSv		129.50	28 (52.80)	28 km (52.8 mSv)
	0.01mSv		2573.60	80.00 (5.37)	80 km (5.37 msv)



III.6. Worst scenario of release

Table 15 gives the extension of area where early protection actions must be taken. It is found that most extending areas are obtained for northern site for winter, autumn and Springer seasons except during summer when highest areas are given for South site. Also, we notice that highest seasonal evacuation and sheltering areas are obtained under meteorological conditions of winter with a maximum evacuation and sheltering areas in Marsa-Dhouiba site, respectively, 11 km and 20 km. Whereas, if we consider the worst release scenario (calm wind, very stable atmosphere and higher relative humidity), the maximum evacuation and sheltering zones are respectively 28 km and 60 km. This is the worst possible case we may have.

Table 15. Early protection actions for hypothetical accident for each season and for worst release case

Season	site	Max Evacuation area [km]	Max Sheltering area [km]	KI admission
Winter	North	11.27	20	8.4
	South	8	16	3.22
Autumn	North	4.83	8	8.04
	South	2.41	4.48	8.4
Springer	North	4.8	20	8
	South	4.83	8	8
Summer	North	1.61	3.22	3.22
	South	2.41	4.83	3.22
Worst Case	Both site	28	60	28

It is clear that for both sites, the evacuation and sheltering areas are not very wide this is explained by the fact that the two preselected sites are characterized mainly by a neutral and unstable meteorological stability (Table 5).

IV. CONCLUSION

For accidental atmospheric dispersion following the hypothetical accident of Loss of Coolant Accident, defining as uncovered core events accident, was been treated using RASCAL code. Two mainly results are obtained: the Total Effective Dose Equivalent (TEDE) and the Thyroid Commitment Dose Equivalent (TCDE) around the reactor sites. According to dose's thresholds for TEDE and TCDE, we highlight three main areas extensions colored in green (safety area), yellow (intermediate zone) and red (hazardous area). A protection measures shall be applied in the short distance (approximately less than 5 km) due to the good atmospheric parameters but this distance extends for much distances in case of northern site. RASCAL simulations were done for both sites and for every season taking into account its specific

meteorological conditions. It was been demonstrated that under meteorological conditions of winter season, relatively we obtained the highest doses and the broadest extensions for 2 sites. For instance, in winter, if we consider the EPA limits, for the northern site, the evacuation zone on within that TEDE exceeds 50 mSv reached up to 11 km for north site, the sheltering zone (TEDE>10 mSv) is estimated at 20 km and the admission of KI is recommended within 8 km.

We have also simulated the worst release scenario assuming a calm winds (wind speed is 1 m/s), a very stable atmosphere (F stability class) and the highest relative humidity (HR=90%) and it is found that the maximum evacuation and sheltering zones are respectively 28 km and 60 km. Not that and as a result of the analysis the meteorological conditions of the two sites, we find that these conditions rarely occur in two sites.

Finally, we can conclude that the atmospheric dispersion of the hypothetical accident under specific meteorological stabilities, which are almost neutral and unstable, of the two preselected sites, has no significant health effects because either evacuation or sheltering areas are not very extended and the highest seasonal evacuation and sheltering areas are obtained under meteorological conditions of winter with a maximum evacuation and sheltering areas in Marsa-Dhouiba site, respectively, 11 km and 20 km. Whereas, these areas could reached 28 Km for evacuation and 60 km for sheltering if the accident occurs during the worst meteorological conditions.

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