Environmental impact assessment of tritium release over the Western Mediterranean Basin

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The environmental impact of systems managing large (kg) tritium amount represents a public scrutiny issue for the next coming fusion facilities as DEMO. Furthermore, potentially new dose limits imposed by international regulations (ICRP) shall impact next coming devices designs and the overall costs of fusion technology deployment. Refined environmental tritium dose impact assessment schemes are then overwhelming. Detailed assessments can be procured from the knowledge of the real boundary conditions of the primary tritium discharge phase into atmosphere and into soils. Lagrangian dispersion models using real-time meteorological and topographic data provide strong refinement. Advance simulation tools are being developed in this sense. The tool integrates modeled numerical records from European Centre for Medium range Weather Forecast (ECMWF) with a lagrangian atmospheric dispersion model (FLEXPART). The model results can be coupled with tritium dose secondary phase pathway assessment tools. Nominal tritium discharge operational reference and selected incidental ITER-like plant systems tritium form source terms have been assumed. The real-time daily data and mesh-refined records together with lagrangian dispersion model approach provide accurate results for doses to population by inhalation or ingestion in the secondary phase.

Keywords: Tritium, dose impact, dispersion model, lagrangian models

1. Introduction

Present devices as ITER manage amounts of tritium in the order of tens of kilograms. Tritium release guidelines at ITER nominal conditions; < 1 g of tritium in HT form per year, < 0.1 g per year of tritium in HTO form, are known to be below but within the order of magnitude of CEDE dose prescribed limits by international regulations (1 mSv) [e.g.: ICRP-60]. Future potential decrease of those prescribed limits could mean potential dramatic impact on fusion plants design requirements and costs [1]. Present dose assessments deterministic and probabilistic schemes [2] can be assumed at present as strong conservative and rough. Such schemes are mainly based on the assumption of Gaussian models for discharges and the consideration of diverse atmosphere stability classes using the results in similar scenarios using NORMTRI code [**3**]. Therefore, present dose assessments should be assumed as overestimated by principle. Today, highly sophisticated atmospheric models are open to the use of real-time numerical meteorological/geographical synoptic data; e.g.: 91 atmospheric vertical levels and 25 km terrestrial meshing [**4**]. The use of real-time data and precise boundary conditions for both, atmosphere and soil, together with lagrangian dispersion models and its coupling with sophisticated tritium dose transfer schemes at secondary phases by ingestion and/or inhalation, can determine the two chemical tritium forms (HT or elemental tritium and HTO or tritiated water) environmental impact at any low level of required limit.

Section 2 presents, the coupling procedures of wind-solar radiation-precipitation-relative-humidity-temperature fields records of input *European Centre for Medium range Weather Forecast* (ECMWF) with the lagrangian atmospheric dispersion model FLEXPART [5]. ECMWF is twofold; a real-time processing meteorological data source (or rich data assimilation system) and a *quasi-lagrangian* forecasting model.

Section 3 forecasts two different reference meteo scenarios for 2D HT/HTO primary plumes with continuous tritium releases complex from dispersion assessment point of view. The Case 1 assesses the tritium dispersion towards the interior of Iberian Peninsula (due to S, SE and SW wind component: *migjorn, xaloc* and *àbrec*). The Case 2 quantifies daily HT/HTO concentrations in air, towards the sea (due to N, W and NW wind component: *tramontana*, ponent and *mistral*), determining the maximum of radial concentrations from the emission point. The emission source is modeled in FLEXPART as a continuous punctual source from a 10 meters tower. As source value it has been assumed the daily continuous release of tritium in HT form concentrated in 1 hour of emission. Results of the primary phase are shown.

As discussed, the final qualification of the refinement soundness of the proposed method shall be established by the comparison of the predictions between Gaussian [6] and ECMWF/FLEXPART lagrangian modeling approaches and with their confrontation with available experimental records [7]. Roadmap of the ECMWF/FLEXPART development needs to qualify the new proposed schemes for dose assessments (*Section 4*).

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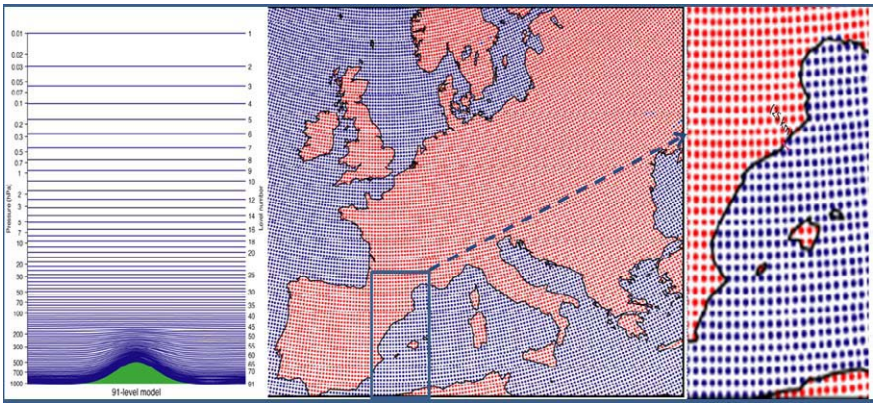

Figure 1. Next ECMWF numerical scheme grid; left, 91 vertical levels between the earth's surface and 1Pa; center, the model has ~ 76 millions grid points separated by about 25 k in the horizontal around the globe; right Mediterranean area selected for FLEXPART.

2. ECMWF weather prediction & FLEXPART lagrangian dispersion Model

The ECMWF Integrated Forecast System (IFS) consists of a general circulation model, a data assimilation system and an ensemble forecast system. ECMWF is a Medium range Weather Forecast Model (with forecast fields valid until 240 h) [4]. The numerical scheme will consists in a spectrum (with triangular truncation, 799 waves around a great circle on the globe; 91 vertical levels between the earth's surface and 1Pa (about 85 Km). It has a semi-Lagrangian formulation. The model has 76 million grid points separated by about 25 km (Figure 1), in the horizontal around the globe. In this work actual IFS consist we use 50 km resolution. The variables at each grid point are: wind (including vertical velocity), temperature, humidity, and cloud water and ice and cloud fraction, ozone (also pressure at surface grid-points). Data assimilation is hourly in surface observations and 3 hourly for synops. Soundings made in specific points at 00 and 12 UTC. Finally there is a variational assimilation of Radiative Transfer Models.
We use the model for detecting, mainly but not only, Mediterranean cyclogenesis responsible for organizing the inflow of wet and warm Mediterranean air. We consider this type of meteorological situation as responsible for potential dispersion at largest scales. At present stage of tool developments, and among many other fields, we use wind forecast fields from IFS as linked input in the Lagrangian System, which reading run specifications integrate a cluster of particle positions.

The IFS output couples with FLEXPART as input. This model is a Lagrangian particle dispersion model that simulates in short (temporal) range the long (spatial) range/meso-scale transport, diffusion, dry and wet deposition, and radioactive decay of tracers. Dispersion from the release point has been obtained by fixing the level in 10 m (or point between 9.99 and 10.01 m).

In this work FLEXPART has been used forward in time to simulate the dispersion of tracers from source or emission point. The limited domain used is centered in the site selected with a cross (Figures 2 and 3) [5].

The atmospheric dispersion model needs five three-dimensional fields: horizontal and vertical wind components, temperature and specific humidity.

Input data must be on numerical ECMWF format which are defined by a hybrid coordinate system. The vertical wind in hybrid coordinates is calculated mass-consistently from spectral data at the pre-processor level. A surface level is defined in addition to the regular levels. 2 m temperature, 10 m winds and specific humidity from the first regular model level are assigned to this level, to represent surface values. Parameterized random velocities in the atmospheric boundary layer are calculated. Therefore, in order to avoid time-consuming coordinate transformations every time step, all three-dimensional data are interpolated linearly from the ECMWF model levels to terrain-following Cartesian z coordinates. FLEXPART also needs the two-dimensional fields: surface pressure, total cloud cover, 10 m horizontal wind components, 2 m temperature and dew point temperature, large scale and convective precipitation, sensible heat flux, solar radiation, east/west and north/south, surface stress, topography, land-sea-mask and subgrid standard deviation of topography.

2.1. HT and HTO tritium forms in FLEXPART

Lagrangian dispersion model coupled with ECMWF we can provide highly detailed daily concentration tritium even at short periods (hours).

Table I. FLEXPART considered dispersants and HT/HTO physical data.

Input file for the Lagrangian particle dispersion model FLEXPART.
Definition file of chemical species/radionuclides

	SPECIES	Radioactivity HALF LIFE [s]	Wet depo A	B	Dry depo (gases) D	H	F0	Dry depo (particles) rho	dquer	dsig	Dry depo vd	molweight
1	TRACER	-999.9	-9.9E-09		-9.9			-9.9E09			-9.99	350.00
2	O3	-999.9	-9.9E-09		1.5	1.0e-02	1.0	-9.9E09			-9.99	48.00
3	NO	-999.9	8.0E-06	0.62	1.2	2.0e-03	0.0	-9.9E09			-9.99	30.00
4	NO2	-999.9	1.0E-05	0.62	1.6	1.0E-02	0.1	-9.9E09			-9.99	46.00
5	HNO3	-999.9	8.0E-04	0.62	1.9	1.0e+14	0.0	-9.9E09			-9.99	63.00
6	HNO2	-999.9	-9.9E-09		1.6	1.0e+05	0.1	-9.9E09			-9.99	47.00
7	H2O2	-999.9	1.0E-04	0.62	1.4	1.0e+05	1.0	-9.9E09			-9.99	34.00
8	SO2	-999.9	-9.9E-09	0.62	2.0	1.0e+05	0.0	-9.9E09			-9.99	64.00
9	HCHO	-999.9	-9.9E-09		1.3	6.0e+03	0.0	-9.9E09			-9.99	30.00
10	PAN	-999.9	-9.9E-09		2.6	3.6e+00	0.1	-9.9E09			-9.99	121.00
11	NH3	-999.9	-9.9E-09		1.1	2.0e+14	0.0	-9.9E09			-9.99	17.00
12	SO4-aero	-999.9	1.0E-04	0.80	-9.9			2.0E03	4.0E-7	3.0E-1	-9.99	-9.99
13	NO3-aero	-999.9	1.0E-04	0.80	-9.9			2.0E03	4.0E-7	3.0E-1	-9.99	-9.99
14	I2-131	691200.0	8.0E-05	0.62	2.7	1.0e+05	0.1	-9.9E09			-9.99	-9.99
15	I-131	691200.0	1.0E-04	0.80	-9.9			2.5E03	6.0E-7	3.0E-1	-9.99	-9.99
16	Cs-137	948287520.0	1.0E-04	0.80	-9.9			2.5E03	6.0E-7	3.0E-1	-9.99	-9.99
17	Y-91	3037120.0	1.0E-04	0.80	-9.9			2.5E03	6.0E-7	3.0E-1	-9.99	-9.99
18	Ru-106	31536000.0	1.0E-04	0.80	-9.9			2.5E03	6.0E-7	3.0E-1	-9.99	-9.99
19	Kr-85	-999.9	-9.9E-09		-9.9			-9.9E09			-9.99	-9.99
20	Sr-90	-999.9	1.0E-04	0.80	-9.9			2.5E03	6.0E-7	3.0E-1	-9.99	-9.99
21	Xe-133	198720.0	-9.9E-09		-9.9			-9.9E09			-9.99	-9.99
22	CO	-999.9	-9.9E-09		-9.9			-9.9E09			-9.99	28.00
23	NO2TRACER	-999.9	-9.9E-09		-9.9			-9.9E09			-9.99	46.00
24	AIRTRACER	-999.9	-9.9E-09		-9.9			-9.9E09			-9.99	29.00
25	NA-CO	-999.9	-9.9E-09		-9.9			-9.9E09			-9.99	28.00
26	EU-CO	-999.9	-9.9E-09		-9.9			-9.9E09			-9.99	28.00
27	AS-CO	-999.9	-9.9E-09		-9.9			-9.9E09			-9.99	28.00
28	SO2TRACER	-999.9	-9.9E-09		-9.9			-9.9E09			-9.99	64.00
29	HT	387892800.0	9.9E-09		-9.9			-9.9E09			-9.99	4.00
30	HTO	387892800.0	9.0E-05	0.60	-9.9			-9.9E09			-9.99	20.00

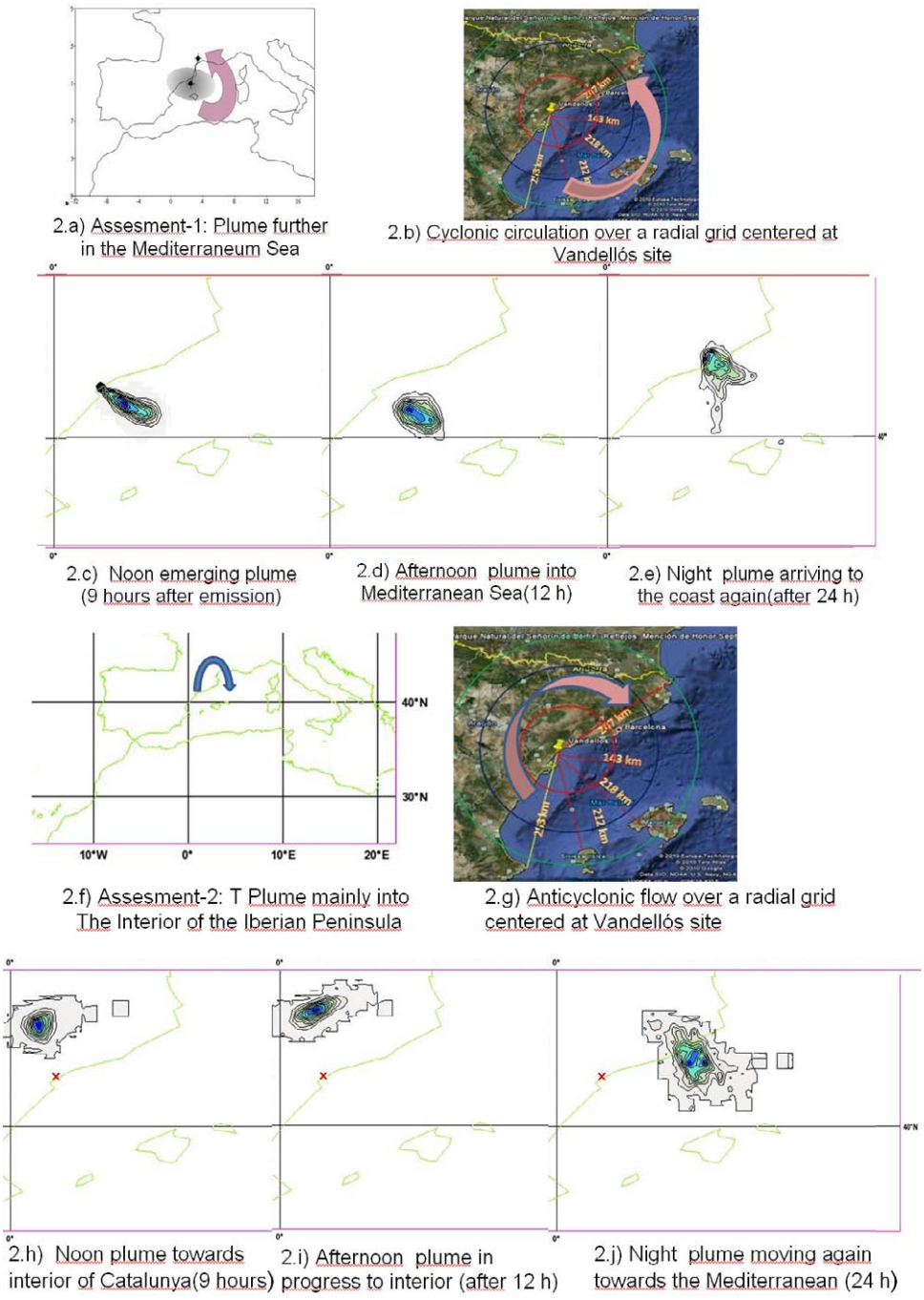

Figure 2. *Top*: Assessment-1: Primary tritium plume over Mediterranean and bottom: Assessment-2: primary plume mainly over the Interior of Iberian Peninsula

These selection allows us to assess probabilistically the release of tritium primary plume emerging from the emission point. Tritium is not explicitly included in the FLEXPART dispersants database, but similar chemical forms (as water vapor, inert gases gas or reactant gases as oxygen or hydrogen) they are. Both chemical form of tritium with their physical properties including its decay have been included (Table I). Particularly important is the consideration of deposition velocities for both chemical forms of tritium linked to 13 soil categories and lands.

2.2. FLEXPART outputs

We made an output database including daily tritium concentration products at surface level; 3 for HT and 3 for HTO, in the release site and surroundings area of Vandellós (from 38º N 1º 27' W to 43º N 7º 38' E, including Balearic Islands –in outgrid file-).

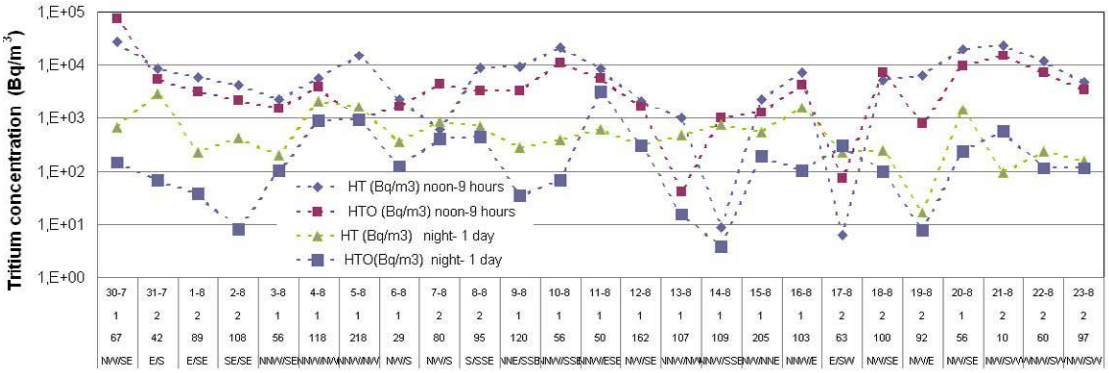

Figure 3. Daily Tritium concentration in air (Bq/m^3) in both Scenarios; (1) Mediterranean Sea & (2) Interior Iberian Peninsula by days, wind direction and distance (km).

All of the products present a color scale of concentration values. Distance from the detected maximum from emission site, was daily registered. The meteorological input data must be organized such that all data for a domain and a certain date must be contained in a single grib file. The available file lists all available dates and the corresponding file names. For each nesting level, the input files must be stored in a different directory and the available file must contain the same dates.

3. Assessment of daily evolution of tritium forms air concentrations

Fictitious exaggerated tritium sources of about 2.7 mg of tritium per event-day (~ 25 Ci/event-d) in HT form (e.g. emitted 3.65 mg of HT) or 0.27 mg (~ 2.5 Ci/event-d) of tritium per event-day in HTO (e.g. emitted: 1.8 mg of HTO) can be considered. Two specific meteorological scenarios for tritium primary plume passing by downwind, in summer are modeled hereafter.

3.1. Cyclogenesis SE winds (xaloc) by or warm/humid advection in summer periods

It can typically occurs that *cyclogenesis* or warm/ humid sea advection introduces SE winds (xaloc) in the NE of Spain, even with hot and humid advections in typically summer (e.g. after a night of NW-mistral) (Assessment-1). Figure 2 shows this scenario with an example of a cyclonic motion of tritium primary plume detected in sequence from noon to night in the atmospheric boundary layer. Figure 2.b shows this flow in the radial grid with distances to Vandellós FPR. Noon plume is presented in figure 2.c shows; afternoon plume within sea (fig. 2 d) and again night plume arriving the coast (fig 2.e). It can also be also due to a strong mistral (NW winds) at night followed by a coastal xaloc (SE winds).

3.2. South winds and anticyclonic flows

Another typical condition (Asessment-2) consists of tritium release from Vandellós towards the interior of Iberian peninsula due coastal Migjorn S winds (figure.2f). The primary plume is mainly over the Interior of Iberian Peninsula. Figure 2.g shows the anticyclonic derived flux within a radial grid centered in the emision point. The primary plume is presented in a sequence of 3 consecutive outputs on noon and afternoon the 2nd and during the night of the 3rd of August in the figures 2h, 2i and 2j.

The daily tritium concentration in air during period 30-July to 23-August is presented in figure 3, valid at noon and night. Tritium values of concentration ranges between 10 and 10^5 Bq/m^3.

In this case tritium values of concentration are ranging in 4 orders of magnitude from 10 to 10^4 Bq/m^3, therefore a reduction of elemental tritium concentration in air during the night (perhaps due lack of solar radiation and different wind velocities) is detected by the model. The comparison of tritium concentration activities in air, into the interior of Iberian peninsula with that into the sea shows no strong differences. However, we check the capability of the model to detect the maxima concentration corresponding to different wind components in each scenario. The distance to which the primary plume arrives in a radial direction has been calculated. In the Gaussian model is in order of 10^8 Bq/m^3 in 150 m until 10^4 Bq/m^3 at 1 km at the release emission. Therefore Gaussian model overestimates this value.

Mediterranean Sea Scenary-1 (figure 2) was effective during the following days: 30th July, from the 3rd to the 6th August and from 9th to the 16th and the 20th of August, all of them characterized mainly by with NW component. Tritium values of logarithmic concentration ranges between 10 Bq/m^3 and 10^5 Bq/m^3. Maxima concentration occurs in the 30th July 28.631 Bq/m^3 (figure 2). Major primary plume when NW component is not blocked by a surface high. Otherwise a significant concentration occurs as e.g. the 10th of August with NNW by night and SSE by noon. Scenary-2 (figure 3), was effective during period from 30-July to 23-August the following days: 31st of July, 1-2, 7-8, 17-19 and 21-23 of August. Tritium concentration ranges again between 5 orders of magnitude.

Primary plume extends and flows around more than 95 km “downwind distance” SSE. Daily Tritium Concentration in air over Iberian Peninsula during some

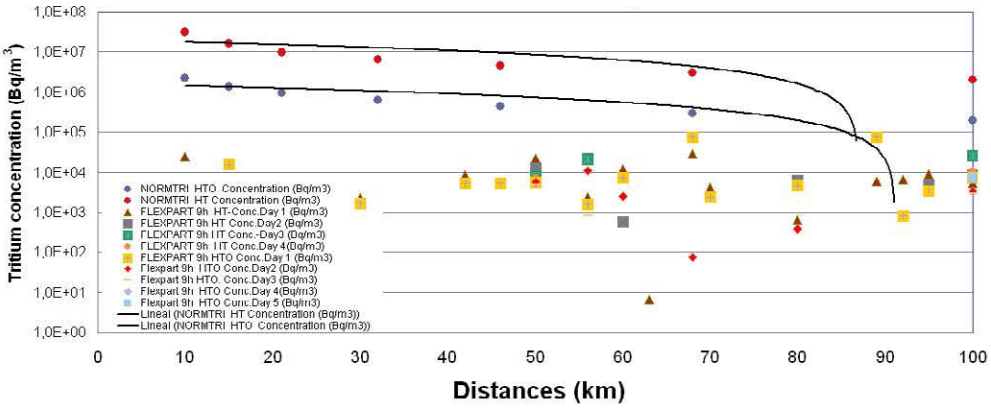

Figure 4. HT and HTO concentration at different distances from the release emission using same weather time.

days of period 30-July to the 23th August with S, SE or SSE forecast winds at noon in the Mediterranean coast. Tritium concentrations (HT and HTO forms) in different distances from the release emission, using same weather time, with NORMTRI and FLEXPART, is presented in figure 4. The models comparison is made in the space up to 100 km. From analysis of lagrangian noon tritium concentrations, in both scenarios, in the summer. During 45 days (30 July to 11 September 2010) maximum concentrations are, mainly but not only, between 10^3 and 10^4 Bq/m^3 , in the first 100 km from the point of emission for the lagrangian model. On the other hand Gaussian sequence data remains between 10^5 and 10^7 Bq/m^3. Therefore these results overestimate the air concentration of tritium near of the point of emission, up two orders of magnitude higher than the lagrangian model. At larger distances from the site, 100 km, Gaussian results remains overestimated just by one order of magnitude with respect to FLEXPART data. This may be due to previous (sections 2 and 3) real time winds variability considerations, taken for the first time in the lagrangian model.

4. Conclusions

The environmental impact of tritium systems shall represent a major public scrutiny issue fusion technology deployment (DEMO). Furthermore, potentially new dose limits imposed by international regulations (ICRP) shall impact next coming devices designs and costs. Highly refined environmental tritium dose impact assessment schemes will be prospectively required.

The lagrangian model (ECMWF/FLEXPART) gives us the real-time tritium dispersion behavior data and allows the accurate determination of concentration in extended areas around the emission point. Gaussian results are seen to overestimate the air tritium concentration up two orders of magnitude higher than the FLEXPART data for both HT and HTO forms. The present real-time lagrangian model should be contrasted with other high resolution real-time couplings –i.e. as MM5/FLEXPART[**8**] or HIRLAM/FLEXPART [**9**]. The tool qualification have to be confronted with tritium concentrations in air direct data [**7**].

Acknowledgments

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