Nucl. Sci. and Tech, Vol.4, No. 4 (2014), pp. 09-16

Nuclear Science and Technology

Journal homepage: https://jnst.vn/index.php/nst

Assessment of radiation dose caused by radioactivegaseous effluent released from nuclear power plant Ninh Thuan 1 under scenario of normal operation

Do Xuan Anh, Le Dinh Cuong, Duong Duc Thang, Vuong Thu Bac, Nguyen Thi Thu Ha, Nguyen Quang Long, Trinh Van Giap, Nguyen Hao Quang*, Nguyen Tuan Khai

Institute for Nuclear Science and Technology (INST), 179 Hoang QuocViet, Hanoi

**Vietnam Atomic Energy Institute (VINATOM), 59 Ly Thuong Kiet, Hanoi*

Abstract: Based on guides RG 1.109, RG 1.111 published by United States Nuclear Regulatory Commission (USNRC) our research concentratesinassessing radiation doses caused by radioactive substances released from the nuclear power plant (NPP) Ninh Thuan 1 under the scenario of normal operation using software package NRCDose72 provided by the USNRC. The database including the released radioactive nuclides, meteorology, terrain, population and agricultural production activities have beencollectedand processed to build the input data for the model calculation. The wind rose distribution obtained from the meteorological data in a five-year period from 2009-2013 showed that the radioactive nuclides released to environment spread in two main wind directions which are North East and South West. The X/Q (s/m^3) and D/Q (s/m^2) qualities which are, respectively, the ratio of activity concentration to release rateand that of deposition density of radioactive nuclides to release rate were calculated within an area of 80 km radius from the NPP site using XOQDOQ. Population doses were calculated using GASPAR. The XOQDOQ and GASPAR are two specific softwares in NRCDose72 package.

Keywords: NPP, *radioactive release, radiation dose, population dose, X/Q and D/Q*

I. INTRODUCTION

Currently, Vietnam is actively preparing infrastructure forthe first two nuclear power plant (NPP) projects Ninh Thuan 1&2 which is planned to build with a total capacity of 2,000 MW for each. When going into operation, the NPP will release radioactive nuclides into the atmosphere. The radioactive effluent undergoing dispersion in air and deposition on ground will cause impact to the environment and human. Therefore, research for transport and dispersion of radioactive substances in atmosphere, and assessment for radiation dose to the public are of essential requirement for an NPP project. In addition, the calculation results will provide the necessary data for the Environmental Impact Assessment (EIA) and support for regulatory organization in reviewing the Safety Analysis Report (SAR).

Radioactive releases from various nuclear facilities, in general, may contribute to radiation exposure through two main pathways: (1) External exposures by direct radiation from radioactive plumes or from radioactive nuclides deposited on the ground, and (2) Internal exposure due to inhalation and ingestion of radioactive substances. The magnitude of exposure is dependent on atmospheric dispersion and deposition processes.

https://doi.org/10.53747/jnst.v4i4.238
Received 15 December 2014, accepted 23 January 2015

In this work we focused on investigating the radioactive release from the NPP Ninh Thuan 1 and assessing radiation dosesfor the populationunder the scenario of normal operationusing software package NRCDose72.To build the data input for the model calculation the database on meteorology, terrain, population and agricultural production activities has been collected and processed within a radius scope of 80 km from the NPP site, where the wind rose distributionwas obtained from processing the meteorological data in a five-year period of 2009-2013.The released nuclear data is referred from the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), in which the annual normalized release in Bq/(GW_e-year) for the radioactive isotopes has been published for the popular reactor types such as PWR, BWR, FBR and some others based on the average evaluation on a period from 1990-1997 [1,2]. Our assessments have been performed using the released data for PWR type with an assumed total power of 2000 MW_e. The ratio of activity concentrations X/Q (s/m^3) and that of radioactive deposition densities D/Q (s/m^2) were calculated using XOQDOQ, in which it is assumed that the radioactive substance is dispersed by the Gaussian model. The obtained results on X/Q and D/Q values were used for evaluating the population doses using GASPAR. As mentioned above, the XOQDOQ and GASPAR are two softwares in NRCDose72 package [3,4].

II. COMPUTER CODE DESCRIPTION

A. XOQDOQ

Computation program XOQDOQ is used in the independent meteorological evaluation of routine or anticipated, intermittent releases of radioactive nuclides at commercial nuclear power plants. It is primarily designed to calculate annual relative effluent concentrations, X/Q values, and annual average relative deposition, D/Q values, at locations specified by the user, and at various standard radial distances and segments for downwind sectors. Evaluations of anticipated intermittent (e.g. containment or purge) releases which occur during routine operation may also be evaluated using the program. Evaluation of intermittent releases provides both X/Q and D/Q values at various standard locations, as well as user-inputted specific points of interest.

The input of the program includes meteorological and topographic data. Meteorological data is as a joint frequency table, i.e. a table of the fractional occurrence during a given time period of a particular combination of stability class type, wind direction, and wind speed class. The wind direction is classified into 16 sectors proceeding clockwise from N through NNW. The wind speeds are grouped into classes, with the program allowing up to 14 separate classes, which include a class for calm wind speeds. Atmospheric stability is grouped according to seven categories from extremely unstable to extremely stable. Terrain elevation (in meters, compared to the factory floor) is the maximum height in the topographic data collected in the 80 km radius from the NPP site. The direction and distance from the source are included in terrain elevation data.

In this work the meteorological data at Ninh Thuan including wind direction, wind speed and atmospheric stability has been collected and processed based on a five-year database provided by Phan Rang meteorological stationand the National Oceanic and Atmospheric Administration of United States (NOAA). The terrain data is built using the topographic map within the 80 km radius around the site planned for NPP Ninh Thuan 1.

The values X/Q is determined by the following formula [3]:

$$\frac{X}{Q}(x,K) = \frac{2.032}{x} \times RF(x,K) \times \sum_{i,j}^{N,7} \frac{DEPL_{ij}(x,K)DEC_i(x)f_{ij}(K)}{U_i(x)\sigma_{Zj}(x)} \times exp - 0.5\left(\frac{h_e^2}{\sigma_{Zj(x)}^2}\right) \quad (1)$$

where $\frac{X}{Q}(x,K)$ is average effluent concentration normalized by source strength at distance x in directional sector K (s/m^3); x is the downwind distance (meters); i is the ith wind-speed class; $j$is the jth atmospheric stability class; K is the kth wind-direction class; $U_i$is mid-point value of the ith wind-speed class; $\sigma_{Zj}(x)$ is the vertical plume spread for stability class j at distance x; $f_{ij}(K)$ is the joint probability of occurrence of the ith wind-speed class, jth is stability class, and Kth is wind direction sector; h_e is the effective plume height (in meters); $DEC_i(x)$is the reduction factor due to radioactive decay at distance x for the ith wind-speed class; $DEPL(x,K)$ is the reduction factor due to plume depletion at distance x for the ith wind-speed class, jth stability class and Kth wind-direction class; $RF(x,K)$is the correction factor for recirculation and stagnation at downwind distance x and Kth wind-direction class.

For each directional sector, relative deposition is computed by the following relationship for a specific downwind distance [3]:

$$\frac{D}{Q}(x,K) = \frac{RF(x,K)\sum_{ij}^{N,7} D_{ij}f_{ij}(K)}{\left(\frac{2\pi}{16}\right)x} \quad (2)$$

where $\frac{D}{Q}(x,K)$ is the average relative deposition per unit area at a downwind distance x and direction K, in meter^{-2}; $D_{ij}$is the relative deposition rate for the ith wind-speed class and the jth stability class; $f_{ij}(K)$ is the joint probability of occurrence of the ith wind-speed class; $RF(x,K)$ is the correction factor for recirculation and stagnation at downwind distance x and Kth wind-direction class.

B. GASPAR

GASPAR is a computer code used by the USNRC in radiation dose assessment for individuals and groups of people contaminated by the release of radioactive nuclides into the air environment of nuclear power plants in normal operation conditions. The theoretical basis for the radiation dose calculations of the code is based on Regulatory Guide 1.109 and NUREG/CR-4653 [5,6]. Data input of the program includes:

(1) Population: Data on the total population and population distribution for four distinct age groups: infant, child, teenager and adultin each sector (subregion);

(2) Crop and cattle breeding: Data on production and distributions of meat, milk and production.

These two data sets have been processed within the 80 kmradius around the NPP site.

(3) Radioactive release: Data on the activity (Ci) of theradioactive nuclides released to the environment and the rate of the radioactive waste (Ci/year);

(4) Meteorology:

- Data on atmospheric dispersion parameters (sec/m^3) for use in population dose calculations for the undecayed/undepleted dispersion and the decayed/undepleted dispersion;

- Data onatmospheric dispersion parameters (sec/m^3) with decay and depletion for use in population dose calculations for the decayed/depleteddispersion;

- Data on ground deposition parameter (m^{-2}/year) for use inpopulation dose calculations;

It should be noted that the meteorological data can be imported either directly into the software or from the output of XOQDOQ software.

The outputs of GASPAR include:

- Gamma air and beta air dose;
- Annual effective dose from all other noble gas releases;
- Skin dose;
- Annual organ dose from external irradiation by deposited radioactive nuclides;
- Annual organ dose from inhalation;
- Annual organ dose from ingestion of radioactive nuclides in food;
- Annual population integrateddose.

III. RESULTS AND DISCUSSION

A. Meteorological data processing

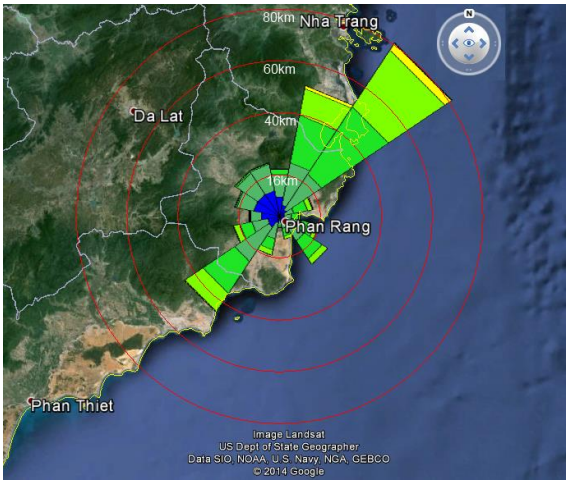

Fig. 1: The wind rose distribution obtained from the database of the Phan Rang station

Based on the database provided by the Phan Rang station in the five-year period from 2009 to 2013 the meteorological data was processed to obtainthe wind rose distribution as shown in figure 1 for the wind direction and speed in the area planned for construction of the NPP Ninh Thuan 1.We can see that the wind direction and intensity is mainly concentrated in two directions which are the North East and South West. These are the two main wind directions passing through the provinces of the region in the South Central Coast and Tay Nguyen.

At present it is impossible to determine the atmospheric stability from the Phan Rang station's database due to the lack of some necessary measurements such as the atmospheric temperature as a function of height. We are discussing on a possibility to evaluate this parameter based on the cloud observation data. In this work the atmospheric stability was evaluated using the meteorological database downloaded from the National Oceanic and Atmospheric Administration (NOAA) of the United States.

B. Gaseous effluent distribution

The output from the program XOQDOQ was designed to present the maximum amount of information on each release point, including:

- X/Q values (s/m^3) at 22 specific distances ranging from 0.80 to 80 kmfrom the site;
- X/Q values for 10 distance intervals;
- D/Q values (s/m^2) at 22 specific distances ranging from 0.80 to 80 km from the site;
- D/Q values for 10 distance intervals;
- X/Q and D/Q values at specific points of interest.

The obtained calculation results made us possible to build the X/Q-value and D/Q-value distributions as a function of distance ranging from 0.8 to 80 km from the NPP site as shown in figure 2. We can see clearly that the X/Q and D/Q values are dominant in two directions of North East and South West. This is consistent withthe obtained wind rose distribution, where the wind frequencies are also high in these two directions (as shown in figure 1).

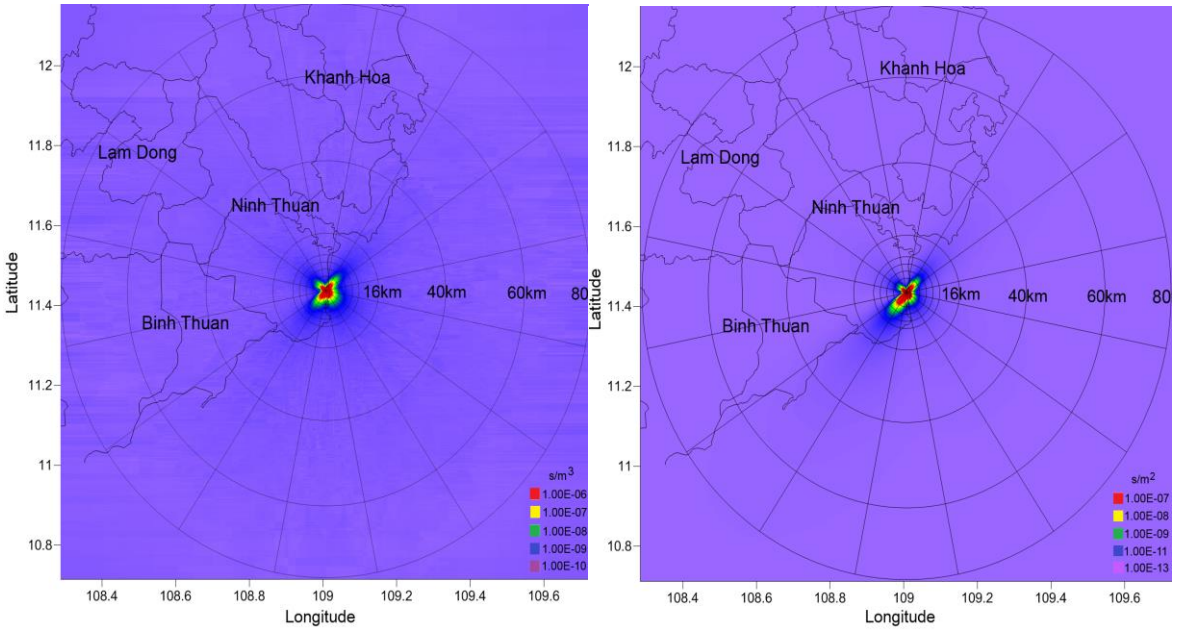

Fig.2. Distribution on X/Q values (left) and D/Q values (right)
Within 80 km radius from the NPP site.

C. Population dose assessment

The output of the program GASPAR gives the calculation results forthe annual total population dose and annual individual dose for three distinct age groups including child, teenager and adult at the locations of interest. The details are given in Tables I-III.

Table I: Calculation results for the annual total population dosein 80 km radius

Pathway	Annual total population dose (mSv)							
	Effective	Gi-lli	Bone	Liver	Kidney	Thyroid	Lung	Skin
Plume	2.30E-02	2.30E-02	2.30E-02	2.30E-02	2.30E-02	2.30E-02	2.55E-02	2.21E-01
	2.12%	2.11%	2.15%	2.14%	2.15%	1.71%	2.39%	13.30%
Ground	9.97E-01	9.97E-01	9.97E-01	9.97E-01	9.97E-01	9.97E-01	9.97E-01	1.41E+00
	92.09%	91.58%	93.57%	92.95%	93.50%	74.23%	93.16%	84.61%
Inhalation	2.31E-02	2.20E-02	2.20E-02	2.22E-02	2.20E-02	3.64E-02	2.51E-02	2.18E-02
	2.13%	2.02%	2.07%	2.07%	2.06%	2.71%	2.34%	1.31%
Vegetable	1.83E-02	2.76E-02	1.63E-02	2.01E-02	1.67E-02	2.62E-02	1.57E-02	1.02E-02
	1.69%	2.54%	1.53%	1.87%	1.56%	1.95%	1.47%	0.61%
Cowmilk	1.06E-02	1.81E-03	1.30E-03	1.36E-03	1.27E-03	1.91E-01	1.24E-03	5.26E-04
	0.98%	0.17%	0.12%	0.13%	0.12%	14.22%	0.12%	0.03%
Meat	1.07E-02	1.74E-02	5.98E-03	9.02E-03	6.39E-03	6.95E-02	5.63E-03	2.41E-03
	0.99%	1.59%	0.56%	0.84%	0.60%	5.17%	0.53%	0.14%
Total	1.08E+00	1.09E+00	1.07E+00	1.07E+00	1.07E+00	1.34E+00	1.07E+00	1.66E+00

Table II: Calculation results for the annual total population doseinduced by the released radio-nuclides

Radioactive nuclide	Annual total population dose (mSv)							
	Effective	Gi-lli	Bone	Liver	Kidney	Thyroid	Lung	Skin
^{3}H	3.49E-02	3.49E-02	3.49E-02	3.49E-02	3.49E-02	3.49E-02	3.49E-02	3.49E-02
	3.23%	3.21%	3.28%	3.26%	3.27%	2.60%	3.26%	2.10%
^{58}Co	2.38E-02	2.85E-02	2.29E-02	2.34E-02	2.30E-02	2.28E-02	2.31E-02	2.77E-02
	2.19%	2.62%	2.15%	2.18%	2.16%	1.70%	2.16%	1.66%
^{60}Co	8.69E-01	8.82E-01	8.66E-01	8.73E-01	8.67E-01	8.66E-01	8.68E-01	1.03E+00
	80.24%	81.03%	81.27%	81.36%	81.29%	64.44%	81.12%	62.15%
^{85}Kr	8.46E-05	8.46E-05	8.46E-05	8.46E-05	8.46E-05	8.46E-05	1.98E-04	9.36E-03
	~0%	~0%	~0%	~0%	~0%	~0%	0.02%	0.56%
^{131}I	1.49E-02	1.27E-03	1.23E-03	1.19E-03	1.19E-03	2.80E-01	1.22E-03	2.06E-03
	1.37%	0.12%	0.11%	0.11%	0.11%	20.81%	0.11%	0.12%
^{133}Xe	1.65E-02	1.65E-02	1.65E-02	1.65E-02	1.65E-02	1.65E-02	1.87E-02	1.65E-01
	1.52%	1.51%	1.55%	1.54%	1.55%	1.23%	1.75%	9.92%
^{135}Xe	6.38E-03	6.38E-03	6.38E-03	6.38E-03	6.38E-03	6.38E-03	6.62E-03	4.69E-02
	0.59%	0.59%	0.60%	0.59%	0.60%	0.47%	0.62%	2.82%
^{134}Cs	1.95E-02	1.98E-02	1.95E-02	1.95E-02	1.95E-02	1.94E-02	1.93E-02	2.65E-02
	1.80%	1.81%	1.83%	1.82%	1.83%	1.45%	1.81%	1.59%
^{137}Cs	9.80E-02	9.91E-02	9.82E-02	9.80E-02	9.80E-02	9.80E-02	9.80E-02	3.18E-01
	9.05%	9.10%	9.21%	9.13%	9.19%	7.30%	9.15%	19.08%
Total	1.08E+00	1.09E+00	1.07E+00	1.07E+00	1.07E+00	1.34E+00	1.07E+00	1.66E+00

Table III: Calculation results for theannual total effective dose to individual for three age groups: child, teenager and adult at the locations of interest.

Location	Direction	Distance (km)	Annual total effective dose to individual for age groups (mSv) for age groups		
			Adult	Teenager	Child
VinhTuong (Thuan Nam)	N	1.165	1.46E-04	1.93E-04	3.15E-04
Son Hai (Thuan Nam)	S	2.18	3.15E-05	4.16E-05	6.77E-05
TuThien (Thuan Nam)	N	3.38	2.36E-05	3.12E-05	5.07E-05
BauNgu (Thuan Nam)	NW	5.9	6.01E-06	7.92E-06	1.29E-05
HoaThuy (NinhPhuoc)	NNW	9.1	3.45E-06	4.54E-06	7.34E-06
Phuoc Lap (Thuan Nam)	NW	11.25	1.96E-06	2.57E-06	4.15E-06
Quan The (Thuan Nam)	W	12.5	2.47E-06	3.24E-06	5.23E-06
HieuThien (Thuan Nam)	WNW	13.45	1.61E-06	2.12E-06	3.42E-06
Thuong Diem (Thuan Nam)	SW	15.48	1.58E-05	2.09E-05	3.41E-05

Lac Tien (Thuan Nam)	WSW	14.42	3.65E-06	4.80E-06	7.78E-06
Ca Na (Thuan Nam)	SW	16.79	1.38E-05	1.83E-05	2.99E-05
Phan Rang - Thap Cham	N	14.2	1.98E-06	2.59E-06	4.18E-06
Lien Huong (TuyPhong)	SW	38.75	3.34E-06	4.41E-06	7.19E-06
Cho Lau (BacBinh)	WSW	60.9	3.15E-07	4.09E-07	6.53E-07
Thanh My (Don Duong)	NW	66.3	1.02E-07	1.31E-07	2.08E-07
To Hap (Khanh Son)	N	63.6	1.56E-07	2.02E-07	3.20E-07
Cam Ranh	NNE	62.4	4.61E-07	6.03E-07	9.69E-07
Lien Nghia (DucTrong)	WNW	78	8.03E-08	1.03E-07	1.63E-07

We can see that the obtained results for dose evaluation induced by the released radioactive nuclides from the NPP Ninh Thuan 1 are much lower than the permitted value of 1 mSv guided by NRC Regulations [7].

The annual individual dose values given in Table 3 show a quickly decreasing tendency with respect to distance, for example at Lien Nghia village which is nearly 80 km in the WNW direction from the NPP site the dose value is about 4 orders less than the dose at the Vinh Tuong, near the NPP site.

From the obtained calculation results shown in tables 1-3 we can see that:

- From table I: The dose induced by the ground deposition gives the greatest contribution, from 74.2% for thyroid to 93.6% for bone, to the annual total population dose.

- From table II: The radioactive isotope ^{60}Co induces a greatest dose contribution, from 62 to 81%, tothe annual total population dose. This is consistent with the real released data at normal operation conditions, where the ^{60}Co isconsidered as a typical representative for the radioactive nuclei produced from neutron-induced activation reactions on the reactor core materials and moderatorand released via corrosion phenomenon [8]. Besides, the contribution from the fission products, typically ^{137}Cs, to the total dose is clearly proved.

- From table III: The effective dose for the child is about 1.5 and 2 times, respectively, greater than those for the teenager and adult.

Based on the calculation results for the annual dose evaluations obtained from analyzing the database and practical conditions in the area around the NPP Ninh Thuan 1 we can conclude that the gaseous effluent release from the NPP satisfies the requirement on radiation safety for population and production activities in the normal operating condition.

IV. CONCLUSION

We have built the data inputs for two computer codes XOQDOQ and GASPAR based on collecting and processing a huge database including the data on population and population distribution for distinct age groups, the data on agricultural production activities, the terrain data and the meteorological data in the five-year period 2009 - 2013.

The obtained calculation results for the annual total population dose and the annual individual dose at the specific locations within the 80 km radius from the site of NPP Ninh Thuan 1 showed that under a normal operation scenario with the routine release of radioactive nuclides from the NPP to the atmosphere all

the dose values are much less than the permitted limit of 1 mSv.

The X/Q value and D/Q value distributions which are predominant in two directions of North East and South West are consistent with the wind rose distribution in the 80 km radius from the NPP site.

ACKNOWLEDGEMENT

This work has been performed in frame work of the National Program on Science and Technology in 2011-2015 Periodunder grant no. KC-05.04/11-15.

REFERENCES

[1]. UNSCEAR 2000 Report Vol.1, Exposures from man-made sources of radiation.

[2]. UNSCEAR 2008 Report Vol.2, Radiation exposures in accidents.

[3]. XOQDOQ: Computer Program for the Meteorological Evaluation of Routine Releases at Nuclear Power Stations; NUREG/CR-2919; J. F. Sagendorf, J. T. Goll, and W. F. Sandusky, U.S. Nuclear Regulatory Commission; Washington, D.C; (1982).

[4]. GASPAR II – Technical Reference and User Guide, NUREG/CR-4653; D. L .Strenge, T. J. Bander, J. K. Soldat; U.S. Nuclear Regulatory Commission; Washington, D.C; (1987).

[5]. Regulatory Guide 1.109 – Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I; U.S. Nuclear Regulatory Commission, (1977).

[6]. Regulatory Guide 1.111 - Methods for Estimation Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light – Water – Cooled Reactor; U.S. Nuclear Regulatory Commission, (1977).

[7]. Subpart D-Radiation Dose Limits for Individual Members of the Public; Part 20-Standards for protection against radiation;NRC Regulations (10 CFR).

[8]. Manual for Reactor Produced Radioisotopes, IAEA-TECDOC-1340, Jan. 2003, P.O.Box 100, A-1400 Vienna, Austria.