THEORETICAL DETERMINATION OF THE SIZE OF THE EMERGENCY PLANNING ZONES PERTINENT TO A POSTULATED SEVERE ACCIDENT OF THE SAFARI-1 RESEARCH REACTOR AT NECSA DUE TO GASEOUS RELEASES

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Abstract

In South Africa the requirement for emergency planning at nuclear installations is a statutory requirement. Emergency planning consists of two distinct functions, preparedness and response. The preparedness functions deals proactively with issues such as threat quantification, the infrastructure and resources to manage the threat, and aspects of mitigating the consequences to the worker, public and environment. The response function, on the other hand, deals with actions and organisations implemented during the event. Preparedness therefore is the planning and preparation function and response is the actual implementation of all the planned activities.

Due to the public sensitivity to effects of radiological and nuclear emergencies, it is of the utmost importance to be appropriately prepared to manage any unplanned event, even those of very low probabilities, before it manifests. Preparedness commences with threat identification and threat quantification. The design of the facility should eliminate most of the threats. However, those of very low frequencies would not be accounted for by design. It is for these events that the emergency plan must be in place.

At SAFARI-1, the research reactor at Necsa, changes were made to the composition of the fuel elements. These changes would affect on the quantities of radioactive material that could be released under remote circumstances. That necessitated a recalculation of the extent of planning and the size of the zone for which this planning is performed. The emergency

planning zone at question is that in which urgent protective actions may require implementation. Off-site consequences are included.

The perimeter of the radial zone was derived to be at the level at which sheltering, as a protective action, is to be implemented. Calculation of the zone size was performed with acceptable codes, PC COSYMA and Interras. The input data required for the use of the code, include amongst other, the source term and meteorological information.

The outputs of the codes were compared with work done previously on fuel elements containing 200g U-235. It was concluded, from the results of this work, that the size of the urgent protective may be reduced to less than one kilometre from the point of release, if all the assumptions that were made are valid and all the uncertainties regarding the source term and dispersion modelling are acceptable. However more work is required on the validation of the model, the verification of assumptions and uncertainties regarding the source term.

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Declaration

I hereby declare that the work contained in this dissertation is my own work and has not been submitted for a degree or other qualification in any other university or institution.

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Chapter 1
Introduction

1.1. Title

Determine theoretically the size of the emergency planning zones pertinent to a postulated severe accident of the SAFARI reactor at NECSA due to gaseous releases.

1.2. Introduction

In order to operate legitimately, a holder of a nuclear installation license, such as Necsa, requires authorization from the National Nuclear Regulator. In order for the regulator to issue an authorization, the Operator must perform a safety assessment on the quantities of radioactive material and the operational processes. The Regulator reviews the safety assessment with regard to safety of the workers, the public and the environment under normal and accident conditions for compliance with applied standards before an authorization with specific conditions is issued. When the type or quantity of radioactive material or the operational process requires to be changed, e.g. the content of the fuel rods in the SAFARI reactor, the safety assessment must be revised and resubmitted to the Regulator for approval. The Regulator issues revised conditions of operation when it is satisfied that the safety criteria will be met.

In this instance the use of new fuel assemblies has been reviewed. Due to the change in fuel composition there would be a change in fission products generated during fuel burn-up. This requires changes in the conditions of operation. One of the conditions of operation is that NECSA should have an effective emergency plan. The boundaries of the emergency plan would be determined by the potential effect on the public and the environment of the radioactive material that could be released through the ventilation stack at SAFARI. The effect of a potential release is a function of the type of material released, the quantities released, the intake pathways and the duration of the exposure. Due to changes in some of these parameters it is required to review the boundaries of the existing emergency planning zones.

The aim of this study is to determine theoretically, by using predetermined codes, for gaseous releases, the size of the emergency planning zones pertinent to a postulated severe accident of the SAFARI 1 research reactor at Necsa. In addition, a quick reference guide consisting of a spreadsheet or a graphic display of results for a unit release for various isotopes under different atmospheric conditions would be derived.

1.3. <u>Problem statement</u>

The emergency planning zones of Necsa must be modelled theoretically in order to determine the area for which emergency planning must be performed. The re-modelling was necessitated by a change in gaseous source term that could be released from the SAFARI reactor.

1.4. <u>Methodology</u>

Gathering and analysis of information from local and international sources to determine:

- The criteria for sizing the urgent protective action zone for emergency planning;
- Through modeling, the dispersion of gaseous radioactive material from a given source with uncertainties regarding the release fractions of radioactive material and the amount of conservatism in the results of the model;
- The prevailing meteorological conditions at the Necsa site in order to perform dispersion modeling for:
  - The worst case atmospheric conditions at Necsa and;
  - The most probable atmospheric conditions.
- The source term to be applied in the dispersion model;
- How the results of two frequently used codes compare with each other; and
- How the results from this study compare with results from previous studies.

1.5. Demarcation of the terrain of study

1.5.1. Study

The research was performed to determine the boundaries for the urgent protective action zone at Necsa based on a postulated severe accident for a gaseous release from the SAFARI-1 stack.

1.5.2. Assumptions

The following assumptions were made with an unquantified amount of uncertainty:

- That the dispersion models used provide conservative results;
- That the impacts of the terrain (topography) on the dispersion patterns would not affect the results to such an extent that the results cannot be applied to determine the size of the urgent protective action zone;
- That the worst case postulated scenario is indeed the worst case;
- That the source term specified for the atmospheric release and the associated fractions of release has been correctly derived.

1.5.3. Importance

It is important:

- For Necsa, as a Holder of an authorization (Operator) to operate, to determine the extent of the urgent protective action zone in which detailed emergency planning is required in order to be able to adequately prepare, in terms of planning and preparation, for any possible emergency situation at Necsa, which could involve workers, the public and the environment;
- For Necsa to be adequately prepared to respond to any possible emergency situation at Necsa;
- For Necsa, as the Operator, and the Off-site Authorities, to be adequately prepared to activate well trained response teams to efficiently mitigate the consequences of any potential situation;

- And for the National Nuclear Regulator (NNR), as the national regulatory authority, to have the confidence that the extent of emergency preparedness and response, involving Necsa and the Off-site Authorities, would be appropriate to mitigate consequences to acceptable national and international standards in order to protect the worker, the public and the environment.

Chapter 2
Emergency planning

2.1 Legal framework in South Africa

The National Nuclear Regulator Act, No 47 of 1999, governs the Nuclear Industry in South Africa. The aim of the act is "to provide for the establishment of a National Nuclear Regulator in order to regulate nuclear activities" and "to provide safety standards and regulatory practices for protection of persons, property and the environment against nuclear damage". [9]. In section 38 of the act, it is specified that the holder of a nuclear authorization, (the Operator) must have an emergency plan approved by the National Nuclear Regulator.

2.2 Emergency planning

Emergency planning is the collective name given by the IAEA [11] for emergency preparedness and emergency response. The preparedness section refers to proactive actions such as planning, training, etc. and response refers to the actual actions implemented for controlling the emergency situation. These include actions of first responders, classification of the event, emergency categorization, decision making regarding the implementation of mitigating actions, etc.

Furthermore, the nature of emergency planning would vary in accordance with the threat that requires to be managed. Internationally [11] there is also a distinction made between emergency planning for sources and emergency planning for installations. Sources refer to smaller quantities of radioactive material, such as a sealed source used in a teletherapy unit in hospital, where installations would refer to nuclear facilities such as Pelindaba (fuel cycle facility) or Koeberg (nuclear reactor).

Lastly, emergency planning has objectives for protection and objectives for safety. The objectives for protection refer to the prevention of detrimental health effects, and the objectives for safety refer to conventional safety aspects such as physical injuries and damage to equipment or property.

2.3 Goals of emergency response for sources

Protection objective: to prevent the occurrence of deterministic effects in individuals by keeping doses below the relevant threshold and to ensure that all reasonable steps are taken to reduce the occurrence of stochastic effects in the population at present and in the future.

Safety objective: to protect individuals, society and the environment from harm by establishing and maintaining effective defences against radiological hazards from sources. [11]

2.4 Goals of emergency response for nuclear installations

Radiation protection objective: To ensure mitigation of the radiological consequences of any accident

Technical safety objective: To take all reasonable practical measure to prevent accidents in nuclear installations and to mitigate their consequences should they occur; to ensure with a high level of confidence that, for all possible accidents taken into account in the design of the installation, including these of very low probability, any radiological consequences would be minor and below prescribed limits. [11]

2.5 Practical goals of emergency response.

The goals for emergency response are:

- To regain control of the situation;
- To prevent or mitigate consequences at the scene;
- To prevent the occurrence of deterministic health effects in workers and the public;
- To render first aid and to manage treatment of radiation injuries;
- To prevent, to the extent practicable, the occurrence of non-radiological effects on individuals and among the population;
- To protect, to the extent practicable, the property and the environment; and
- To prepare, to the extent practicable, for the resumption of normal social and economic activity. [11]

2.6 *Principles of intervention*

The principles of intervention are two fold.

- Principle of Justification: Any proposed intervention shall do more good than harm; and

- Principle of Optimisation: The form, scale and duration of any intervention shall be optimised so that the net benefit is maximized. [11]

2.7 Goal of emergency preparedness

The primary goals of emergency preparedness are:

- To achieve the goal of emergency response in accordance with the principles of intervention by having a sound program for emergency preparedness in place as part of the infrastructure for protection and safety; and
- To build confidence that an emergency response would be managed, controlled and coordinated effectively. [11]

2.8 Practical goal of emergency preparedness

The practical goals of emergency preparedness is to ensure that arrangements are in place for a timely, managed, controlled, coordinated and effective response at the scene, and at the local, regional, national and international level, to any nuclear or radiological emergency. [11]

2.9 Emergency planning Requirements

The National Standards for the Nuclear Industry in South Africa has not yet been approved. However, the National Nuclear Regulator has issued a document, LG-1036 "EMERGENCY PREPAREDNESS AND RESPONSE REQUIREMENTS" [10]. This document is based on update of IAEA-

TECDOC-953 [4], "Method for developing Arrangements for Response to a Nuclear or Radiological Emergency".

The TECDOC refers to Urgent Protective Action Zones (UPZ) as "a predestined area around a facility in threat category I or II, where preparations are made to promptly implement urgent protective actions based on environmental monitoring data and assessment of facility conditions." In Category I facilities off-site consequences of severe deterministic nature is expected. In category II facilities, severe deterministic effects off-site is not expected. SAFARI falls in threat category II according to the categorization criteria specified in the same TECDOC. The IAEA also proposes, as a guideline, that the size of the Urgent Protective Action Zone (UPZ) of a category II facility is between 0.5 and 5 km. Categorization is based on the potential nuclear damage to people, property or the environment around that facility.

In the same TECDOC in Appendix 1 the urgent protection actions are tabulated below. In the table, the avertable dose referred to is effective dose accrued over a specified period.

Urgent protection actions

Action	Avertable dose
Sheltering	10 mSv
Evacuation	50 mSv
Iodine prophylaxis	100 mGy absorbed by thyroid

Avertable dose is dose that could be averted if a countermeasure or a combination of countermeasures was taken. The dose referred to is effective dose (whole body dose) and includes exposures from all pathways accrued over a specified short period.

The South African public dose limit is 1 mSv/a. The current worker dose limit is 50 mSv/a, but is expected to be lowered to 20 mSv/a with a maximum of 50 mSv averaged over a 5 year period. The sheltering limit lies in between. In addition, urgent protective actions: Sheltering, evacuation, iodine prophylaxis are also specified in Schedule (V) of the Safety Series No. 115, International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, International Atomic Energy Agency, Vienna, 1996 [1]. Therefore the boundary for the Urgent protective action zone was taken as the boundary for implementing sheltering, which is 10 mSv.

If equivalent dose, or dose to the organ was taken as the limit, the following comparison could be made.

Comparison of action levels based on organ dose for sheltering

Organ	PC COSYMA [14]	IAEA [4]	Schuykens [15]	ANSI/ANS-15.16 [17]
Lung	50 mSv		50 mSv	
Thyroid	50 mSv	100 mGy		500 mSv
Effective dose	5 mSv	10 mSv		100 mSv

Organ specific action levels, using organ-weighting factors, can be derived from the sheltering action level of 10 mSv as a basis. These values would be useful when comparing organ dose with effective dose to determine whether dose to any organ may influence the size of the emergency planning zone. Using an action level as a basis for another action level is not preferred. It would be more correct to derive action levels from organ sensitivity to radiation. More work is required in this area. However, these values could be used to determine the relative importance of radiation to the different organs.

Organ	Weighting factor [1]	Shelter criteria (mSv)	Rounded values (mSv)
Whole body	1	10	10
Lung	0.12	83	100
Thyroid	0.05	200	200
Skin	0.01	1000	1000

2.10 Emergency classes

In order to activate the response the event should be classified. This classification is performed according to the possible extent of the consequences of the event. Four different classes can be identified, which could evolve from a lower class into a higher class. Actions implemented would be aimed at mitigating consequences of the event, protecting the people and the environment and control of the consequences.

2.10.1 Alert

An emergency is classified as an alert when a safety barrier has been broken that could lead to a release of radioactive material or the exposure of people. Usually the extent of consequences is limited to a small, localized area within a facility or building, for example spillage of a container with a small amount of granulated radioactive material.

2.10.2 Facility emergency

The effect of the event would have expected consequences further than the immediate location of the event, but limited to the inside of the building or facility, such as a spillage of an amount of liquid.

2.10.3 Site emergency

The consequences of the event would be expected to extend beyond the perimeters of the building, but be limited to the site owned or fenced by the Operator. In this case members of the public, who are on-site may also be affected. The mitigating actions would be limited actions implemented by the Operator. The responsibility of the actions would be limited to the Operator.

2.10.4 General emergencies

The effect of a general emergency would be expected to extend beyond the boundaries of the site perimeter. The authority of the Operator usually ends at the site boundary; therefore timeous activations of off-site Authorities would be required.

2.11 Emergency planning Areas and zones.

2.11.1 Emergency planning areas

Emergency planning can be divided into two areas distinctively defined by the authority for response. The on-site area is that area surrounded by the security perimeter for which the holder of an authorisation (Operator) is responsible. The holder has the authority to implement and control mitigating actions as required. The Operator usually owns this area.

In the off-site area, the property is usually privately owned and the holder has no authority over actions implemented on that land. In such a case the local, provincial or national authority is responsible for the implementation of the mitigating actions.

2.11.2 Emergency planning Zones

Emergency planning zones are classified in terms of the severity of possible effects due to a postulated worst-case scenario. The boundary of the zone is determined by a specific dose value expected at that point when dispersion is modelled. In these zones planning for the implementation of urgent actions to avert the detrimental health affects of unwanted exposure to radioactive material is required. The action will be determined by the magnitude of the effect on the worker, public or environment. Three distinct zones can be identified.

2.11.2.1 Precautionary action zone (PAZ)

The precautionary action zone starts at the source of release and extends to the point where severe deterministic health effects are expected when the release of radioactive material is considered. Severe deterministic effects are considered at doses in the region of one sievert (Sv) and higher. Actions are based on in-plant conditions and may be implemented before the release commences or shortly thereafter. The actions would be severe, such as evacuation of the population in that area.

2.11.2.2 Urgent protective action zone. (UPZ)

The size of the UPZ is determined by the urgent protective actions to be implemented. These actions include sheltering, evacuation and the prophylaxis of stable iodine. The lowest level of implementation of and mitigating action is 10 mSv, where sheltering is required. Decision-making on the protective actions to be implemented will be based on in-plant conditions and results from environmental monitoring by field teams. Subjective criteria based on cost benefits would also be applied. The actions will be implemented to avert possible doses.

2.11.2.3 Long term planning zone (LPZ)

The boundaries of the long term planning zone is determined by the actions that may be required in the late phase. The late phase is that phase which is after termination of the immediate urgent protective actions and that may require actions such as temporary relocation or resettlement or food ban. These implementations of these actions depend on the results of environmental surveillances and may be implemented for very long periods of time. The zone size may extend to several kilometers further than that of the UPZ. In this region, no detailed planning is required since there should be sufficient time to plan and take action.

2.12 Planning levels and responsibilities

Effective emergency planning response requires integrated planning of emergency actions at three levels, which is from the Operator, the Off-site Authorities and thirdly, Authorities across international boarders. In the case of Necsa, Authorities across international borders would not be required.

2.12.1 Operator responsibilities

The operator would typically be responsible for the following actions:

- Taking immediate action to mitigate the emergency
- Protect people on site
- Notify off-site officials and recommend protective actions and provide technical assistance.
- Provide radiological monitoring

2.12.2 Responsibilities of Off-site Authorities

The responsibilities of Off-site Authorities may typically include actions such as public notification, prophylaxis of stable iodine, sheltering, evacuation, mass care centres, relocation, radiological monitoring, decontamination, fire fighting, traffic control, food control, protection of the public and property, etc.

2.13 Emergency Action levels.

In preparing for an emergency, action levels for the implementation of mitigating factors must be determined by the Regulatory Authority for application by the holder. In South Africa, International standards are applied. These standards are based on effective dose. Tabulated below are the recommendations proposed by the International Atomic Energy Agency (IAEA) [1], which are promulgated by the National Nuclear Regulator.

Urgent protective actions: Sheltering, evacuation, iodine prophylaxis [1]

Action	Avertable dose
Sheltering	10 mSv in 2 days (417 $\mu Sv.h^{-1}$)
Evacuation	50 mSv in 1 week (298 $\mu Sv.h^{-1}$)
Iodine prophylaxis	100 mGy absorbed by thyroid

Generic action levels in foodstuffs (BSS Schedule V) [1]

Radionuclide	Foods destined for general consumption ($kBq.kg^{-1}$)	Milk, infant foods and drinking water ($kBq.kg^{-1}$)
Cs-134, Cs-137, Ru-103, Ru-106, Sr-89	1	1
I-131		0.1
Sr-90	0.1	
Am-241, Pu-238, Pu-239	0.01	0.001

Temporary relocation and permanent resettlement [1]

Action	Intervention level (mSv)	Operational Intervention Level ($\mu Sv.h^{-1}$)
Initiating temporary relocation	30 mSv in 1 month	42
Termination of temporary relocation	10 mSv in 1 month	14
Permanent resettlement	1 Sv in lifetime (50 a)	2.3

Action levels of dose for acute exposure to low LET radiation.

Organ or tissue	Action Level (Projected absorbed dose to the organ or tissue in less than 2 days (Gy)	Expected dose rate (mGy/h)
Whole body	1	20
Lung	6	250
Skin	3	62.5
Thyroid	5	104
Lens of eye	2	41.6
Gonads	3	62.5
Foetus	0.1	2

Chapter 3
Transport of Radionuclides in the Atmosphere

3.1 Exposure pathways

Radiological harm to the human can be caused by radioactive material from an external or and internal pathway. The external pathway would include exposure to a source outside the body such as a passing cloud of air born radioactive particulates or from particulates deposited on a surface. Exposure could also come from and source within the body when radioactive material was inhaled, ingested or absorbed through the skin. This is called the internal pathway of exposure.

3.2 Transport of Radionuclides in the Atmosphere

3.2.1 Atmospheric Dispersion

Dispersion of radioactive material via the atmospheric pathway consists of two mechanisms. [3] Diffusion is the process during which the released particulates spread from an area of high concentration to an area of low concentration in order to reach equilibrium. Transportation is the process of moving the released particulates from point A to point B. In order to move the particulates a force, such as the wind is required. When the effects of diffusion and transportation is added together it, is called dispersion.

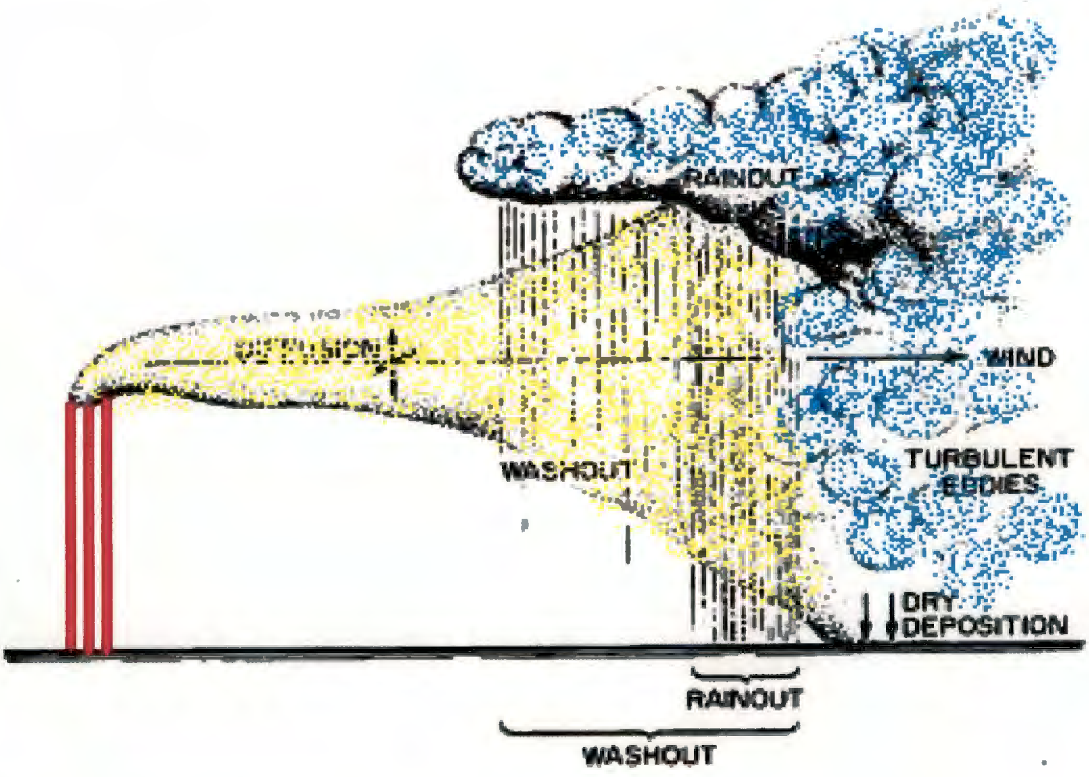


Figure 1 Atmospheric dispersion and removal process.

Radionuclides are removed from the atmosphere through various processes, as demonstrated in figure 1. When the particulates is taken up in the clouds and is part of the rain forming process, it is removed from the atmosphere through rainout. When the particulates pass underneath a raining cloud and is removed by the rain, it is called washout. Particles can also settle to the ground through normal gravitation or it can be removed from the atmosphere by vegetation or physical structures. These processes are called dry deposition.

3.2.2 <u>Atmospheric turbulence and dispersion.</u>

The bottom part of the atmosphere, from ground level upwards is called the Planetary Boundary Layer (PBL). [3] The PBL is illustrated in figure 2. In this area the earth's surface has effects of importance to the dispersion of radionuclides on the atmosphere. The effects are caused by various different mechanisms, such as the surface roughness on turbulence and the irradiation of heat on buoyancy. In the atmosphere these effects would result in temperature variations and differences in wind speed, which varies with height heights.

The atmospheric stability in the PBL describes the intensity of turbulence and therefore the diffusion process. To illustrate atmospheric stability due to turbulence, a parcel of air, such as a balloon can be used. The air inside the balloon does not mix with its surroundings. If the balloon has no net force working in on it, it would not move in any direction. In this case this atmosphere would be called neutral. Atmospheric conditions are considered unstable when the balloon is moved further away from its source of origin by forces in the atmosphere. In stable conditions, the balloon would tend to move back to it position of origin.

Atmospheric stability may also be a function of temperature (buoyancy). In dry air, the rate of temperature change is -0.98 ^{0} C/100 m. This is called the dry adiabatic lapse rate. Therefore if the balloon were displaced adiabatically at this lapse rate, it would be exposed to the same temperature and pressure as it's surroundings, and therefore no net force will be created. The atmospheric condition under these circumstances is said to be neutral. When the lapse rate in the environment is greater than dry adiabatic, the balloon will be warmer in the upward motion than the environment and be accelerated upward. Similarly in the downward motion, the balloon will be cooler and accelerated downwards. This atmospheric condition in called unstable. When the temperature lapse rate is less than dry adiabatic, in the upward motion the balloon will be cooler and decelerate to its original position. Similarly in the downward motion, the balloon will be warmer and be accelerated upward to its original position. These conditions are called stable.

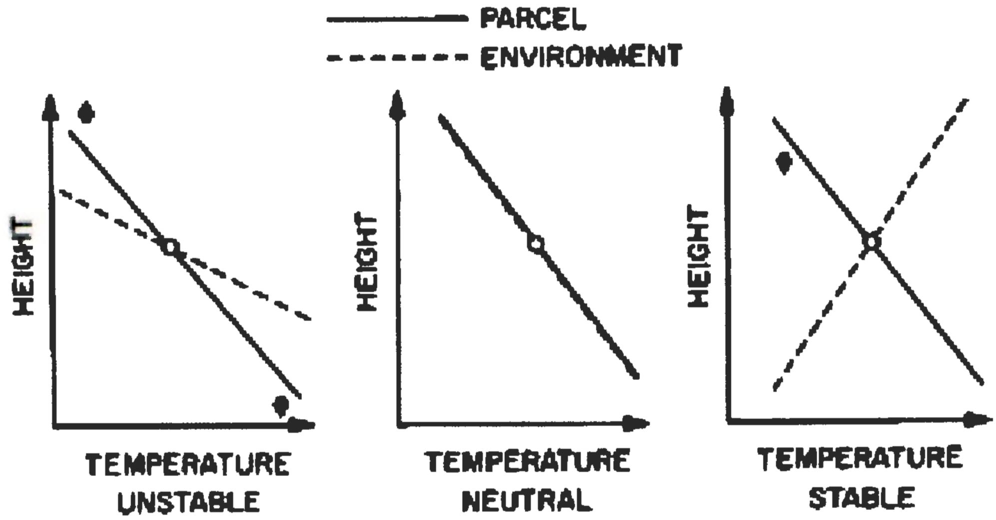


Figure 2 Illustration of PBL stability conditions.

3.2.3 Estimates of Atmospheric Dispersion

This section outlines the basic procedures used in making air pollution dispersion estimates. [12]

Figure 3 shows how one would mathematically simulate dispersion from a smoke stack.

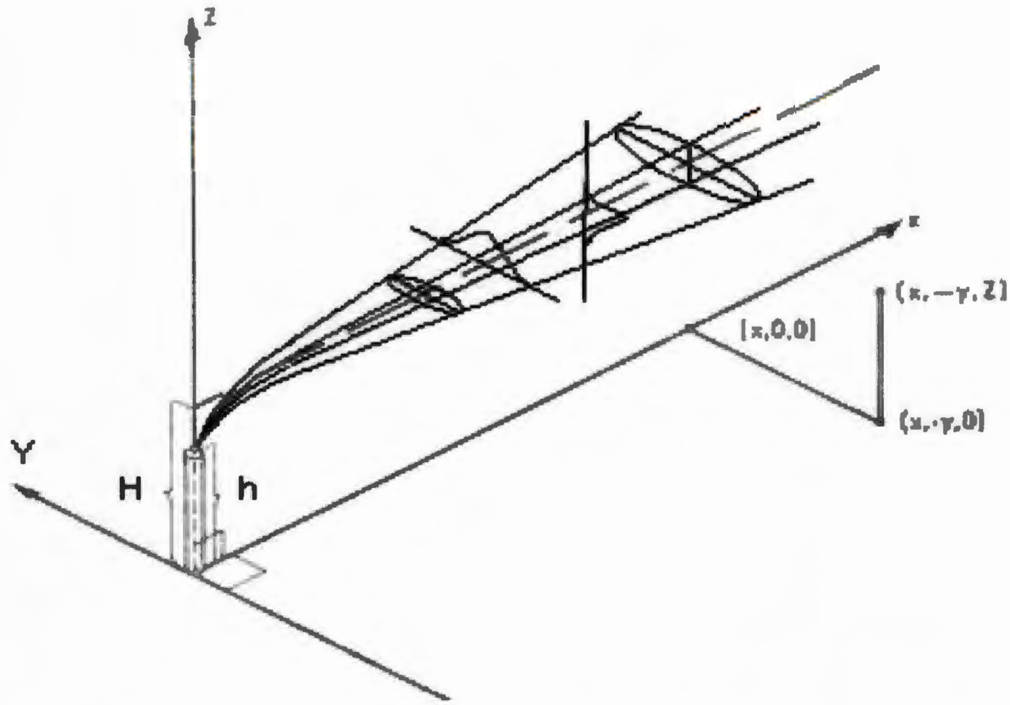


Figure 3: Coordinate system showing Gaussian distribution in the horizontal and vertical.

The origin is at ground level or beneath the point of emission, with the x-axis extending horizontally in the direction of the mean wind. The y-axis is the horizontal plane perpendicular to the x-axis, and the z-axis extends vertically. The plume (pollutants emitted from the stack) travels parallel to the x-axis.

The concentration of gas, χ, at the point (x,y,z) from a continuous emission with emission height, H, is given by the following equation: (1)

$$\chi(x,y,z;H) = \frac{Q}{2\pi \sigma_y \sigma_z u} * \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

$$\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right\}$$

Where:

χ(x, y, z; H) = concentration of gas at any x,y,z coordinate

H = height of the plume centreline when it becomes level

u = mean wind speed affecting the plume

Q = uniform emission rate of the pollutant

σ_y = standard deviation of plume concentration distribution in the horizontal direction

σ_z = standard deviation of plume concentration distribution in the vertical direction

The plume rise depends on stack temperature and flow rate as well as atmospheric conditions. The plume spread has a **Gaussian distribution** in the horizontal and vertical planes. This equation assumes that total reflection of the plume takes place at the earth's surface, (i.e. there is no deposition or reaction at the surface.) The values of both σ_y and σ_z are evaluated in terms of the downwind distance, x.

Equation (1) is valid where there is no diffusion in the downwind direction. This may be assumed if the release is continuous or if the duration of release is equal to or greater than the travel time (x/u) from the source to the location of interest.

For concentrations calculated at ground level, z = 0, the equation simplifies to: (2)

$$\chi(x,y,0;H)=\frac{Q}{\pi\sigma_y\sigma_z u}*\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\left\{\exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right]\right\}$$

When the concentration is to be calculated along the centreline of the plume, y = 0, the following results: (3)

$$\chi(x,0,0;H)=\frac{Q}{\pi\sigma_y\sigma_z u}*\left\{\exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right]\right\}$$

For a ground-level source with no effective plume rise, H = 0, the equation simplifies even further to: (4)

$$\chi(x,0,0;0)=\frac{Q}{\pi\sigma_y\sigma_z u}$$

The amount of dispersion, represented by σ_y and σ_z, varies with the turbulent structure of the atmosphere, the height above the surface, the surface roughness, the sampling time over which the concentration is to be estimated, the wind speed, and the distance from the source.

The turbulent structure of the atmosphere and wind speed determines the stability class of the atmosphere. Values for σ_y and σ_z are estimated from the stability of the atmosphere, which is in turn estimated from the wind speed at a height of about 10 meters and, during the day, the incoming solar radiation or, during the night, the cloud cover. Stability categories are given in the following table:

	Day	Day (Incoming solar radiation)	Day	Night	Night
Surface wind speed at 10m (m/sec)	strong	moderate	slight	Thinly overcast or >4/8 cloud cover	Clear or <3/8 cloud cover
< 2	A	A-B	B		
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
> 6	C	D	D	D	D

Class A is the most unstable class and class F is the most stable class. Night refers to the period from 1 hour before sunset to 1 hour after sunrise. The neutral class, D, can be assumed for overcast conditions during day or night, regardless of wind speed. These methods will give representative indications of stability over open country or rural areas, but are less reliable for urban areas due to factors such as local heating. However, methods are available for adjusting classifications to account for urban areas.

Once the stability class is known, the values of σ_y and σ_z may be determined from Figure 4 and Figure 5 below: (For these graphs the following assumptions are made: the sampling time is about 10 minutes, the height is the lowest several hundred meters of the atmosphere and the surface is relatively open country.)

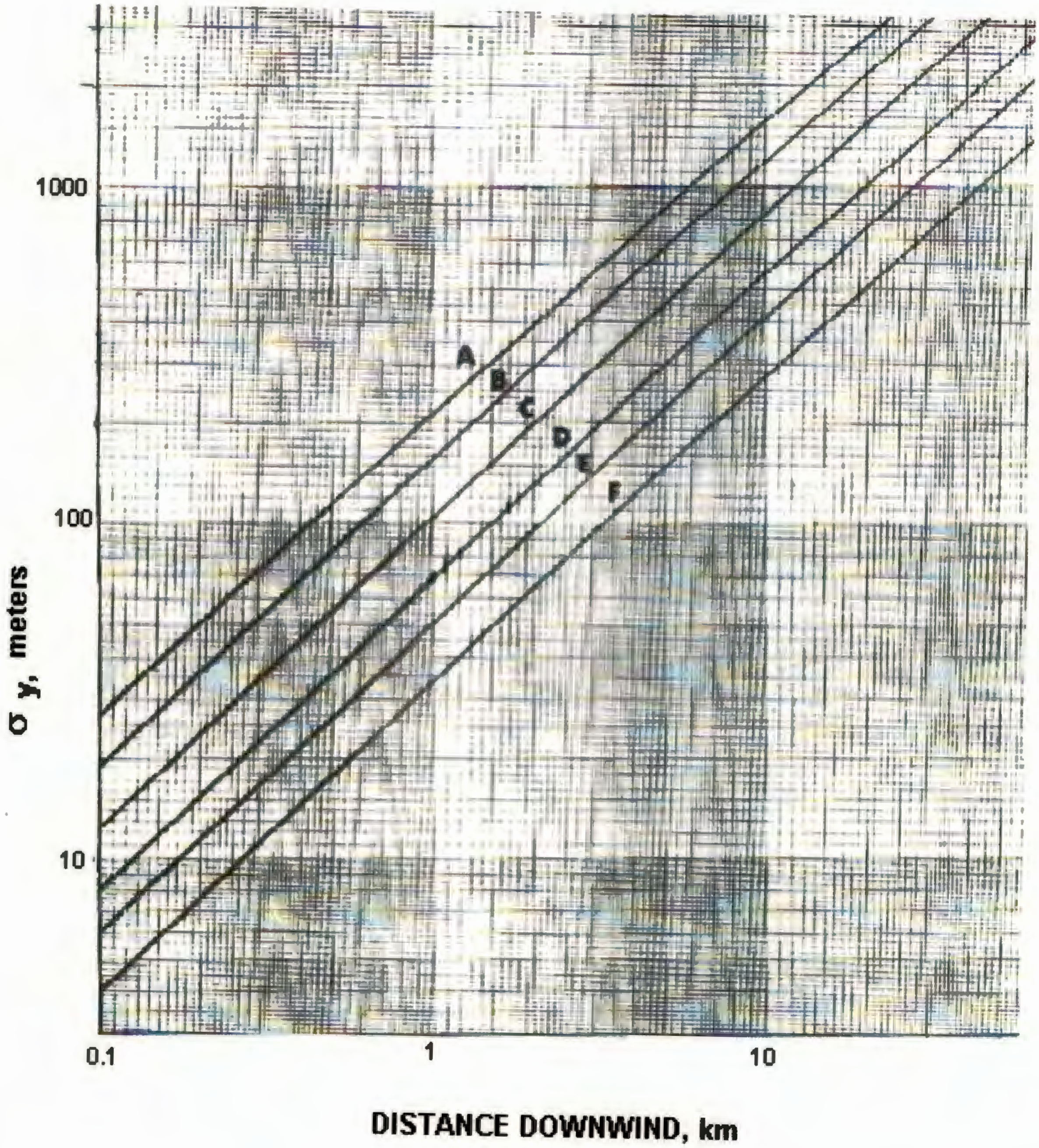


Figure 4: Horisontal dispersion coefficient as a function of downward distance from the source.

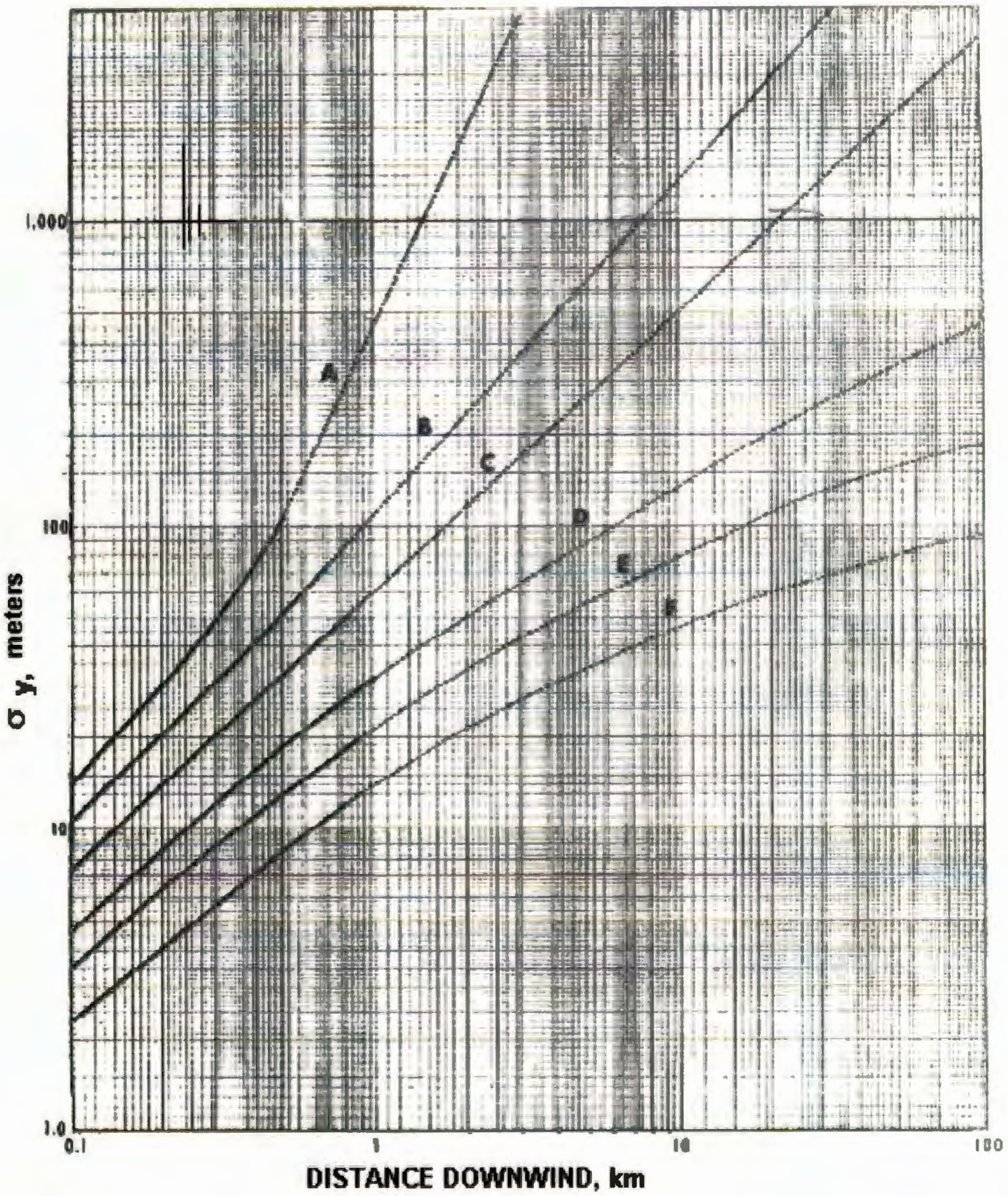


Figure 5: Vertical dispersion coefficient as a function of downward distance from the source.

3.3 Dispersion codes

Two codes were used for this study, PC COSYMA [13] and Interras [14]. It must be understood that the normal application of the codes differs vastly. PC COSYMA is normally used for proactive planning and Interras is used as a tool to provide a rough estimate under emergency conditions. It should therefore be expected that Interras would be much more conservative, giving much higher doses than PC COSYMA. PC COSYMA was used to perform the modeling and Interras was used to verify the results. Large discrepancies in the results of the code outputs were found, as predicted due to the different application of the codes. Attempts were made to explain these discrepancies.

3.3.1 PC COSYMA

The European Commission initiated a project called MARIA (Methods for Assessing Radiological Impacts of Accidents) in 1983. One of the objectives of the project was to develop a computer program system for use in accident consequence assessment. The program system COSYMA (Code system from MARIA) was developed primarily by FZK and NRPB with contributions from other organizations in the European Union (EU). The code was partly designed for use in standard applications and partly to allow users to perform detailed investigations. COSYMA is a large flexible code system, which is not user friendly and requires a mainframe computer. PC COSYMA was developed from COSYMA for routine less complex uses. Two versions of PC COSYMA are available. One for use in simple applications using default values and one where default values could be changed allowing flexibility. The model used allows for the presentation (also graphically) of results of deterministic and probabilistic calculations.

Deterministic calculations refer to a single set of atmospheric conditions (meteorological data). Probabilistic calculations refer to a situation in which a range of atmospheric data was used. Inputs can be made for gridded data on the population and on agricultural activities in the area of study. The user must also provide the source term (amount of radioactive material released, the height of release and the rate of release).

3.3.1.1 Generic PC COSYMA input

PC COSYMA has a wide range of applications, which includes the following:

- Early health effects;
- Late health effects;
- Emergency action which may be invoked;
- Doses which may be considered for invoking emergency actions;
- Criteria for imposing withdrawing emergency actions; etc.

The inputs will vary with the required output. For this study, a simplistic maximum dose at various points was required. Therefore, early effects were considered. In such a case the inputs parameters specified in the model would be limited. The following were some of the parameters that were provided:

- The source term – which is specified per nuclide. Release phases and release fractions can also be specified.
- Deposition rates – the rate at which the dispersed nuclide would settle to the ground;
- Stability class - In the example below, category “A” was used. This category influences the mixing height used by the model.
- Wind speed in meters per second;

- The rainfall;
- Wind speed and direction; etc.
- The exposure pathways included cloud shine, ground shine and inhalation, re-suspension from ground and re-suspension from clothes

PC COSYMA is a sophisticated code, which takes various other input parameters. An example of a complete input file for PC COSYMA is given in Annexure 1.

Example of PC COSYMA output

Run	S2830A1	S2830A3	S2830A5	S2830A7	S2830A8	S2830A9	S2830A15
Weather							
Stability	A	A	A	A	**A**	A	A
Mixing height (m)	1600	1600	1600	1600	**1600**	1600	1600
Wind speed (m/s)	1	3	5	7	**8**	9	15
Rain (mm)	0	0	0	0	**0**	0	0
Wind direction (deg)	360	360	360	360	**360**	360	360
Season	S	S	S	S	**S**	S	S
Results (Max)							
Distance (m)	600	350	350	350	**350**	350	350
Eff dose (mSv)	1.88	6.49	15.44	18.09	**18.22**	17.99	14.71
Thyroid (mSv)	2.15	8.35	20.09	23.58	**23.76**	23.46	19.19
Eye lens (mSv)	2.09	7.11	16.89	19.78	**19.93**	19.67	16.09
Ovaries (mSv)	1.57	5.9	14.15	16.6	**16.73**	16.51	13.51
Skin (mSv)	80.48	280.8	739.6	877.7	**886.2**	876.2	718.6
Lung (mSv)	1.93	6.88	16.42	19.25	**19.39**	19.14	15.66
B Marrow (mSv)	1.76	6.29	15.02	17.6	**17.73**	17.51	14.32
Gi tract (mSv)	1.68	5.77	13.71	16.67	**16.19**	15.98	13.07

3.3.1.2 Generic Interpretation of PC COSYMA Output

The table above provides and example of the output file used in this study. It is important to note that basis for the decisions made to determine the radial size of the emergency planning zone is effective dose because the decision to shelter is made on effective or whole body dose received within a specified period. The criteria for iodine prophylaxis pertains to the thyroid and is therefore specified as an organ dose (mGy to the thyroid). The size of the zone would be radial because topography and population densities were not considered. That means that the whole body accrued dose over a short period is considered. However, it is also important to note that the size of the emergency planning zone may also be influenced by the dose to an individual organ. The dose to the organ must be linked to the deterministic effect but are very high as can be seen from the table in section 2.13. Doses to the individual organs or tissue did not affect the size of the emergency planning zones in this study.

3.4 Information on the land use of member of the public in the formal emergency-planning zone.

The results of the land use census [7] performed by NECSA during 2002 will be used as an input to the dispersion models, PC COSYMA and Interras.

PC COSYMA is a software package used for assessing the off-site consequences of accidental releases of radioactive material to the atmosphere. The code was developed as part of the European Communities program, Methods for Assessing the Radiological Impact of Accidents (MARIA). The project was sponsored by organizations, such as KfK (Germany), National Radiological Protection Board (United Kingdom).

COSYMA contains five different models for atmospheric dispersion to be used as appropriate. The basis of the program is a segmented Gaussian plume model. The code has limited application to complex terrain. The user can specify parameters such as deposition velocity, wind speed, wind direction, rainfall and atmospheric stability. In our modelling for worst-case conditions, a straight line was used for deposition of radioactive nuclides from the plume. Washout from the plume due to rain was not considered. The model has also applications for consequence assessment, which was not required for this application. In South Africa, PC COSYMA is widely used in the nuclear industry by the National Nuclear Regulator (NNR), Nuclear Energy Corporation of South Africa (Necsa), Pebble Bed Modular Reactor (PBMR) and Eskom (Koeberg) for previous scenario modeling. This code was used for detailed analysis of gaseous releases to the environment. An example of the output is provided below.

Example: PC COSYMA dose per organ output

Cosyma Max output" Stability A wind speed 8m/s Top 25 nuclides (Section 4.4)
Dose in Sv

DISTANCE (km)	EFFECTIVE	THYROID	EYE LENS	OVARIES	SKIN	LUNG	B. MARROW	GI-TRACT
0.1	3.26E-02	4.26E-02	3.58E-02	3.00E-02	1.50E+00	3.38E-02	3.18E-02	2.91E-02
0.35	3.81E-02	4.99E-02	4.18E-02	3.51E-02	1.81E+00	3.95E-02	3.72E-02	3.40E-02
0.6	1.87E-02	2.45E-02	2.06E-02	1.73E-02	8.83E-01	1.94E-02	1.83E-02	1.67E-02
0.85	1.08E-02	1.42E-02	1.19E-02	9.97E-03	5.09E-01	1.12E-02	1.06E-02	9.64E-03
1.25	5.64E-03	7.37E-03	6.19E-03	5.19E-03	2.64E-01	5.84E-03	5.50E-03	5.02E-03
1.75	3.11E-03	4.07E-03	3.42E-03	2.87E-03	1.45E-01	3.23E-03	3.04E-03	2.78E-03
2.25	1.98E-03	2.59E-03	2.17E-03	1.82E-03	9.23E-02	2.05E-03	1.93E-03	1.76E-03
2.75	1.37E-03	1.79E-03	1.51E-03	1.26E-03	6.38E-02	1.42E-03	1.34E-03	1.22E-03
3.25	1.01E-03	1.32E-03	1.11E-03	9.28E-04	4.68E-02	1.05E-03	9.84E-04	8.99E-04
3.75	7.73E-04	1.01E-03	8.48E-04	7.11E-04	3.58E-02	8.01E-04	7.54E-04	6.89E-04
4.25	6.12E-04	7.99E-04	6.72E-04	5.63E-04	2.83E-02	6.34E-04	5.97E-04	5.45E-04
4.75	4.96E-04	6.49E-04	5.45E-04	4.57E-04	2.30E-02	5.15E-04	4.84E-04	4.42E-04
5.25	4.12E-04	5.38E-04	4.52E-04	3.79E-04	1.91E-02	4.27E-04	4.02E-04	3.67E-04

3.5 Interras

The Radiological Assessment System for Consequence Analysis, Version 2.2 (RASCAL 2.2), has been developed for use by U.S. Nuclear Regulatory Commission (NRC) staff that respond to power reactor accidents and other radiological emergencies. The model is designed to provide a comparison to the U.S. Environmental Protection Agency (EPA) Protective Action Guidance and thresholds for acute health effects. Interras is a modification of RASCAL. RASCAL was used to conduct an independent evaluation of dose and consequence projections. The model was developed to allow consideration of the dominant aspects of source term, atmospheric transport, radiological dose, and consequences. The results can be displayed as text or maps. RASCAL runs on a DOS-based personal computer. RASCAL has been widely distributed and used in the United States of America and in other foreign countries.

RASCAL has been designed to require only those data that might reasonably expected to be available during a radiological emergency. Data on reactor configurations, possible accident scenarios, and the effectiveness of release reduction mechanisms (such as filters, sprays, etc.) have been incorporated in Interras. The resulting graphics are fairly crude, to remind the analyst that data available during an accident (particularly weather predictions) are not to be considered very reliable. All results are presented in terms of possible health effects to the general public.

RASCAL has been developed through a collaboration of ORNL staff, Pacific Northwest Laboratories staff, and other NRC contractors. ORNL staff has been working primarily on the reactor source-term and dosimetry calculations, as well as the user interface.

Work on RASCAL continues with plans to create a Windows version. All the calculations in RASCAL will be revised to reflect the current needs of NRC. Two special- purpose versions of RASCAL have been developed. The first, called Interras, incorporates the ability to compute reactor source terms for East European reactors and has been given to the East Block countries by NRC and IAEA for use in analysing the consequences of accidents at their own and neighbouring reactor sites. The second version, called HPAC, was funded by the Defence Nuclear Agency. HPAC extends the capabilities of RASCAL to include accident scenarios for all types of radiological facilities in the world, including, for example, enrichment facilities, research reactors, storage facilities, etc. HPAC currently includes calculations for all operating power reactors, worldwide. HPAC has been used in several military exercises at non-US reactor sites.

Interras is a conservative quick tool, which could be used in an emergency to provide an analysis of conditions and project doses for the implementation of mitigating actions. An example of the output is provided in section 3.5.2.

3.5.1 Interras inputs

To obtain results from Interras is a very quick process and the user has very limited inputs. The following input parameters can be specified in the use of Interras:

- The time and duration of the release;
- The nuclides and quantities of each released;

- The stability class;
- The rainfall;
- The wind speed and direction

Interras does take the buildup of progeny and the decay of radionuclides into consideration.

3.5.2 Interpretation of Interras output

The table below is an example of the simplistic output of results obtained from Interras. The run is identified by "S2830A" . The run identification was given to identify the source term of 28 elements at 30 MW for the "A" stability class. The time of output is also given for convenience and future references. Interras out gives results in dose (mSv) at various distances from the source of release. The results given can be interpreted as follows:

- Total Effective dose - whole body dose as a result of cloud shine, ground shine and inhalation;
- Thyroid dose – dose to the thyroid due to exposure to iodine;
- Cloud shine – external dose due from the plume passing over a point due to dispersed particulate which has not settled on the surface yet;
- Ground shine – external dose at a point due to the deposited particulates on the ground; and
- Effective inhalation – dose due to the inhalation of particulates in the air which has not yet settled and also due to particulates which has been re-suspended from the ground.

Interras Output

S2830A 02/11/03 17:41

Distance Maximum EARLY Doses (mSv)

Distance (km)	1	2	5	25	50
Total Effective	3.4E+02	2.1E+02	9.5E+01	1.7E+01	6.3E+00
Thyroid	5.4E+03	3.2E+03	1.5E+03	2.2E+02	7.8E+01
Cloud shine	4.9E+01	3.4E+01	1.5E+01	5.4E+00	2.1E+00
Ground shine	5.5E+01	3.3E+01	1.5E+01	2.3E+00	8.1E-01
Eff. Inhalation	2.3E+02	1.4E+02	6.5E+01	9.8E+00	3.4E+00

NOTES for International Version:

1. All values below 1.0E-02 have been set to zero

2. Thyroid dose includes Iodine only

3. Total ED = Eff. Inhalation + Cloud Shine + Ground Shine

3.6 Weather data

3.6.1 Atmospheric stability

The atmospheric stability category for the worst case was determined by performing various runs with PC COSYMA. During these runs, at wind speeds of 5m/s, with no rainfall, in the summer season, with the same source term, it was found that the "A" stability class revealed the highest doses. As can be seen from the results below, the stability class has an effect on the mixing height, which has an effect on the amount of activity deposited at a specific point taking deposition velocity into consideration. The higher the mixing height, the larger the area in which the nuclides are deposited, therefore the lower the nucleic concentration per unit area. (In the table below, the reactor power level was reduced to 0 as an input to the model during this run. The reduction in power level had no influence on the results.)

PC COSYMA runs at various whether categories and 5m/s

Run	S2830D5E	S2830C5	S2830B5	**S2830A5**	S2830E5	S2830F5
Weather						
Stability	D	C	B	**A**	E	F
Mixing height (m)	560	800	1200	**1600**	320	200
Wind speed (m/s)	5	5	5	**5**	5	5
Rain (mm)	0	0	0	**0**	0	0
Wind direction (deg)	360	360	360	**360**	360	360
Season	S	S	S	**S**	S	S
Results (Max)						
Distance (m)	200	850	350	**350**	2750	3250
Eff dose	6.9	3.23	6.15	**15.44**	3.06	3.76
Thyroid	9.01	4.2	7.95	**20.09**	3.99	4.92
Eye lens	7.55	3.54	6.74	**16.89**	3.35	4.12
Ovaries	6.43	2.96	5.61	**14.15**	2.81	3.46
Skin	336.8	152.7	278	**739.6**	149.7	184.4
Lung	7.35	3.438	6.53	**16.42**	3.26	4.01
B Marrow	6.72	3.14	5.97	**15.02**	2.98	3.67
Gi tract	6.13	2.87	5.46	**13.71**	2.72	3.35
Power (MW)	0	0	0	**0**	0	0

Statistical analysis of the stability class most frequently experienced at Necsa revealed the "D" class with 26.11 %. Whether data gathered by Necsa for the period 1998 to 2000 was also used for this purpose.

Statistical annual stability class distribution at Necsa

Stability class	Percentage Abundance
A	12.21
B	5.46
C	9.06
D	**26.11**
E	25.26
F	11.81
G	10.09
Total	100.00

3.6.2 Wind speed

In determining the worst case or the case with the highest dose, the wind speed would affect the nuclide deposition. In strong winds, the plume is spread over a longer distance at a narrower angle. The optimum angle and wind speed for the highest nuclide deposition at a specific point could be calculated by using the gaussian plume equations quoted earlier in chapter 3. However for the purpose of this study, PC COSYMA was used to determine the wind speed at which a maximum dose was to be expected. The results of the modeling revealed the highest individual dose at a wind speed of 5 m/s.

In determining the wind speed with the highest frequency of appearance, whether data provided by Necsa was analyzed for the period 1998 to 2000.

Hourly weather data collected from 10m and 50m weather masts at Necsa was categorized [8]. The information for the years 1998 to 2000 was used in this study to determine the most frequent stability class and the most frequent wind speed. The highest frequency of wind speeds was found to be between 1.6 and 3.3 m/s. (Abundance of 33.54% from table below.)

Statistical annual wind speed distribution per stability class

Wind speed (m/s)	**0-0.9**	**1-1.5**	**1.6-3.3**	**3.4-5.4**	**5.5-7.9**	**8.0-10.7**	**10.8-12.5**	**>12.5**	
Stability category									
A	3.87	2.16	**4.85**	0.98	0.27	0.08	0	0	
B	0.48	0.61	**2.87**	1.22	0.2	0.08	0	0	
C	0.37	0.65	**4.25**	3.07	0.59	0.13	0	0	
D	0.61	1.25	**8.99**	10.11	4.16	0.87	0.12	0	
E	0.8	1.1	**7.91**	8.26	5.54	1.39	0.19	0.07	
F	0.63	0.74	**2.48**	2.61	3.5	1.57	0.19	0.09	
G	3.9	1.8	**2.19**	0.47	0.89	0.63	0.16	0.05	
Total (%)	**10.66**	**8.31**	**33.54**	**26.72**	**15.15**	**4.75**	**0.66**	**0.21**	**100**

Chapter 4
Safari

4.1 Safari-1: General facility description

SAFARI-1 is a pool type research reactor. The reactor is light water moderated and cooled. Beryllium and water is used as reflectors. It is commonly known as a Material Test Reactor (MTR). The reactor currently uses highly enriched uranium alloy plate-type fuel. The reactor is operated at powers of up to 20 MW thermal for the commercial production of medical and industrial isotopes, activation analysis, material modifications and other support services.

4.2 Safari-1: Operational history

1965 First time critical in March 1965 at 6,67 MW thermal using very highly enriched fuel.

1968 Shut down for 9 months to upgrade heat removal train for 20 MW thermal.

1977 The usage of the reactor was reduced to 5 MW during weekdays only.

1981 The fuel supply was operated on locally manufactured Medium Enriched Uranium fuel (MEU) at 5 MW for the next 12 years.

1988 The reactor was shut down for 6 months for repairs.

1993 Extensions in the commercial program required operation at 10 MW.

1994 Medium enriched fuel was replaced with highly enriched fuel.

1995 Operating power increased to 20 MW thermal; millionth MWth total energy production reached since first start up.

2000 Uranium content of locally manufactured uranium was increased from 200g to 300g.

Future plans for the research reactor includes, in the short term, that the reactor will be licensed to operate at 30 MW thermal and the introduction of Low enrichment uranium (LEU).

4.3 Safari-1: Safety features

The principles of design is based on the "defence in depth" philosophy as follows:

To prevent damage to the fuel core under adverse operating conditions; and
In the unlikely event of core damage, to contain the fission products released from the core and to prevent harm caused by the fission products to workers, the public and the environment.

The features designed to prevent core damage are:

An increase in moderator temperature leads directly to a reduction in core power;
A shutdown margin is maintained so that the reactor could be made sub critical with any 4 of the 6 control rods;

The following control parameters are continuously monitored in three independent channels to action shutdown when a predetermined threshold level is reached:

Neutron flux;

Gamma flux;

Reactor period (rate of change in neutron flux)

Primary coolant temperature rise over the core;

Primary coolant flow rate;

Primary coolant pressure drop over coolant.

Emergency core cooling is provided by shut down pumps, which are supplied independently from a fail free electrical supply system such with diesel generator support.

Notwithstanding the reliable availability of cooling capacity, the core can also be cooled, under failure or forced coolant circulation conditions by natural convection, without sustaining damage.

The following features were designed to mitigate core damage and prevent release of fission products to the environment:

The uranium fuel and fission products are contained in a solid uranium-aluminium (UAl) alloy matrix;

The UAl alloy matrix is hermetically sealed inside a cladding of pure aluminium;

The primary coolant system is a closed loop and is ventilated to the off-gas ventilation system;

The reactor hall ventilation pressure is maintained below atmospheric pressure to avoid the leaking out of fission products and other radioactive contaminants to the environment, i.e. the hall is ventilated through the main ventilation stack;

In the event of airborne radioactivity measured in the reactor hall, an emergency ventilation system, which is effectively filtered, takes over the function of the main ventilation system and further reduces the pressure in the reactor hall;

The reactor building is situated more or less 1 km from the nearest public area, which is the main road. (Not taking into consideration private individuals that are allowed on-site.)

4.4 Source Term

The source term, that is a quantity of radioactive nuclides that could be released to the environment, was taken from a supplementary report to the SAFARI probabilistic safety analysis. This report, "A nuclide release model for the SAFARI-1 reactor under accident conditions" was compiled by H van Graan in December 1992 [16]. When Necsa determined the source term, the code ORIGEN was used to generate quantities of the primary isotopes at a specific point of fuel burn-up. This value was refined by the application of various models to determine the theoretical release fractions. These release fractions are very important when the dispersion modeling of any kind is determined, because that determines the amount of activity released to the environment. The release fractions used in this study were those used in the safety assessment and has not been verified by the NNR. As a matter of fact, these release fractions vary quite substantially (is much less than) from those used in previous studies by Schuykens [15]. Nevertheless, a list of 62 isotopes was used in the modeling with PC COSYMA. Interras has a more limited library; therefore the isotopes contributing least to the dose were omitted.

The different operating conditions identified in the safety analysis report [2] for the SAFARI-1 reactor operating with high enriched uranium (HEU) are for the following:

- 20 MW: 28 fuel elements, each containing 200g of ^{235}U;
- 20 MW: 28 fuel elements, each containing 300g of ^{235}U;
- 30 MW: 28 fuel elements, each containing 300g of ^{235}U;

The specific scenario included a release of the volatile radioactive material equivalent to the inventory of four irradiated fuel elements. In the table below, the amount of activity released was also expressed in terms of a release rate, Bq/s. The total amount of activity that could be released was determined by multiplying the ORIGEN modeled amount of activity in the reactor at a specific time, with the release fraction. The release was modeled to take place over a period of 1 hour. Therefore the release rate (Bq/s) was obtained by dividing the total amount of activity available for dispersion by 3600 seconds to obtain a release rate in Bq/s.

SAFARI Source term for 300 g fuel elements at 30 MW

Isotope	Half-life	COSYMA group	Inventory 28 core, 300g, 30 MW Bq	Release fraction	A Released Bq	Release rate Bq/s
Kr-83m	1.86h	1	4.93E+15	1	4.93E+15	1.37E+12
Kr-85	10.72a	1	5.76E+13	1	5.76E+13	1.60E+10
Kr-85m	4.48h	1	1.22E+16	1	1.22E+16	3.39E+12
Kr-87	1.272h	1	2.37E+16	1	2.37E+16	6.58E+12
Kr-88	2.83h	1	3.34E+16	1	3.34E+16	9.28E+12
Xe-131m	11.9d	1	2.98E+14	1	2.98E+14	8.28E+10
Xe133m	2.19d	1	1.90E+15	1	1.90E+15	5.28E+11
Xe-133	5.245d	1	6.49E+16	1	6.49E+16	1.80E+13
Xe-135m	15.65min	1	1.07E+16	1	1.07E+16	2.97E+12
Xe-135	9.104h	1	3.44E+15	1	3.44E+15	9.56E+11
Xe-138	14.08min	1	5.82E+16	1	5.82E+16	1.62E+13
I-129	1.6e7a	2	8.97E+07	0.05	4.49E+06	1.25E+03
I-131	8.04d	2	2.75E+16	0.05	1.38E+15	3.82E+11
I-132	2.284h	2	4.19E+16	0.05	2.10E+15	5.82E+11
I-133	20.8h	2	6.31E+16	0.05	3.16E+15	8.76E+11
I-134	52.6min	2	7.12E+16	0.05	3.56E+15	9.89E+11
I-135	6.55h	2	5.94E+16	0.05	2.97E+15	8.25E+11
Cs-134	2.062a	3	3.52E+14	0.0082	2.89E+12	8.02E+08
Cs-136	13.16d	3	1.33E+14	0.0082	1.09E+12	3.03E+08
Cs-137	30a	3	4.67E+14	0.0082	3.83E+12	1.06E+09
Te-125m	58d	4	2.51E+12	0.0096	2.41E+10	6.69E+06
Te-127m	109d	4	8.94E+13	0.0096	8.58E+11	2.38E+08
Te-127	9.35h	4	1.18E+15	0.0096	1.13E+13	3.15E+09
Te-129m	33.6d	4	8.05E+14	0.0096	7.73E+12	2.15E+09
Te-131m	1.25d	4	3.43E+15	0.0096	3.29E+13	9.15E+09
Te-131	25min	4	2.38E+16	0.0096	2.28E+14	6.35E+10
Te-132	3.26d	4	4.07E+16	0.0096	3.91E+14	1.09E+11
Te-133m	55.4min	4	2.85E+16	0.0096	2.74E+14	7.60E+10
Te-134	41.8min	4	6.31E+16	0.0096	6.06E+14	1.68E+11
Ru-103	39.254d	6	2.56E+16	0.00025	6.40E+12	1.78E+09
Ru-106	1.02a	6	7.87E+14	0.00025	1.97E+11	5.47E+07
Tc-99	213000y	6	5.90E+10	0.00025	1.48E+07	4.10E+03
Tc-99m	6.006h	6	5.17E+16	0.00025	1.29E+13	3.59E+09
Mo-99	2.7477d	6	5.91E+16	0.00025	1.48E+13	4.10E+09
Sr-89	50.55d	5	3.62E+16	0.01	3.62E+14	1.01E+11
Sr-90	28.5a	5	4.53E+14	0.01	4.53E+12	1.26E+09
Sr-91	9.52h	5	5.54E+16	0.01	5.54E+14	1.54E+11

Isotope	Half-life	COSYMA group	Inventory 28 core, 300g, 30 MW	Release fraction	A Released	Release rate
Ba-140	12.746d	5	6.05E+16	0.01	6.05E+14	1.68E+11
Sb-125	2.73a	5.00E+00	2.22E+13	0.01	2.22E+11	6.17E+07
Pm-147	2.6234a	7	9.48E+14	0.00015	1.42E+11	3.95E+07
Pm-149	2.2117d	7	1.77E+16	0.00015	2.66E+12	7.38E+08
Pr-143	13.58d	7	5.61E+16	0.00015	8.42E+12	2.34E+09
Pr-145	5.98h	7	3.68E+16	0.00015	5.52E+12	1.53E+09
Y-90	2.671d	7	4.78E+14	0.00015	7.17E+10	1.99E+07
Y-91	58.51d	7	4.22E+16	0.00015	6.33E+12	1.76E+09
Y-92	3.54h	7	5.58E+16	0.00015	8.37E+12	2.33E+09
Nd-147	10.98d	7	2.18E+16	0.00015	3.27E+12	9.08E+08
La-140	1.678d	7	6.15E+16	0.00015	9.23E+12	2.56E+09
Ce-141	32.5d	7	4.98E+16	0.00015	7.47E+12	2.08E+09
Ce-143	1.375d	7	5.62E+16	0.00015	8.43E+12	2.34E+09
Ce-144	284.9d	7	1.33E+16	0.00015	2.00E+12	5.54E+08
Zr-95	64.02d	7	4.38E+16	0.00015	6.57E+12	1.83E+09
Nb-95m	3.61d	7	3.00E+14	0.00015	4.50E+10	1.25E+07
Nb-95	34.97d	7	3.08E+16	0.00015	4.62E+12	1.28E+09
Np-238	2.117d	7	2.12E+15	0.00015	3.18E+11	8.83E+07
Np-239	2.355d	7	7.69E+15	0.00015	1.15E+12	3.20E+08
Pu-238	87.74a	7	1.86E+12	0.00015	2.79E+08	7.75E+04
Pu-239	24110a	7	2.63E+10	0.00015	3.95E+06	1.10E+03
Pu-240	6563a	7	1.98E+10	0.00015	2.97E+06	8.25E+02
Pu-241	14.4a	7	5.00E+12	0.00015	7.50E+08	2.08E+05

In order to determine the maximum dose from a single nuclide from the total inventory that could be released, the noble gasses had to be separated from the other isotopes. It was calculated that most significant contributor in the noble gas group was Kr-88 with 9.74 E+6 Sv, followed by Kr-87 with 2.80 E6 Sv. This is useful information in the case of determining exposures to individual nuclides. (The dose conversion factors were taken from the IAEA Basic Safety Standards in reference 1.)

Dose contribution per nuclide for the full inventory

Isotope	Half-life	Activity Released Bq	Dose conversion factor Sv/Bq	Dose conversion factor:-Noble gas (Sv/d)/Bq/m3)	Dose Sv
Kr-83m	1.86h	4.93E+15		2.10E-13	3.59E+01
Kr-85	10.72a	5.76E+13		2.20E-11	4.40E+01
Kr-85m	4.48h	1.22E+16		5.90E-10	2.50E+05
Kr-87	1.272h	2.37E+16		3.40E-09	2.80E+06
Kr-88	2.83h	3.34E+16		8.40E-09	9.74E+06
Xe-131m	11.9d	2.98E+14		3.20E-11	3.31E+02
Xe133m	2.19d	1.90E+15		1.10E-10	7.26E+03
Xe-133	5.245d	6.49E+16		1.20E-10	2.70E+05
Xe-135m	15.65min	1.07E+16		1.60E-09	5.94E+05
Xe-135	9.104h	3.44E+15		9.60E-10	1.15E+05
Xe-138	14.08min	5.82E+16		4.70E-09	9.50E+06
I-129	1.6e7a	4.49E+06	7.20E-08		3.23E-01
I-131	8.04d	1.38E+15	7.20E-08		9.90E+07
I-132	2.284h	2.10E+15	1.10E-09		2.30E+06
I-133	20.8h	3.16E+15	1.90E-08		5.99E+07
I-134	52.6min	3.56E+15	4.80E-10		1.71E+06
I-135	6.55h	2.97E+15	4.10E-09		1.22E+07
Cs-134	2.062a	2.89E+12	7.00E-08		2.02E+05
Cs-136	13.16d	1.09E+12	1.50E-08		1.64E+04
Cs-137	30a	3.83E+12	1.10E-07		4.21E+05
Te-125m	58d	2.41E+10	1.70E-08		4.10E+02
Te-127m	109d	8.58E+11	4.10E-08		3.52E+04
Te-127	9.35h	1.13E+13	1.20E-09		1.36E+04
Te-129m	33.6d	7.73E+12	3.80E-08		2.94E+05
Te-131m	1.25d	3.29E+13	7.00E-09		2.30E+05
Te-131	25min	2.28E+14	2.40E-10		5.48E+04
Te-132	3.26d	3.91E+14	1.50E-08		5.86E+06
Te-133m	55.4min	2.74E+14	1.00E-09		2.74E+05
Te-134	41.8min	6.06E+14	5.60E-10		3.39E+05
Ru-103	39.254d	6.40E+12	1.30E-08		8.32E+04
Ru-106	1.02a	1.97E+11	2.60E-07		5.12E+04
Tc-99	213000y	1.48E+07	4.10E-08		6.05E-01

Tc-99m	6.006h	1.29E+13	1.30E-10	1.68E+03
Mo-99	2.7477d	1.48E+13	2.80E-09	4.14E+04
Sr-89	50.55d	3.62E+14	3.90E-08	1.41E+07
Sr-90	28.5a	4.53E+12	4.20E-07	1.90E+06
Sr-91	9.52h	5.54E+14	3.50E-09	1.94E+06
Ba-140	12.746d	6.05E+14	2.90E-08	1.75E+07
Sb-125	2.73a	2.22E+11	4.20E-08	9.32E+03
Pm-147	2.6234a	1.42E+11	2.10E-08	2.99E+03
Pm-149	2.2117d	2.66E+12	5.30E-09	1.41E+04
Pr-143	13.58d	8.42E+12	1.30E-08	1.09E+05
Pr-145	5.98h	5.52E+12	1.60E-09	8.83E+03
Y-90	2.671d	7.17E+10	1.30E-08	9.32E+02
Y-91	58.51d	6.33E+12	4.30E-08	2.72E+05
Y-92	3.54h	8.37E+12	1.90E-09	1.59E+04
Nd-147	10.98d	3.27E+12	1.20E-08	3.92E+04
La-140	1.678d	9.23E+12	8.80E-09	8.12E+04
Ce-141	32.5d	7.47E+12	1.60E-08	1.20E+05
Ce-143	1.375d	8.43E+12	5.90E-09	4.97E+04
Ce-144	284.9d	2.00E+12	3.60E-07	7.18E+05
Zr-95	64.02d	6.57E+12	2.40E-08	1.58E+05
Nb-95m	3.61d	4.50E+10	4.60E-09	2.07E+02
Nb-95	34.97d	4.62E+12	7.70E-09	3.56E+04
Np-238	2.117d	3.18E+11	9.00E-09	2.86E+03
Np-239	2.355d	1.15E+12	5.90E-09	6.81E+03
Pu-238	87.74a	2.79E+08	2.00E-04	5.58E+04
Pu-239	24110a	3.95E+06	2.10E-04	8.28E+02
Pu-240	6563a	2.97E+06	2.10E-04	6.24E+02
Pu-241	14.4a	7.50E+08	2.80E-06	2.10E+03

When the results produced by PC COSYMA were analyzed it was found that the doses varied pending on the number of nuclides that was used when modeling was performed. The results of the variations with number of isotopes is tabulated and discussed in more detail in chapter 5. In addition, the results obtained from PC COSYMA modeling revealed much lower doses than that obtained by modeling performed with Interras. In order to find a reason for the discrepancies, various aspects were investigated. Amongst those investigated was to see what the effect on the results of PC COSYMA was when selected nuclides were chosen for modeling. In order to choose the nuclides on some basis, the contribution to dose of the individual nuclides was determined. Therefore the results of the dose contribution per nuclide calculations are presented in the table below. The calculations show that I-131 was the isotope that would result in the highest dose when the full inventory was released (9.9 E+7 Sv) followed by I-133 (5.99 E+7 Sv).

Dose contribution per nuclide from full inventory, sorted from maximum to minimum contribution

Isotope	Half-life	Activity Released Bq	Dose conversion factor Sv/Bq	Dose conversion factor:-Noble gas (Sv/d)/Bq/m3)	Dose Sv
I-131	8.04d	1.38E+15	7.20E-08		9.90E+07
I-133	20.8h	3.16E+15	1.90E-08		5.99E+07
Ba-140	12.746d	6.05E+14	2.90E-08		1.75E+07
Sr-89	50.55d	3.62E+14	3.90E-08		1.41E+07
I-135	6.55h	2.97E+15	4.10E-09		1.22E+07
Kr-88	2.83h	3.34E+16		8.40E-09	9.74E+06
Xe-138	14.08min	5.82E+16		4.70E-09	9.50E+06
Te-132	3.26d	3.91E+14	1.50E-08		5.86E+06
Kr-87	1.272h	2.37E+16		3.40E-09	2.80E+06
I-132	2.284h	2.10E+15	1.10E-09		2.30E+06
Sr-91	9.52h	5.54E+14	3.50E-09		1.94E+06
Sr-90	28.5a	4.53E+12	4.20E-07		1.90E+06
I-134	52.6min	3.56E+15	4.80E-10		1.71E+06
Ce-144	284.9d	2.00E+12	3.60E-07		7.18E+05
Xe-135m	15.65min	1.07E+16		1.60E-09	5.94E+05
Cs-137	30a	3.83E+12	1.10E-07		4.21E+05
Te-134	41.8min	6.06E+14	5.60E-10		3.39E+05
Te-129m	33.6d	7.73E+12	3.80E-08		2.94E+05
Te-133m	55.4min	2.74E+14	1.00E-09		2.74E+05
Y-91	58.51d	6.33E+12	4.30E-08		2.72E+05
Xe-133	5.245d	6.49E+16		1.20E-10	2.70E+05
Kr-85m	4.48h	1.22E+16		5.90E-10	2.50E+05

Te-131m	1.25d	3.29E+13	7.00E-09		2.30E+05
Cs-134	2.062a	2.89E+12	7.00E-08		2.02E+05
Zr-95	64.02d	6.57E+12	2.40E-08		1.58E+05
Ce-141	32.5d	7.47E+12	1.60E-08		1.20E+05
Xe-135	9.104h	3.44E+15		9.60E-10	1.15E+05
Pr-143	13.58d	8.42E+12	1.30E-08		1.09E+05
Ru-103	39.254d	6.40E+12	1.30E-08		8.32E+04
La-140	1.678d	9.23E+12	8.80E-09		8.12E+04
Pu-238	87.74a	2.79E+08	2.00E-04		5.58E+04
Te-131	25min	2.28E+14	2.40E-10		5.48E+04
Ru-106	1.02a	1.97E+11	2.60E-07		5.12E+04
Ce-143	1.375d	8.43E+12	5.90E-09		4.97E+04
Mo-99	2.7477d	1.48E+13	2.80E-09		4.14E+04
Nd-147	10.98d	3.27E+12	1.20E-08		3.92E+04
Nb-95	34.97d	4.62E+12	7.70E-09		3.56E+04
Te-127m	109d	8.58E+11	4.10E-08		3.52E+04
Cs-136	13.16d	1.09E+12	1.50E-08		1.64E+04
Y-92	3.54h	8.37E+12	1.90E-09		1.59E+04
Pm-149	2.2117d	2.66E+12	5.30E-09		1.41E+04
Te-127	9.35h	1.13E+13	1.20E-09		1.36E+04
Sb-125	2.73a	2.22E+11	4.20E-08		9.32E+03
Pr-145	5.98h	5.52E+12	1.60E-09		8.83E+03
Xe133m	2.19d	1.90E+15		1.10E-10	7.26E+03
Np-239	2.355d	1.15E+12	5.90E-09		6.81E+03
Pm-147	2.6234a	1.42E+11	2.10E-08		2.99E+03
Np-238	2.117d	3.18E+11	9.00E-09		2.86E+03
Pu-241	14.4a	7.50E+08	2.80E-06		2.10E+03
Tc-99m	6.006h	1.29E+13	1.30E-10		1.68E+03
Y-90	2.671d	7.17E+10	1.30E-08		9.32E+02
Pu-239	24110a	3.95E+06	2.10E-04		8.28E+02
Pu-240	6563a	2.97E+06	2.10E-04		6.24E+02
Te-125m	58d	2.41E+10	1.70E-08		4.10E+02
Xe-131m	11.9d	2.98E+14		3.20E-11	3.31E+02
Nb-95m	3.61d	4.50E+10	4.60E-09		2.07E+02
Kr-85	10.72a	5.76E+13		2.20E-11	4.40E+01
Kr-83m	1.86h	4.93E+15		2.10E-13	3.59E+01
Tc-99	213000y	1.48E+07	4.10E-08		6.05E-01
I-129	1.6e7a	4.49E+06	7.20E-08		3.23E-01

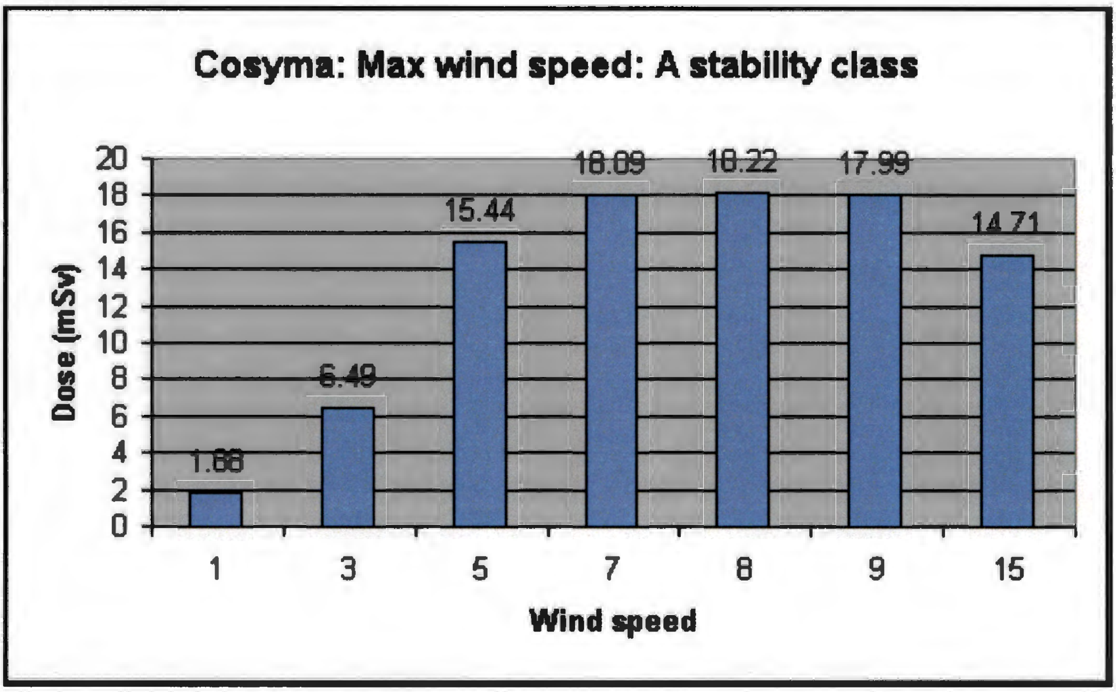
Chapter 5
Results

5.1 PC COSYMA Results

5.1.1 PC Cosyma: Worst case: Wind speed

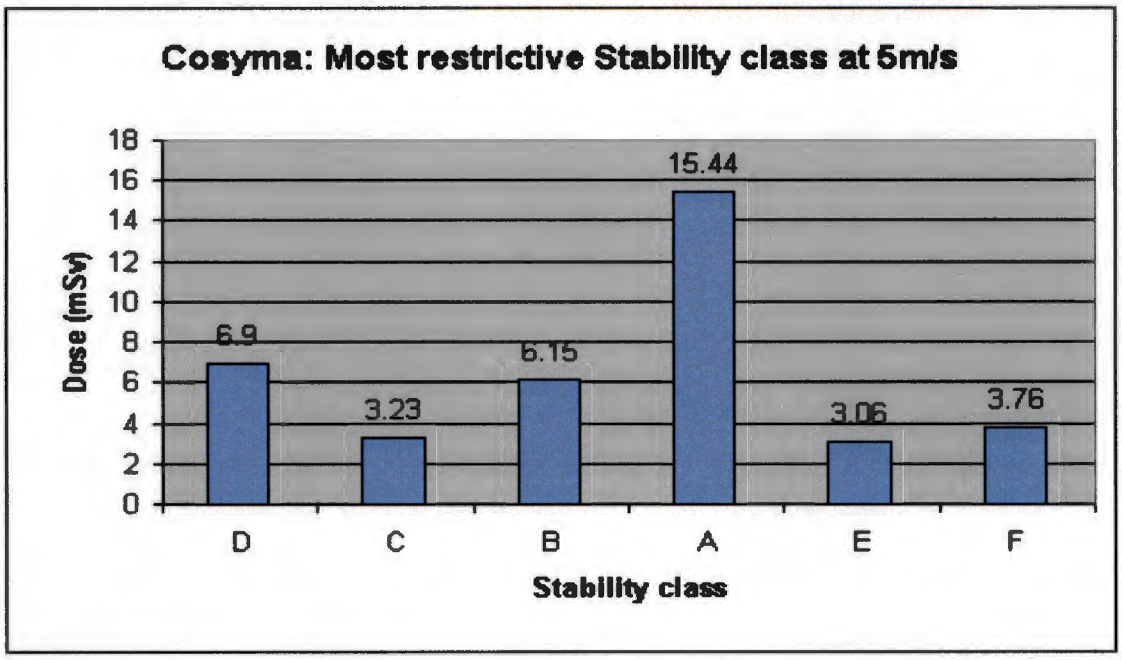
Full results are presented in Annexure 2. To determine the maximum dose at a point, the stability class was kept constant. Wind speeds were varied starting at 1 m/s. All other variable were kept unchanged. The full set of 62 nuclides were used. An increase in maximum dose was found up to 8 m/s, after which the dose decreased. The maximum dose was 18.22 mSv.

Maximum dose found at 8 m/s.



5.1.2 PC Cosyma: Worst case: Stability class

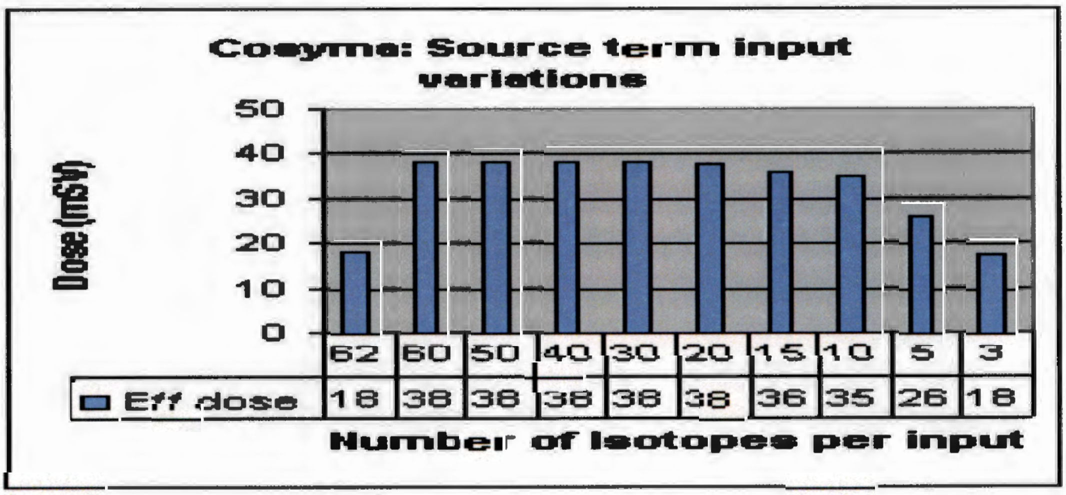
Full results of all the runs performed are presented in Annexure 3. The entire variables were kept constant and only the stability class was varied. The stability class has an influence on the mixing height. Stability class A has a mixing height of 1600 m. The mixing height decrease through classes B to F, which has a mixing height of 200 m. An interesting phenomenon was found. Maximum dose was found for the A stability class, which is expected due to the height of the plume rise. However, the dose decreased through to class C, and formed another peak at D, a decrease to E and a peak again at F. 5 m/s was found to be the wind speed which produced the maximum dose. In this study the maximum dose, 15.44 mSv, is important since it determines the size of the Urgent Protection Action Zone. More studies should be performed to define a dispersion profile at various wind speeds.



5.1.3 PC Cosyma: Worst case: Number of nuclides

Full results of all the runs performed are presented in Annexure 4.

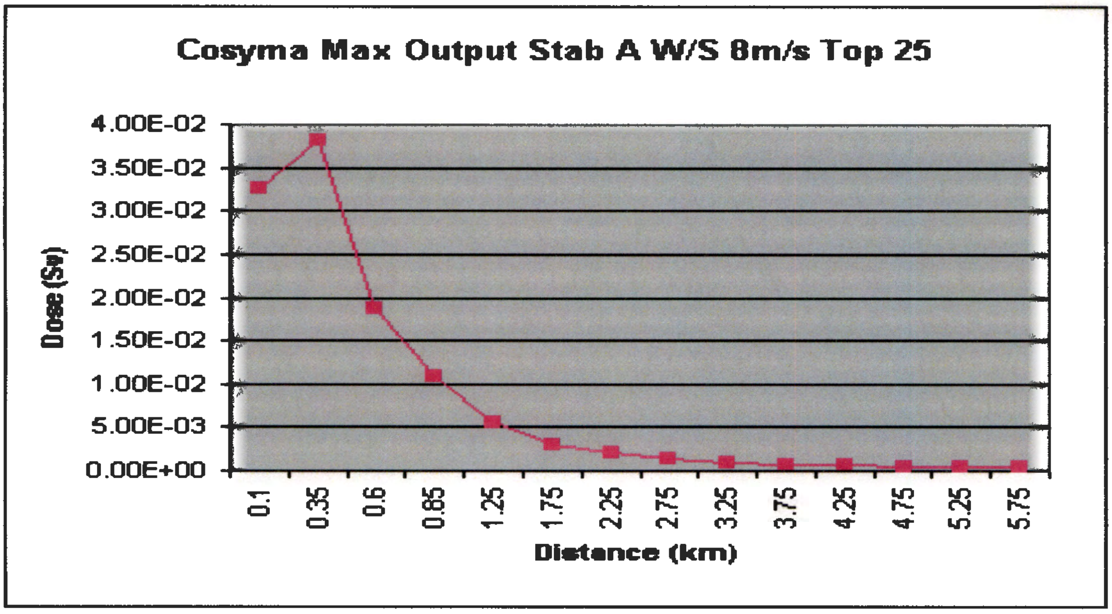
When the results of PC COSYMA and Interras were compared, it was found that the doses from PC COSYMA were much lower under similar conditions. In an effort to find reasons for the variations in output from the codes, the number of nuclides provided as an input to PC COSYMA was varied. The exercise started with the top 3 nuclides identified in chapter 4.4. These resulted in a dose of 18 mSv. As the number of nuclides increased the dose increased. A maximum dose of 38 mSv was modeled at an input of the top 25 nuclides. This value remained the same up to 60 nuclides after which a drop in the dose was noticed. This was a very strange phenomenon. It could only be explained by presuming that the code has a preference for specific preprogrammed nuclides. It is also noticeable that the dose due to the input of the top 3 nuclides (18 mSv) was higher than the dose due to the input of 62 nuclides (15.44 mSv) in section 5.1.2. This phenomenon requires more investigation.



5.1.4 PC Cosyma: Worst case : Organ dose

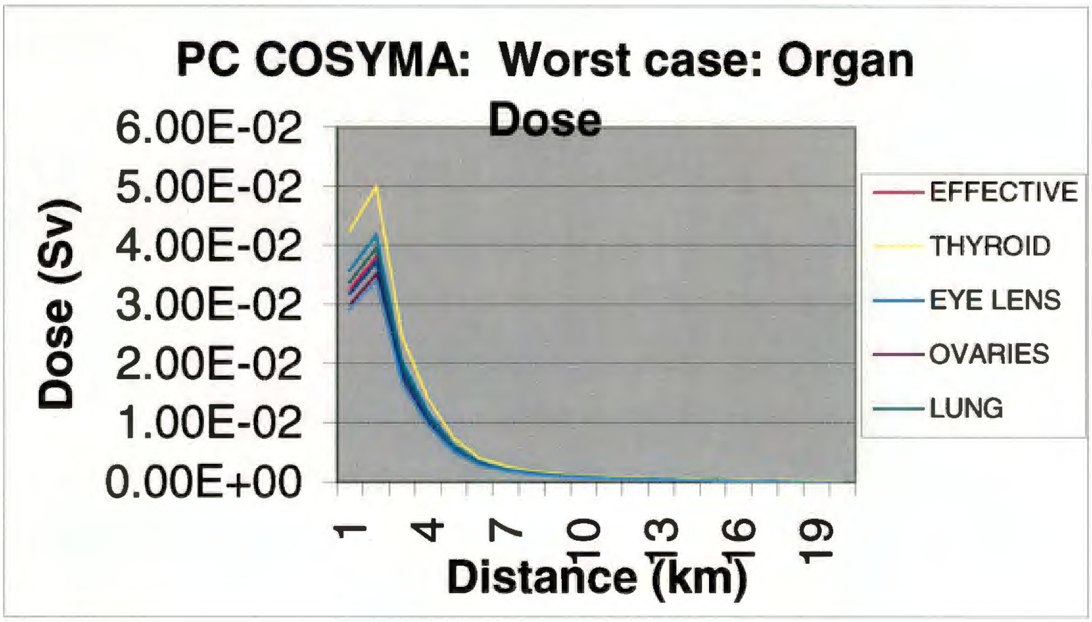
Full results of the run performed for stability class A at 8m/s performed to obtain dose distribution per organ and effective dose over distance, is presented in Annexure 6.

The effective dose is plotted against distance. It can be seen that the border of the Urgent Protective Action Zone, based on effective dose of 10 mSv, would be at about 900 m. A maximum dose of about 38 mSv would be found at 350 m.

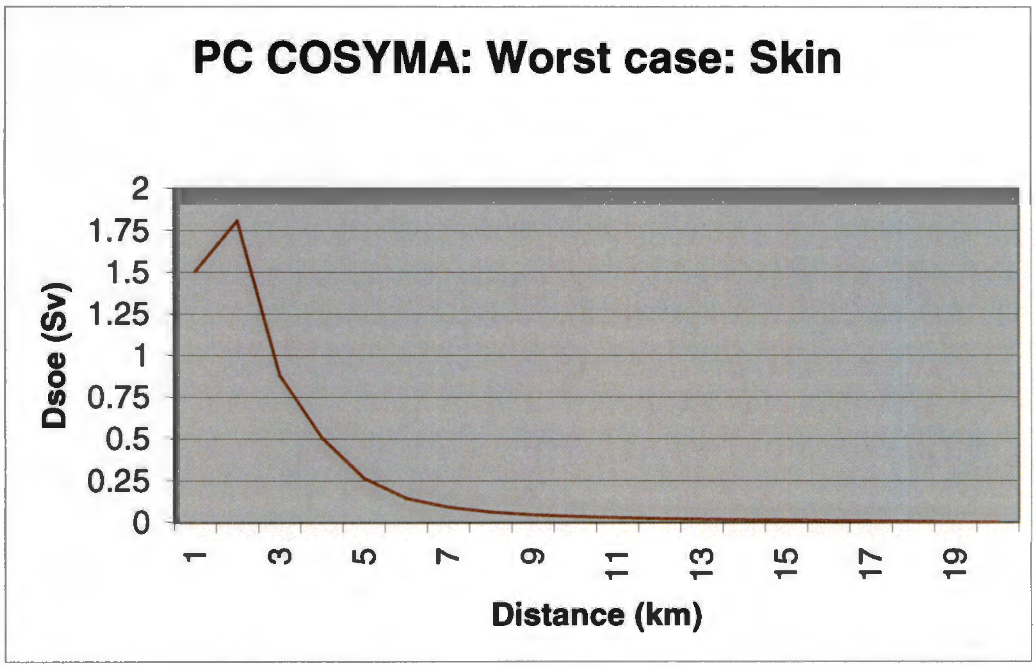


When organ dose, excluding skin dose, is presented graphically, it can be seen that maximum doses are found at 350 m from the point of release. The most sensitive organ is the thyroid (49.9 mSv), followed by the lens of the eye (41.8 mSv) and the lung (39.5 mSv). This was expected from the results in section 4.4, where the 131-I was identified as the most significant nuclide contributing to dose. In section 2.9, action levels per organ was derived, for comparison purposes, weigh the relative dose effects for the implementation of sheltering. The results are tabulated below. These results very clearly demonstrate that the skin dose may be of a concern and must be taken into consideration when the size of the Urgent Protective Action Zone is determined. More work is required in this area.

Organ	Shelter criteria (mSv)	Rounded values (mSv)	Modeled values (mSv)
Whole body	10	10	10
Lung	83	100	39.5
Thyroid	200	200	49.9
Skin	1000	1000	1810



Graphical presentation of the dose to the skin was separated from the other results because the doses are much larger than those of the other organs and to point out what the possible effect on the Urgent Protective Action zone could be. The maximum skin dose was found to be 1.8 Sv or 1800 mSv at 350 m from the point of release. At these doses, evacuation would be required. However, the dose reduced to from 1800 mSv at 350 m to 883 mSv at 600 m and about 400 mSv at 1 km, which is also the size of the Urgent Protective Action Zone (UPZ) due to effective dose. Therefore it can be concluded that the cut off of the skin dose would be at about 400 m. The cut off the UPZ due to dose to any other organ, would not challenge the effective dose cut=off. The cut-off due to effective dose seem to more restrictive from the results used in this study.



5.1.5 <u>PC Cosyma: Most probable case: Other variables</u>

Full results of all the runs performed are presented in Annexure 5.

These runs were performed for various reasons. A comparison is required between worst-case atmospheric conditions and most probable atmospheric conditions. Further more, large differences in the results from PC COSYMA and Interras had to be explained. The largest change in dose was caused by the input of nuclides, therefore the results was discussed separated from the rest. This section deals with the effect of other changes, which is much smaller. Each change will be discussed in short.

5.1.5.1 PC Cosyma: Most probable case: Weather data

Stability class "D" from section 3.6.1 was used as an input, since it was the stability class of highest abundance.

The wind speed was analysed in section 3.6.2. The most abundant wind speed was in the category 1.6 to 3.3 m/s. This was followed by category 3.4 to 5.4 m/s. In order to build in some conservatism, a wind speed of 5 m/s was used.

5.1.5.2 PC Cosyma: Most probable case: Maximum dose

The maximum dose (Run D2830-5) for the full 62-nuclide source term was found to be 12.41 mSv. When this value is compared with the value of 18.22 mSv, which was the highest dose for the same amount of nuclides released, but at severe atmospheric conditions, it was found that the worst case atmospheric conditions resulted in a dose of about 5.8 mSv higher.

5.1.5.3 PC Cosyma: Most probable case: Shielding during release

Run S2830D5A refers. Under the section "Shielding during release", cloud shine, ground shine and inhalation is categorized. The fractions of cloud shine, ground shine and inhalation was increased from default, 0.16, 0.14 and 0.55 respectively, to 1. There was a marginal increase in effective dose of

0.31 mSv due to the change of all three parameters. The effect was very small.

5.1.5.4 PC Cosyma: Most probable case: Dry deposition velocity

Run S2830D5B and S2830D5D refer. In run S2830D5B, the dry deposition velocities for iodine were increased from default, 0.001 and 0.01 m/s respectively, to 0.3 m/s. An increase in maximum dose due to quicker settling velocity was expected. The results verified the assumption, because the maximum effective dose increased from 0.37 mSv to 6.9 mSv. An increase of about 6.5 mSv. It is evident from this change in results that further study is required to determine, for South African conditions, deposition velocities and other dispersion related values, which may influence the dose to the most exposed person.

5.1.5.5 PC Cosyma: Most probable case: Wind speed measuring height

Run S2830D5C refers. The wind speed measuring height was varied from 10 m to 50 m. This resulted in a dose reduction from 6.90 mSv to 1.76 mSv. (About 5.1 mSv). The lower the measuring height, it seems, the higher the dose.

In comparing the dose results of run S2830D5B with S2830D5C it is interesting that the increase in wind speed measuring height resulted in a larger thyroid dose and skin dose ratios. In other words, more dose was ascribed to the thyroid and the skin, when the wind speed was measured at 50 m.

5.1.5.6 PC Cosyma: Most probable case: Re-suspension and deposition on clothes

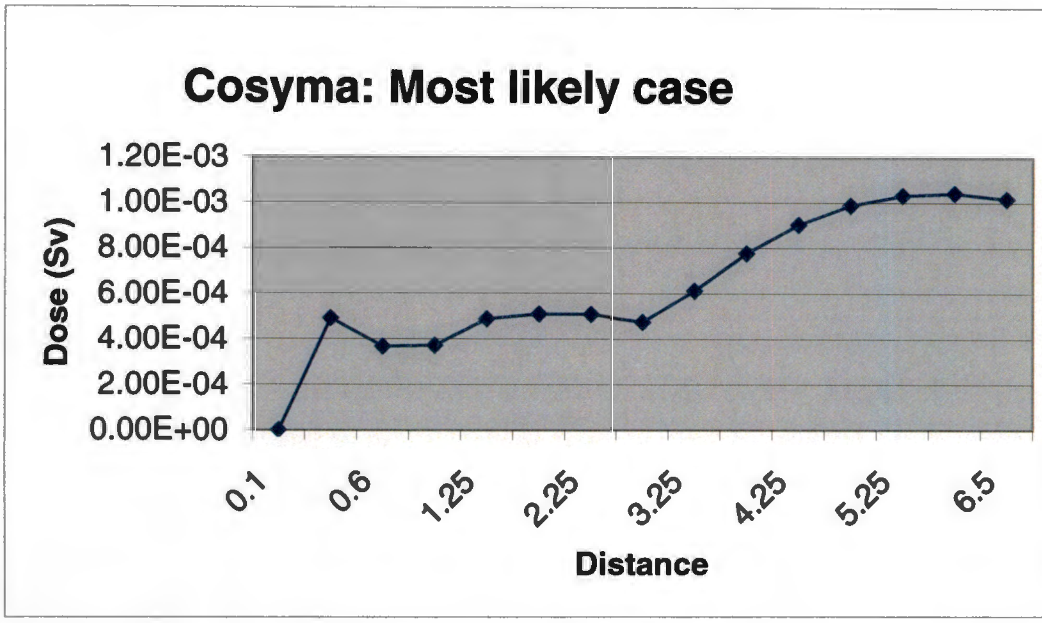
Run S2830D5E refers. The default value of 0.55 for re-suspension and deposition on clothes respectively was increased to 1. The results of runs S2830D5B and S2830D5E must be compared to evaluate the effect of re-suspension and deposition on clothes. All the dose values remained the same, expect for skin dose, as expected. The skin dose increased from 185 mSv to 336 mSv (About an 80% increase.). The skin has a relative low tissue-weighting factor; therefore the contribution to effective dose is relative small. This is also demonstrated in the results.

5.1.6 PC Cosyma: Most probable case: Organ dose

Full results of the run is presented in Annexure 7.

The run was performed for 25 nuclides, D stability class at 5 m/s. A maximum effective dose of 1.04 mSv was found at 5.75 km. All the other organ doses also peaked at that distance. The results were as follows:

Thyroid 1.34 mSv; Eye lens 1.13 mSv; Ovaries 0.94 mSv; Skin 48.3 mSv; Lung 1.11 mSv; Bone Marrow 1.11 mSv and Gastro intestinal tract 0.92 mSv. The effect of most probable case (Effective dose - 1.04 mSv) is therefore much smaller that that of worst case (Effective dose - 38.1 mSv). This comparison (statistical most likely conditions versus most severe conditions) clearly illustrates that at Pelindaba the meteorological conditions can have a very large influence on the dose to individuals.



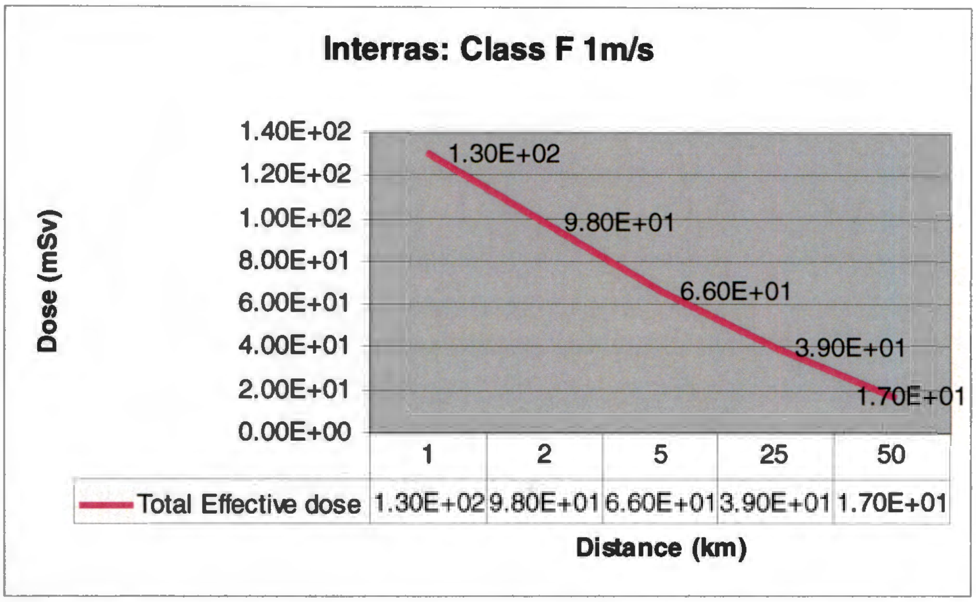
5.2 Interras results

Modeling with Interras was much simpler, since the number of variables were fewer and the results more simplistic.

Full results of all the runs performed are presented in Annexure 8.

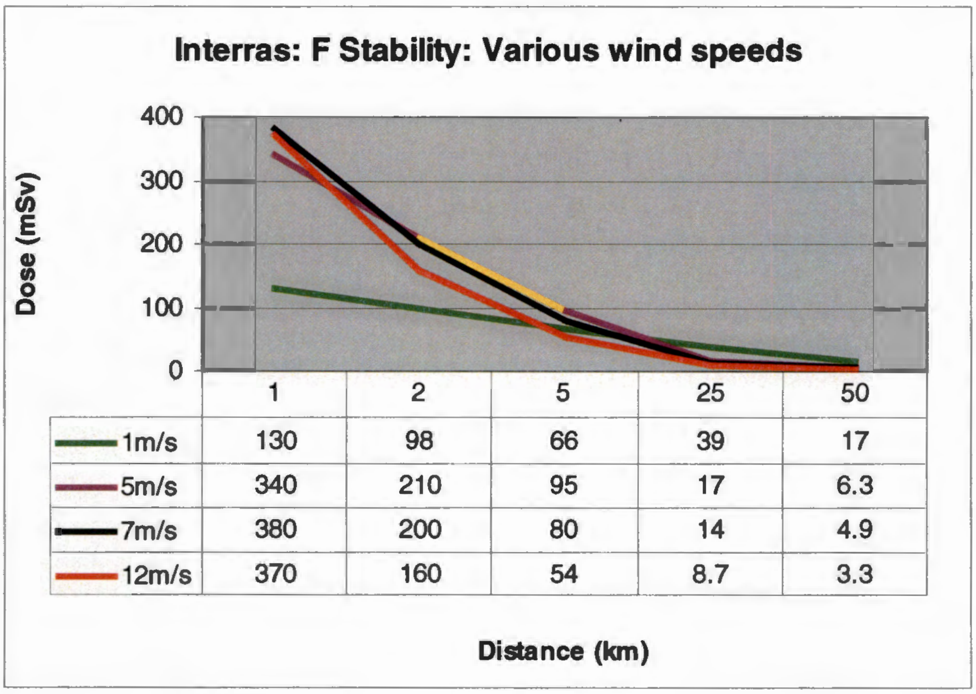
For stability class F the maximum effective dose of 130 mSv was modeled to be at 1 km. The dose reduced with distance, with 17 mSv at 50 km. If these results were to be used to determine the sheltering zone, it would have extended beyond 50 km.

The thyroid dose modeled was 1.5 Sv at 1 km. This compares well with the 1,8 Sv of PC COSYMA at 350 m.



The results of effective doses at various wind speeds modelled with Interras is given in Annexure 9. The graphical display shows clearly that a simplistic gaussian plume model was used, since there is very little variance in the distribution shape. The stronger the wind, the higher the dose close to the point of release. This trend is contrary to what is expected. With stronger winds and the same settling velocity, a shift of maximum dose away from the source of release is expected.

Modelling was only performed up to 12 m/s because that was the maximum range of actual wind speeds measured between 1998 and 2000.



	1	2	5	25	50
1m/s	130	98	66	39	17
5m/s	340	210	95	17	6.3
7m/s	380	200	80	14	4.9
12m/s	370	160	54	8.7	3.3

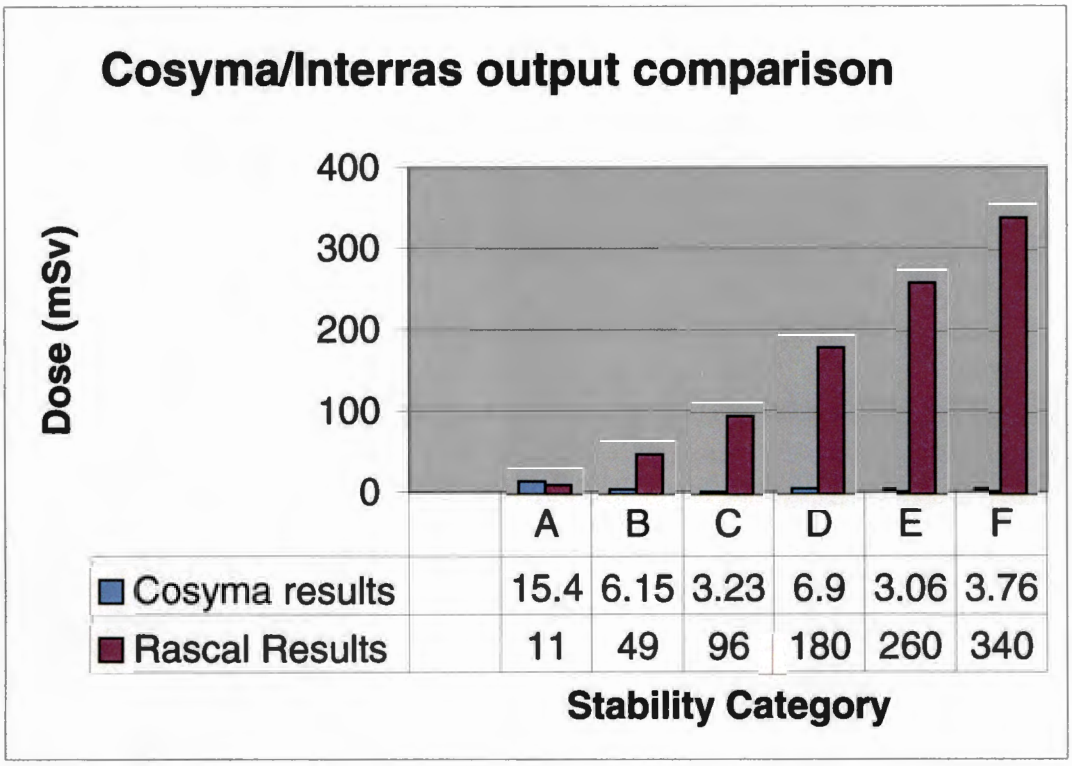
5.3 PC COSYMA/Interras comparisons

Complete results and examples of code out puts are contained in the annexure.

5.3.1 Stability class comparison.

The wind speed chosen for the code output comparison was 5 m/s. The dose in mSv was compared. Full results are given in Annexure 10.

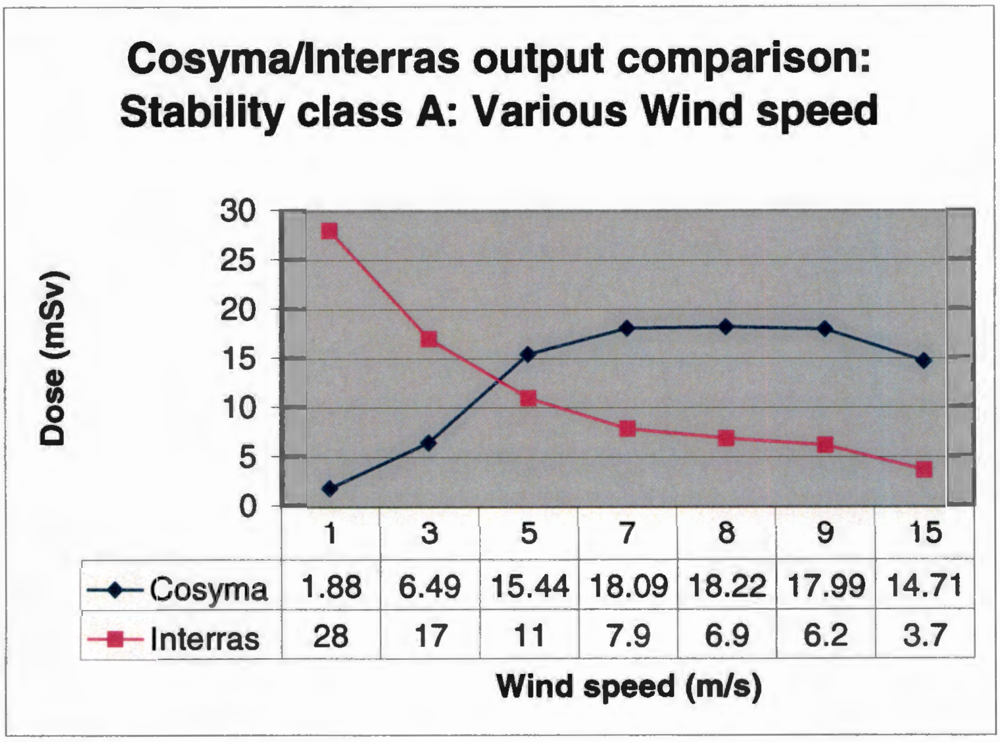
It was explained in section 5.2 that with an increase of mixing height the maximum dose would be expected to be further away from the source of release. From the graphical display this argument is directly applicable to PC COSYMA results. The direct opposite applies to Interras results. Therefore it is assumed that an F stability class in COSYMA should be compared with an A stability class in Interras and visa versa.



5.3.2 Wind speed comparison

Results of the comparisons performed are presented in Annexure 11

A range of wind speeds from 1 to 15 m/s was chosen to represent the frequency file used in the determination of the most frequent whether conditions used in the set of graphs for a unit release. The worst category identified as the worst case by the COSYMA analysis was used as the basis for the wind speed comparison.



	1	3	5	7	8	9	15
Cosyma	1.88	6.49	15.44	18.09	18.22	17.99	14.71
Interras	28	17	11	7.9	6.9	6.2	3.7

5.3.3 Other PC COSYMA/Interras comparisons.

The dispersion codes used have fixed algorithms, based on the gaussian model. These algorithms are not accessible to the modeler. However, the different models allow some parameters to be varied according to the needs of the modeler.

In an attempt to clarify some of the discrepancies between the codes, changes were made to some of the variable parameters. All the controllable parameters were kept the same and only one parameter was changed at a time.

- Wind speeds – (Section 5.3.2) Using PC COSYMA, the dose varies from 1.88 mSv at a wind speed of 1 m/s to 14,77 mSv at 15 m/s. A maximum dose of 18.22 mSv was modeled at 8 m/s. Interras results vary substantially. At 1 m/s a dose of 28 mSv was given and the value constantly decreased to 3.7 mSv at 15 m/s.

- Atmospheric stability classes: (Section 5.3.1) PC COSYMA presented the highest dose at a fixed point for stability class A. Interras provided the highest dose for stability class F.
- Power output of plant in case of reactor. Only PC COSYMA had the option of changing the power out put. When the power was reduced from 30 MW to 0 MW a significant increase was noticed in the dose. (See annexure 5)
- Pathway contribution to intake. Interras takes the full contribution of all pathways specified. PC COSYMA, by default considers only fractions of the specific pathways as contributing to the total dose. These values were altered to include all effects from all pathways. (Example in Annexure 1)
- Deposition velocities: The deposition velocities of PC COSYMA can be changed for the some isotopes in specific classes. Interras has fixed deposition velocities. (Example in Annexure 5)
- Variations in the input of the source term. PC COSYMA chooses, by default a set of nuclides to consider when the list becomes long. (Full source term input Effective dose of 18,22 mSv, top 20 isotopes 38.01 mSv. All at the same distance. Addition of the rest made only a 0.17 mSv difference. It is therefore derived that the code selects certain isotopes by default, when it performs calculations. This may lead to large discrepancies in the results. Example annexure 4)

Chapter 6
Conclusions and Recommendations

6.1 Conclusions

6.1.1 PC COSYMA: Worst case scenario

- The PC COSYMA study demonstrated that maximum doses was modelled at stability class A and at a wind speed of 8 m/s for a 25-nuclide input. (Annexure 2)
- The PC COSYMA study demonstrated that the biggest effect on maximum dose is the source term. This is followed by atmospheric stability and wind speed. (Annexure 2, 3, 4 and 5)
- The PC COSYMA study demonstrated that changes in mixing height, shielding due to cloud shine, ground shine, inhalation, re-suspension, and deposition on clothes have relative small effects on the maximum effective dose. (Annexure 5)
- The PC COSYMA study demonstrated that the 10 mSv action level for the determination of the size of the Urgent Protective Action Zone (UPZ) is the more restricting that the derived organ doses. (Annexure 6)
- The size of the UPZ, from this study, based on 10 mSv action level for sheltering, is radial, with the SAFARI-1 stack as the centre point is about 1 km. This is in line with the IAEA guidelines for a category II facility of between 0.5 and 5 km. (Annexure 6)

6.1.2 PC COSYMA: Most probable case

The most probable case of dispersion was determined by analysis of meteorological data. It was found to be stability class D. A wind speed of 5 m/s was used. The maximum dose modeled was about 1 mSv at 5.75 km. Therefore, sheltering would not be required as a protective action under these atmospheric conditions. (Annexure 7)

6.1.3 Interras

The Interras results are much more restrictive than the PC COSYMA results and the size of the Urgent Protective Action Zone based on sheltering varies from larger than 25 km to more than 50 km. (Annexure 8)

6.1.4 PC COSYMA/Interras comparisons

Two main differences were found. The Interras interpretation of stability class seems to be opposite to that of PC COSYMA, which led to totally different results. (Annexure 10)

Secondly, Interras revealed much higher doses, which could be interpreted as being much more conservative. These differences could be attributed to the fact that Interras only uses a simple model based on gaussian puff model in calculations, where PC COSYMA uses a combination of five different models. It can be concluded that PC COSYMA is more realistic.

6.2 Recommendations

Further study is recommended on the following issues:

- The fractions of the SAFARI-1 fission inventory released to the atmosphere.
- Site-specific validation of a specific dispersion model for South African conditions is required. This would include validation of a specific model, for which the derivation of baseline input parameters such as the particulate deposition velocities, building protection factors, bioaccumulation of nuclides in the environment, re-suspension, deposition of nuclides on clothes, etc. must be derived from local conditions.
- Studies could be performed to derive action levels per organ, which will be determined by the source term. If the source term changes, it would affect the organ contributions to effective dose.

References

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3 NUREG/CR-3332 ORNL-5968, 1983, Radiological Assessment, A Textbook on Environmental Dose Analysis, Edited by John E. Till and H. Robert Meyer.

4 IAEA-TECDOC-953, Method for developing Arrangements for Response to a Nuclear or Radiological Emergency, Updating IAEA-TECDOC-953, IAEA, Vienna, Austria, October 2003.

5 IAEA-TEC-DOC-955, Generic assessment procedure for determining protective actions during a reactor accident, IAEA, Vienna, Austria, August 1997.

6 Annals of the ICRP, Volume 32 No. 1-2 2002, Guide for the practical application of the ICRP human respiratory tract model, Editor J Valintine, ICRP, 2003, ISSN 0146-6453.

7 Report HSE/13-REP-2003/02, March 2003, PR Mogafe, Radiological Environmental Monitoring Report at NECSA Pelindaba: Report for the Year 2002, Necsa.

8 Report HSE/16-REP-2003/01, January 2003, WJ Kok, Meteorological Programme at the Pelindaba Site of NECSA. Data report: January to December 2002.

9 Act No. 47, 1999. National Nuclear Regulator Act, 1999

10 LG-1036 "EMERGENCY PREPAREDNESS AND RESPONSE REQUIREMENTS", Revision 0, National Nuclear Regulator, South Africa, 2003

11 IAEA Safety Standards Series No. GS-R-2 "Preparedness and Response for a Nuclear or Radiological Emergency: IAEA Vienna, 2002

12 Workbook of Atmospheric Dispersions Estimates, EPA, 1998

13 PC COSYMA (Version 2.01): An accident consequence assessment package for use on a PC, European Commission 1995, Report no. EUR 16240 EN and NRPB-SR280, NRPB

14 Interras, International Radiological Assessment System, Version 2.1, (Based on USNRC Rascal), IAEA Vienna, Austria

15 Boundary for the primary emergency planning zone (SAFARI, AEC), IEC, D.M. Schuykens, National Nuclear Regulator, December 1998

16 A nuclide release model for the SAFARI-1 reactor under accident conditions, H van Graan, Necsa, December 1996

17 American National Standards, ANSI/ANS-15.16, 1982

Glossary

Deterministic effects: A health effect of radiation of which generally a threshold level of dose exists above which the severity of the effect is greater for higher dose. Such an effect is described as a "severe deterministic effect" if it is fatal or life threatening or results in a permanent injury that reduces quality of life.

Deterministic health effects: Results from doses in excess of those for which intervention is expected to be undertook under any circumstances.

Holder: Holder of an authorization to operate a nuclear facility.

Nuclear or radiological emergency: An emergency in which there is, or is perceived to be hazard due to:

- The energy resulting from a nuclear chain reaction or from the decay of the products of a chain reaction; or
- Radiation exposure.

Source term: The initial quantity of radioactive material, comprising of all radioactive isotopes, available for dispersion.

Stochastic effects: Radiation induced health effects, the probability of occurrence of which is greater for a higher radiation dose and the severity of which is independent of dose. Stochastic effects may be somatic effects or hereditary effects, and generally are assumed to occur without threshold level of dose. Examples include thyroid cancer and leukaemia

Annexure 1
Example of PC COSYMA input file

```
*****************************************************************************
*                                                                           *
*                              PC COSYMA                                    *
*                             VERSION 2.01                                  *
*                                                                           *
*                         RUN DATE:  11/07/03                              *
*                                                                           *
*                                                                           *
*  RUN NAME: S2830030                                                 *
*  DESCRIPTION OF RUN:                                                     *
*  Safari 28 elements 300 g 30 MW                                           *
*                                Version 2.01                               *
*****************************************************************************


UMMARY OF THE OPTIONS CHOSEN FOR THIS RUN
-----------------------------------------


                        ***** DETERMINISTIC RUN *****

                 *** RESULTS CALCULATED IN THE POPULATION ***


   HOURLY MET FILE:
       \PCCOSYM2\DATA\GERMANY.MH2


   MET SAMPLING PROGRAM: NOT USED


   SOURCE TERM PROGRAM: USED
   SOURCE TERM INPUT FILE:
       \PCCOSYM2\DATA\SA283003.ST3


   RADIONUCLIDE CONCENTRATIONS: YES

   COUNTERMEASURES CONSIDERED: NO
   COUNTERMEASURES AS ENDPOINT: NO
   COUNTERMEASURES - SHORT TERM
      -  PATTERN, POTENTIAL DOSES
         AND PROBABILITIES: NO
      -  NUMBERS AND AREAS: NO
   COUNTERMEASURES - LONG TERM
      -  PATTERN, POTENTIAL DOSES
         AND PROBABILITIES: NO
      -  NUMBERS AND AREAS: NO

   SHORT TERM INDIVIDUAL DOSES: YES
   LONG TERM INDIVIDUAL DOSES: NO
   SHORT TERM INDIVIDUAL RISKS: NO
   LONG TERM INDIVIDUAL RISKS: NO
   SHORT TERM HEALTH EFFECTS: YES
   LONG TERM COLLECTIVE DOSES: NO
   LONG TERM HEALTH EFFECTS: NO
   ECONOMIC CONSEQUENCES: NO
```

SHORT TERM DOSES CALCULATED TO: 1 DAY
HOURLY CHANGES IN WIND DIRECTION FOR EACH HOUR OF EACH PHASE

****
SPATIAL DISTRIBUTION DATA
****

THIS RUN USES 22 DISTANCE BANDS
THE OUTER LIMITS OF THE DISTANCES (IN KM) ARE

4.0000E-01	1.0000E+00	1.8000E+00	2.0000E+00	2.5000E+00
3.0000E+00	3.5000E+00	4.0000E+00	4.5000E+00	5.0000E+00
5.5000E+00	6.0000E+00	6.5000E+00	7.0000E+00	7.5000E+00
8.0000E+00	9.0000E+00	1.0000E+01	2.0000E+01	3.0000E+01
4.0000E+01	5.0000E+01			

THE CUT-OFF DISTANCE FOR CALCULATIONS WHICH INVOLVE EARLY COUNTERMEASURES OR EFFECTS, IF REQUIRED, IS SET AT 9.0000E+00 KM.

DETAILED INFORMATION IS GIVEN AT THE FOLLOWING 2 GRID POINTS
1.4000E+00 KM 6.2500E+00 KM

THIS RUN USES 16 SECTORS.

NUMBERS OF EFFECTS ARE BASED ON A UNIFORM POPULATION DENSITY OF 2.5000E+02 PEOPLE PER KM**2.

****
DOSE PARAMETERS
****

EFFECTIVE DOSE IS CALCULATED (ICRP-60)

BREATHING RATE: 2.6700E-04 M**3/S

RE-SUSPENSION PARAMETERS WLAMR: 3.5000E-08 /S
RESE: 1.0000E-09 /M
RESO: 5.0000E-08 /M

****
MET SAMPLING
****

THIS COSYMA RUN CONSIDERS 1 SEQUENCE, HOUR NUMBER: 1

****

DISPERSION

****

NPUT LIST OF THE METEOROLOGICAL ZONE

HEIGHT OF MIXING LAYER (M) OF THE DIFFUSION CATEGORY

A	B	C	D	E	F

READ IN FROM METEOROLOGICAL DATA FILE

SURFACE ROUGHNESS: ROUGH TERRAIN (FORESTS OR URBAN AREAS; Z0 > 1 M)

NPUT LIST OF THE PARAMETERS FOR THE WIND PROFILE

WIND PROFILE EXPONENT FOR THE DIFFUSION CATEGORY

A	B	C	D	E	F
7.0000E-02	1.3000E-01	2.1000E-01	3.4000E-01	4.4000E-01	4.4000E-01

THE FOLLOWING PARAMETERS ARE A FUNCTION OF THE FOLLOWING HEIGHTS

HEIGHT (M) 5.0000E+01 1.0000E+02 1.8000E+02

DISPERSION COEFFICIENTS FOR ROUGH TERRAIN

CAT.	PY	QY	PY	QY	PY	QY
A	1.5030E+00	8.3300E-01	1.7000E-01	1.2960E+00	6.7100E-01	9.0300E-01
B	8.7600E-01	8.2300E-01	3.2400E-01	1.0250E+00	4.1500E-01	9.0300E-01
C	6.5900E-01	8.0700E-01	4.6600E-01	8.6600E-01	2.3200E-01	9.0300E-01
D	6.4000E-01	7.8400E-01	5.0400E-01	8.1800E-01	2.0800E-01	9.0300E-01
E	8.0100E-01	7.5400E-01	4.1100E-01	8.8200E-01	3.4500E-01	9.0300E-01
F	1.2940E+00	7.1800E-01	2.5300E-01	1.0570E+00	6.7100E-01	9.0300E-01

CAT.	PZ	QZ	PZ	QZ	PZ	QZ
A	1.5100E-01	1.2190E+00	5.1000E-02	1.3170E+00	2.5000E-02	1.5000E+00
B	1.2700E-01	1.1080E+00	7.0000E-02	1.1510E+00	3.3000E-02	1.3200E+00
C	1.6500E-01	9.9600E-01	1.3700E-01	9.8500E-01	1.0400E-01	9.9700E-01
D	2.1500E-01	8.8500E-01	2.6500E-01	8.1800E-01	3.0700E-01	7.3400E-01
E	2.6400E-01	7.7400E-01	4.8700E-01	6.5200E-01	5.4600E-01	5.5700E-01
F	2.4100E-01	6.6200E-01	7.1700E-01	4.8600E-01	4.8500E-01	5.0000E-01

HORIZONTAL STANDARD DEVIATION (DEGREE) OF WIND DIRECTION

A	2.3800E+01	2.0500E+01	2.0500E+01
B	1.8900E+01	1.3900E+01	1.3900E+01

C	1.5300E+01	1.0100E+01	1.0100E+01
D	1.2600E+01	6.9000E+00	6.9000E+00
E	1.0200E+01	4.0000E+00	4.0000E+00
F	8.6000E+00	2.0000E+00	2.0000E+00

****
SOURCE TERM AND DEPOSITION
****

NPUT LIST OF THE NUCLIDE DATA - USING SOURCE TERM PROGRAM

HE SOURCE TERM PROGRAM MAY NOT USE ALL THE NUCLIDES IN THIS FULL LIST,
EPENDING ON THE CUT-OFF SPECIFIED. REFER TO THE OUTPUT FILE :
\PCCOSYM2\RESULTS\SRC*.SRC"
HERE * IS THE NAME OF THE *.ST1 FILE

NO.	NUCLIDE	HALF-LIFE	DEPOSIT.	WASHOUT COEFFICIENT FOR RAIN	
			VELOCITY	TERM A	TERM B
		(Y)	(M/S) *		

* CORRECTION FACTOR FOR CALCULATING THE GROUND CONTAMINATION OF

NOBLE GASES: 1.0000E+00
AEROSOLS: 1.0000E+00
ELEMENTAL IODINE: 1.0000E+00
ORG. BOUND IODINE: 1.0000E+00

EXPOSURE PATHWAYS FOR EACH NUCLIDE ARE DETERMINED
BY THE SOURCE TERM PROGRAM. SEE OUTPUT FILE "\PCCOSYM2\RESULTS\SRC*.SRC".
HERE * IS THE NAME OF THE *.ST1 FILE.

ROWTH OF THE FOLLOWING DAUGHTERS DURING DISPERSION IS CONSIDERED:

DAUGHTER PRODUCT		PARENT		YIELD
NO.	NAME	NO.	NAME	

NPUT LIST OF THE SOURCE TERM

UMBER OF RELEASE PHASES: 1
HIFT OF THE STARTING POINT: 0 H

DELAY	THERMAL ENERGY	INITIAL RELEASE HEIGHT	SOURCE WIDTH	SOURCE HEIGHT
(H)	(MW)	(M)	(M)	(M)

```
. PHASE:          1     3.0000E+01            80        4.0000E+01   1.5000E+01

IST OF THE AMOUNT OF ACTIVITY RELEASED FOR EACH NUCLIDE FOR EACH PHASE IN BQ
-----------------------------------------------------------------------------

                   PHASE 1   PHASE
UCLIDE     SUM    T =  1H   T =

   THE NUCLIDES AND THE AMOUNTS RELEASED ARE CALCULATED
   USING THE SOURCE TERM PROGRAM.  A PRINT OUT OF
   THESE QUANTITIES IS FOUND IN FILE "\PCCOSYM2\RESULTS\SRC\*.SRC"
   WHERE * IS THE NAME OF THE *.ST1 FILE.

******************************************************************************
                            COUNTERMEASURES
******************************************************************************

ALCULATIONS ARE MADE ASSUMING NO COUNTERMEASURES
------------------------------------------------

HE PARAMETER VALUES LISTED IN THIS SECTION ARE THOSE PC COSYMA USES
O MODEL THIS ASSUMPTION

HELTER THEN EVACUATE AUTOMATICALLY
----------------------------------

HIS COUNTERMEASURE IS NOT CONSIDERED.

HELTER THEN EVACUATE, ON DOSE LEVEL
-----------------------------------

HIS COUNTERMEASURE IS NOT CONSIDERED.

HELTERING ON A DOSE LEVEL, NO EVACUATION
----------------------------------------

HIS COUNTERMEASURE IS NOT CONSIDERED.

HELTERING IN A CIRCLE, NO EVACUATION
------------------------------------

HIS COUNTERMEASURE IS NOT CONSIDERED.
```

TABLE IODINE TABLETS

HIS COUNTERMEASURE IS NOT CONSIDERED.

ELOCATION AND RESETTLEMENT

HIS COUNTERMEASURE IS NOT CONSIDERED.

OCATION FACTORS

HERE ARE 4 TYPES OF LOCATION FACTORS, NOT ALL OF WHICH MAY APPLY TO THE ATTERN OF COUNTERMEASURES AND POPULATION BEHAVIOUR IN THIS CALCULATION. HE CORRESPONDING GROUPS AND LOCATION FACTORS ARE:

	LOCATION FACTORS				
	CL	GR	IH	IHR	SK
NORMAL ACTIVITY :	1.600E-01	1.400E-01	5.500E-01	5.500E-01	5.500E-01
INITIAL DELAY :	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00
SHELTERING (BUILDINGS) :	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00
CARS :	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00

****

SHORT TERM DOSES AND RISKS

****

THE FOLLOWING PATHWAYS ARE TAKEN INTO ACCOUNT FOR EARLY DOSE AND RISK CALCULATIONS

- CLOUD SHINE : YES
- GROUND SHINE : YES
- INHALATION : YES
- RE-SUSPENSION : YES
- SKIN/CLOTHES : YES

PARAMETERS OF THE DOSE-RISK RELATIONSHIPS

MORBIDITY

EFFECT	SHAPE PARAMETER	THETA-1 GY**2/H	THETA-INFINITY GY
LUNG IMPAIRMENT	7.0000E+00	1.5000E+01	5.0000E+00
HYPOTHYROIDISM	1.3000E+00	3.0000E+01	6.0000E+01
CATARACT	5.0000E+00	1.0000E-02	3.0000E+00
MENTAL RETARD.	1.0000E+00	0.0000E+00	1.5000E+00
EFFECTS ON SKIN	5.0000E+00	5.0000E+00	2.0000E+01

MORTALITY
=========

EFFECT	SHAPE PARAMETER	THETA-1 GY**2/H	THETA-INFINITY GY
PULMONARY SYNDR	7.0000E+00	3.0000E+01	1.0000E+01
HEMATOP.SYNDR.	6.0000E+00	1.0000E-01	4.5000E+00
GASTROINT.SYNDR	1.0000E+01	0.0000E+00	1.5000E+01
PRE/NEON. DEATH	3.0000E+00	0.0000E+00	1.5000E+00
SKIN BURNS	5.0000E+00	5.0000E+00	2.0000E+01

ATIO OF ACTIVITY CONCENTRATIONS ON SKIN TO DRY DEPOSITED ACTIVITY
ONCENTRATIONS ON GROUND SURFACE

1	NOBLE GASES:	1.0000E+00
2	AEROSOLS:	1.0000E+00
3	ELEMENTAL IODINE:	1.0000E+00
4	ORG. BOUND IODINE:	1.0000E+00

****
LONG TERM DOSES AND RISKS
****

THE FOLLOWING PATHWAYS ARE TAKEN INTO ACCOUNT
FOR LATE DOSE AND RISK CALCULATIONS

- CLOUD SHINE : YES
- GROUND SHINE: YES
- INHALATION: YES
- INGESTION: NO
- RESUSPENSION: YES
- SKIN/CLOTHES: YES

INTEGRATION TIME FOR SKIN DOSES (DAYS): 1.0000E+04
FRACTION OF SKIN CONTAMINATED: 1.0000E-01

THE FOLLOWING PARAMETERS ARE USED TO CALCULATE THE
STOCHASTIC HEALTH EFFECTS:

CANCER MORTALITY FACTORS (PER SV) | CANCER MORTALITY FRACTIONS

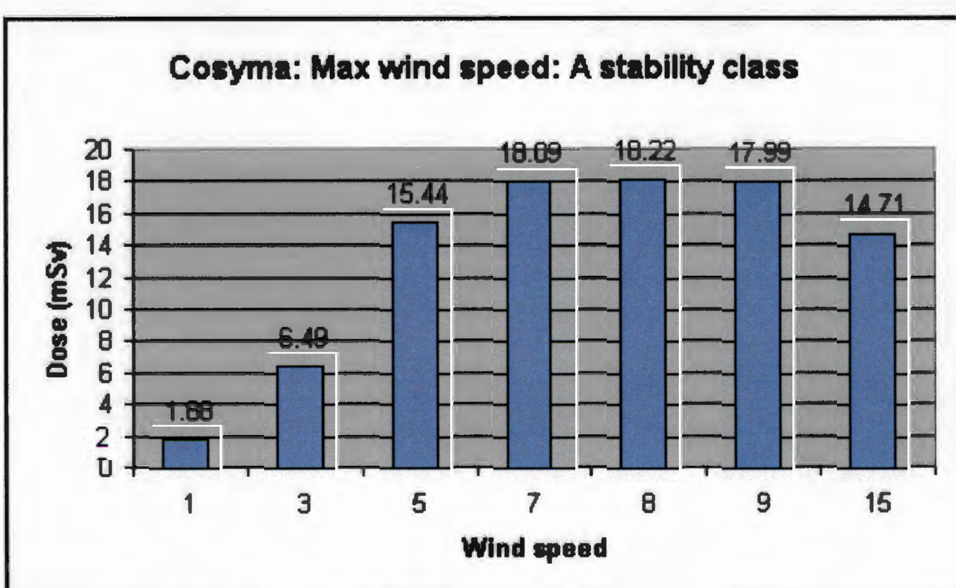
BONE MARROW	5.1600E-03	1.0000E+00
BONE SURF.	1.3300E-04	1.0000E+00
BREAST	8.0000E-03	4.0000E-01
LUNG	9.0000E-03	7.5000E-01
STOMACH	9.0500E-03	8.5000E-01
COLON	3.4300E-03	5.5000E-01
LIVER	4.6700E-03	1.0000E+00
PANCREAS	5.2600E-03	9.0000E-01
THYROID	1.7700E-03	1.0000E-01
REMAINDER	3.8600E-03	6.0000E-01
SKIN	1.3800E-04	1.0000E-02
HERED. EFF.	1.0000E-02	

Annexure 2
ᑭC COSYMA: Worst case: Wind speed

Vorst case: Summary of runs performed to determine the maximum dose by varying the wind speeds ɔr class stability A: 62 nuclides

₹un	S2830A1	S2830A3	S2830A5	S2830A7	**S2830A8**	S2830A9	S2830A15
Veather							
;tability	A	A	A	A	**A**	A	A
⁄ixing height (m)	1600	1600	1600	1600	**1600**	1600	1600
Vind speed (m/s)	1	3	5	7	**8**	9	15
₹ain (mm)	0	0	0	0	**0**	0	0
Vind direction (deg)	360	360	360	360	**360**	360	360
;eason	S	S	S	S	**S**	S	S
)ispersion							
Vs measure height	10	10	10	10	**10**	10	10
'errain	S	S	S	S	**S**	S	S
Vind profile							
⁄in val integ c (Bq.s.m3)	1.00E-12	1.00E-12	1.00E-12	1.00E-12	**1.00E-12**	1.00E-12	1.00E-12
Vind profile exp	0.34	0.34	0.34	0.34	**0.34**	0.34	0.34
)ry Deposition							
ıerosols: Dep vel m/s	0.3	0.3	0.3	0.3	**0.3**	0.3	0.3
:lemental Iodine: Dep vel0.01	0.3	0.3	0.3	0.3	**0.3**	0.3	0.3
)rg bound Iodine	3.00E-01	3.00E-01	3.00E-01	3.00E-01	**3.00E-01**	3.00E-01	3.00E-01
;ource term							
₹elease parameters							
;uilding width (m)	40	40	40	40	**40**	40	40
;uilding height (m)	15	15	15	15	**15**	15	15
ᑭhase (hour)	1	1	1	1	**1**	1	1
₹elease height (m)	80	80	80	80	**80**	80	80
ᑭower (MW)	0	0	0	0	**0**	0	0
ıventory groups	7	7	7	7	**7**	7	7
ᑭathways:							
:louds shine							
;round shine							
ıhalation							
;kin							
ıgestion							
₹elease fractions							
;roup 1	1	1	1	1	**1**	1	1
;roup 2	0.05	0.05	0.05	0.05	**0.05**	0.05	0.05
;roup 3	0.0082	0.0082	0.0082	0.0082	**0.0082**	0.0082	0.0082
;roup 4	0.0096	0.0096	0.0096	0.0096	**0.0096**	0.0096	0.0096
;roup 5	0.01	0.01	0.01	0.01	**0.01**	0.01	0.01

iroup 6	0.00025	0.00025	0.00025	0.00025	**0.00025**	0.00025	0.00025
iroup 7	0.00015	0.00015	0.00015	0.00015	**0.00015**	0.00015	0.00015
odine fractions:							
lemental	0.99	0.99	0.99	0.99	**0.99**	0.99	0.99
rganic	0.01	0.01	0.01	0.01	**0.01**	0.01	0.01
erosol	0	0	0	0	**0**	0	0
hielding during release							
loud shine	1	1	1	1	**1**	1	1
iround shine	1	1	1	1	**1**	1	1
nhalation	1	1	1	1	**1**	1	1
le-suspension	1	1	1	1	**1**	1	1
ep on clothes	1	1	1	1	**1**	1	1
ose conversion factors	ICRP 60	ICRP 60	ICRP 60	ICRP 60	**ICRP 60**	ICRP 60	ICRP 60
ireathing rate (m3/s)	3.33E-04	3.33E-04	3.33E-04	3.33E-04	**3.33E-04**	3.33E-04	3.33E-04
le-suspension:							
VLAMR (/s)	3.50E-08	3.50E-08	3.50E-08	3.50E-08	**3.50E-08**	3.50E-08	3.50E-08
IESE (/m)							
IESO (/m)							
lesults (Max)							
istance (m)	600	350	350	350	**350**	350	350
ff dose	1.88	6.49	15.44	18.09	**18.22**	17.99	14.71
hyroid	2.15	8.35	20.09	23.58	**23.76**	23.46	19.19
ye lens	2.09	7.11	16.89	19.78	**19.93**	19.67	16.09
varies	1.57	5.9	14.15	16.6	**16.73**	16.51	13.51
kin	80.48	280.8	739.6	877.7	**886.2**	876.2	718.6
ung	1.93	6.88	16.42	19.25	**19.39**	19.14	15.66
Marrow	1.76	6.29	15.02	17.6	**17.73**	17.51	14.32
ii tract	1.68	5.77	13.71	16.67	**16.19**	15.98	13.07
lun	S2830A1	S2830A3	S2830A5	S2830A7	**S2830A8**	S2830A9	S2830A15
	1	3	5	7	**8**	9	15



Annexure 3
PC COSYMA: Worst case: Stability class

Worst case: Summary of runs performed to determine the maximum dose by varying the stability class for wind speeds of 5 m/s

Run	**S2830D5E**	**S2830C5**	**S2830B5**	**S2830A5**	**S2830E5**	**S2830F5**
Weather						
Stability	D	C	B	**A**	E	F
Mixing height (m)	560	800	1200	**1600**	320	200
Wind speed (m/s)	5	5	5	**5**	5	5
Rain (mm)	0	0	0	**0**	0	0
Wind direction (deg)	360	360	360	**360**	360	360
Season	S	S	S	**S**	S	S
Dispersion						
Ws measure height	10	10	10	**10**	10	10
Terrain	S	S	S	**S**	S	S
Wind profile						
Min val integ c (Bq.s.m3)	1.00E-12	1.00E-12	1.00E-12	**1.00E-12**	1.00E-12	1.00E-12
Wind profile exp	0.34	0.34	0.34	**0.34**	0.34	0.34
Dry Deposition						
Aerosols: Dep vel m/s	0.3	0.3	0.3	**0.3**	0.3	0.3
Elemental Iodine: Dep vel0.01	0.3	0.3	0.3	**0.3**	0.3	0.3
Org bound Iodine	3.00E-01	3.00E-01	3.00E-01	**3.00E-01**	3.00E-01	3.00E-01
Source term						
Release parameters						
Building width (m)	40	40	40	**40**	40	40
Building height (m)	15	15	15	**15**	15	15
Phase (hour)	1	1	1	**1**	1	1
Release height (m)	80	80	80	**80**	80	80
Power (MW)	0	0	0	**0**	0	0
Inventory groups	7	7	7	**7**	7	7
Pathways:						
Cloud shine						
Ground shine						
Inhalation						
Skin						
Ingestion						
Release fractions						
Group 1	1	1	1	**1**	1	1
Group 2	0.05	0.05	0.05	**0.05**	0.05	0.05
Group 3	0.0082	0.0082	0.0082	**0.0082**	0.0082	0.0082
Group 4	0.0096	0.0096	0.0096	**0.0096**	0.0096	0.0096
Group 5	0.01	0.01	0.01	**0.01**	0.01	0.01

roup 6	0.00025	0.00025	0.00025	**0.00025**	0.00025	0.00025
roup 7	0.00015	0.00015	0.00015	**0.00015**	0.00015	0.00015
odine fractions:						
lemental	0.99	0.99	0.99	**0.99**	0.99	0.99
rganic	0.01	0.01	0.01	**0.01**	0.01	0.01
erosol	0	0	0	**0**	0	0
hielding during release						
loud shine	1	1	1	**1**	1	1
round shine	1	1	1	**1**	1	1
halation	1	1	1	**1**	1	1
e-suspension	1	1	1	**1**	1	1
ep on clothes	1	1	1	**1**	1	1
ose conversion factors	ICRP 60	ICRP 60	ICRP 60	**ICRP 60**	ICRP 60	ICRP 60
reathing rate (m3/s)	3.33E-04	3.33E-04	3.33E-04	**3.33E-04**	3.33E-04	3.33E-04
e-suspension:						
VLAMR (/s)	3.50E-08	3.50E-08	3.50E-08	**3.50E-08**	3.50E-08	3.50E-08
ESE (/m)						
ESO (/m)						
esults (Max)						
istance (m)		850	350	**350**	2750	3250
ff dose	6.9	3.23	6.15	**15.44**	3.06	3.76
hyroid	9.01	4.2	7.95	**20.09**	3.99	4.92
ye lens	7.55	3.54	6.74	**16.89**	3.35	4.12
varies	6.43	2.96	5.61	**14.15**	2.81	3.46
kin	336.8	152.7	278	**739.6**	149.7	184.4
ung	7.35	3.438	6.53	**16.42**	3.26	4.01
Marrow	6.72	3.14	5.97	**15.02**	2.98	3.67
i tract	6.13	2.87	5.46	**13.71**	2.72	3.35
ower (MW)	0	0	0	**0**	0	0
un	S2830D5E	S2830C5	S2830B5	**S2830A5**	S2830E5	S2830F5
	D	C	B	**A**	E	F

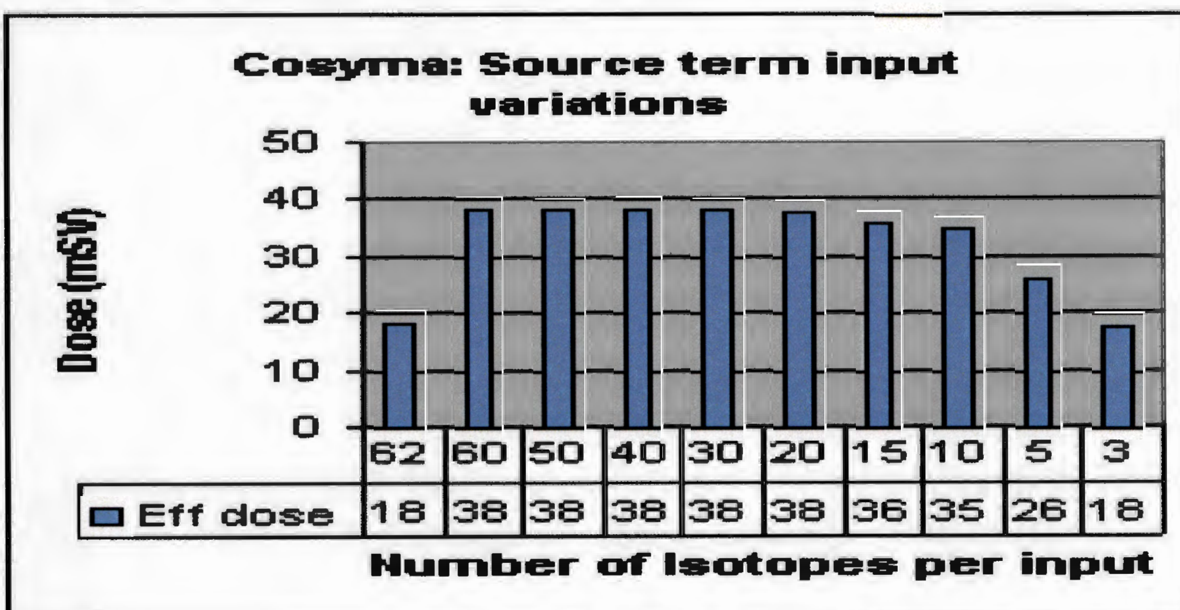
Annexure 4

PC COSYMA: Worst case: Number of nuclides

Summary of runs performed to determine the maximum dose by varying the number of nuclides in the source term

Cosyma Input variations

Results (Max)										
Distance (m)	350	350	350	350	350	350	350	350	350	350
Eff dose	18.22	38.18	38.18	38.18	38.18	38.01	36.13	35.07	26	17.99
Thyroid	23.76	50.02	50.02	50.02	50.02	49.83	47.6	36.34	35.53	25.12
Eye lens	19.93	41.91	41.91	41.91	41.91	41.72	39.65	38.48	28.47	19.67
Ovaries	16.73	35.2	35.2	35.2	35.2	35.05	33.32	32.34	23.96	16.56
Skin	886.2	1879	1879	1810	1810	1807	1772	1736	1566	1184
Lung	19.39	39.59	39.59	39.59	39.59	39.41	37.45	36.35	26.84	18.54
B Marrow	17.73	37.31	37.31	37.31	37.31	37.15	35.31	34.24	25.37	17.53
Gi tract	16.19	34.04	34.04	34.04	34.04	33.89	32.21	31.25	23.11	15.98
	62	60	50	40	30	20	15	10	5	3



nnexure 5

C COSYMA: Most probable case: Other variables

ummary of runs performed to determine the maximum dose by varying the Power level on the eactor, re-suspension and deposition on clothes.

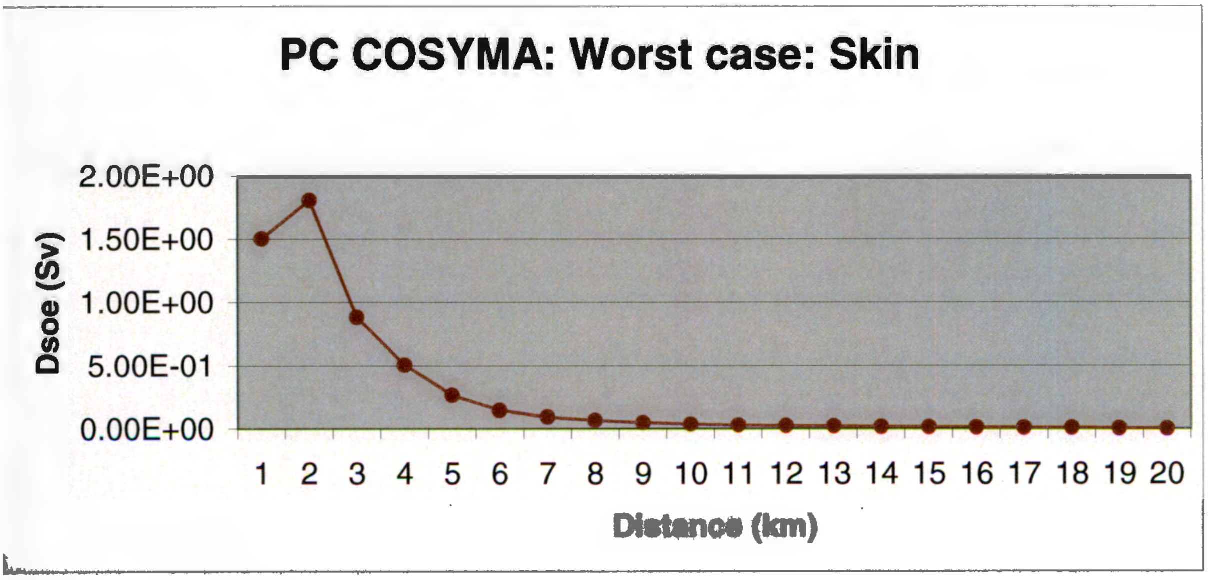
un	D2830-5	S2830D5	S2830D5A	S2830D5B	S2830D5C	S2830D5D	**S2830D5E**
eather							
tability	D	D	D	D	D	D	**D**
ixing height (m)	560	560	560	560	560	560	**560**
ind speed (m/s)	5	5	5	5	5	5	**5**
ain (mm)	0	0	0	0	0	0	**0**
ind direction (deg)	360	360	360	360	360	360	**360**
eason	S	S	S	S	S	S	**S**
ispersion							
s measure height	10	10	10	10	50	10	**10**
errain	S	S	S	S	S	S	**S**
ind profile							
in val integ c (Bq.s.m3)	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	**1.00E-12**
ind profile exp	0.34	0.34	0.34	0.34	0.34	0.34	**0.34**
ry Deposition							
erosols: Dep vel m/s	0.001	0.001	0.001	0.3	0.3	0.003	**0.3**
lemental Iodine: Dep el0.01	0.01	0.01	0.01	0.3	0.3	0.003	**0.3**
rg bound Iodine	5.00E-04	5.00E-04	5.00E-04	3.00E-01	3.00E-01	3.00E-03	**3.00E-01**
ource term							
elease parameters							
uilding width (m)	40	40	40	40	40	40	**40**
uilding height (m)	15	15	15	15	15	15	**15**
hase (hour)	1	1	1	1	1	1	**1**
elease height (m)	80	80	80	80	80	80	**80**
ower (MW)	30	30	30	30	30	30	**0**
ventory groups	7	7	7	7	7	7	**7**
athways:							
louds shine							
round shine							
halation							
kin							
gestion							
elease fractions							
roup 1	1	1	1	1	1	1	**1**
roup 2	0.05	0.05	0.05	0.05	0.05	0.05	**0.05**

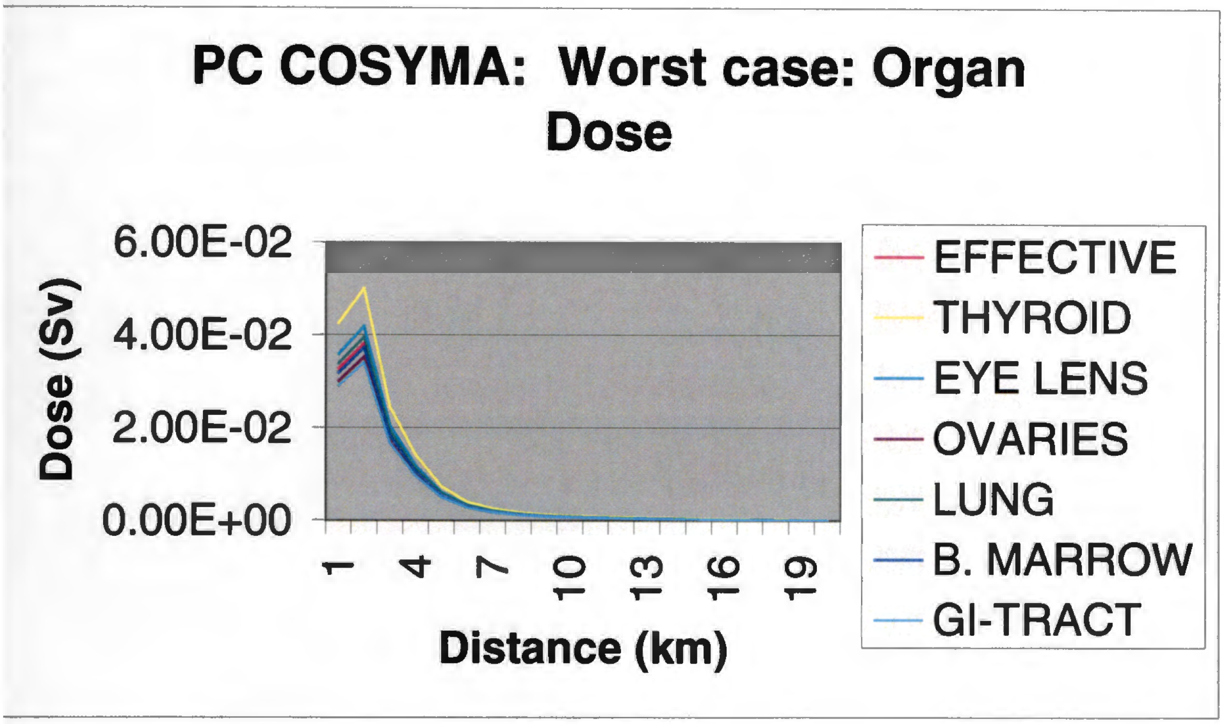
iroup 3	0.0082	0.0082	0.0082	0.0082	0.0082	0.0082	**0.0082**
iroup 4	0.0096	0.0096	0.0096	0.0096	0.0096	0.0096	**0.0096**
iroup 5	0.01	0.01	0.01	0.01	0.01	0.01	**0.01**
iroup 6	0.00025	0.00025	0.00025	0.00025	0.00025	0.00025	**0.00025**
iroup 7	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	**0.00015**
odine fractions:							
lemental	0.99	0.99	0.99	0.99	0.99	0.99	**0.99**
)rganic	0.01	0.01	0.01	0.01	0.01	0.01	**0.01**
erosol	0	0	0	0	0	0	**0**
hielding during release							
loud shine	0.16	0.16	1	1	1	1	**1**
iround shine	0.14	0.14	1	1	1	1	**1**
nhalation	0.55	0.55	1	1	1	1	**1**
le-suspension	0.55	0.55	0.55	0.55	0.55	0.55	**1**
)ep on clothes	0.55	0.55	0.55	0.55	0.55	0.55	**1**
)ose conversion factors	ICRP 60	ICRP 60	ICRP 60	ICRP 60	ICRP 60	ICRP 60	**ICRP 60**
ireathing rate (m3/s)	3.33E-04	3.33E-04	3.33E-04	3.33E-04	3.33E-04	3.33E-04	**3.33E-04**
le-suspension:							
VLAMR (/s)	3.50E-08	3.50E-08	3.50E-08	3.50E-08	3.50E-08	3.50E-08	**3.50E-08**
IESE (/m)							
IESO (/m)							
lesults (Max)							
)istance (m)	200	.	.	.	.		
ff dose	12.41	0.06	0.37	6.9	1.76	0.37	**6.9**
'hyroid	104.8	0.68	1.5	9.01	2.3	1.43	**9.01**
ye lens	7.75	0.065	0.41	7.55	1.93	0.41	**7.55**
)varies	6.379	0.0495	0.31	6.43	1.62	0.31	**6.43**
ikin	91.71	4.877	4.8	185	46.61	1.91	**336.8**
ung	8.003	0.189	0.59	7.35	1.88	0.51	**7.35**
3 Marrow	6.955	0.055	0.34	6.72	1.72	0.35	**6.72**
ii tract	6.634	0.065	0.35	6.13	1.57	0.33	**6.13**
'ower (MW)	30	30	30	30	30	0	**0**

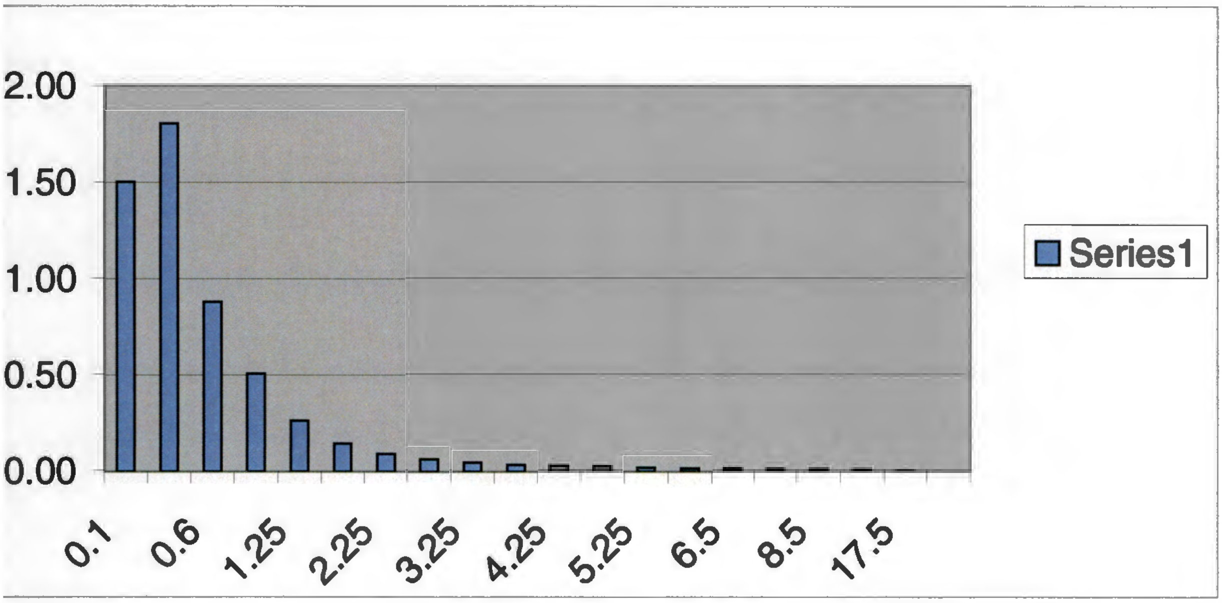
Annexure 6
PC COSYMA: Worst case: Organ dose

Cosyma Max output" Stability A wind speed 8m/s Top 25 isotopes
Dose in Sv

DISTANCE (km)	EFFECTIVE	THYROID	EYE LENS	OVARIES	SKIN	LUNG	B. MARROW	GI-TRACT
0.1	3.26E-02	4.26E-02	3.58E-02	3.00E-02	1.50E+00	3.38E-02	3.18E-02	2.91E-02
0.35	3.81E-02	4.99E-02	4.18E-02	3.51E-02	1.81E+00	3.95E-02	3.72E-02	3.40E-02
0.6	1.87E-02	2.45E-02	2.06E-02	1.73E-02	8.83E-01	1.94E-02	1.83E-02	1.67E-02
0.85	1.08E-02	1.42E-02	1.19E-02	9.97E-03	5.09E-01	1.12E-02	1.06E-02	9.64E-03
1.25	5.64E-03	7.37E-03	6.19E-03	5.19E-03	2.64E-01	5.84E-03	5.50E-03	5.02E-03
1.75	3.11E-03	4.07E-03	3.42E-03	2.87E-03	1.45E-01	3.23E-03	3.04E-03	2.78E-03
2.25	1.98E-03	2.59E-03	2.17E-03	1.82E-03	9.23E-02	2.05E-03	1.93E-03	1.76E-03
2.75	1.37E-03	1.79E-03	1.51E-03	1.26E-03	6.38E-02	1.42E-03	1.34E-03	1.22E-03
3.25	1.01E-03	1.32E-03	1.11E-03	9.28E-04	4.68E-02	1.05E-03	9.84E-04	8.99E-04
3.75	7.73E-04	1.01E-03	8.48E-04	7.11E-04	3.58E-02	8.01E-04	7.54E-04	6.89E-04
4.25	6.12E-04	7.99E-04	6.72E-04	5.63E-04	2.83E-02	6.34E-04	5.97E-04	5.45E-04
4.75	4.96E-04	6.49E-04	5.45E-04	4.57E-04	2.30E-02	5.15E-04	4.84E-04	4.42E-04
5.25	4.12E-04	5.38E-04	4.52E-04	3.79E-04	1.91E-02	4.27E-04	4.02E-04	3.67E-04
5.75	3.47E-04	4.54E-04	3.81E-04	3.19E-04	1.61E-02	3.60E-04	3.39E-04	3.10E-04
6.5	2.76E-04	3.61E-04	3.03E-04	2.54E-04	1.28E-02	2.87E-04	2.70E-04	2.46E-04
7.5	2.12E-04	2.76E-04	2.32E-04	1.95E-04	9.75E-03	2.19E-04	2.06E-04	1.89E-04
8.5	1.68E-04	2.19E-04	1.84E-04	1.54E-04	7.72E-03	1.74E-04	1.64E-04	1.49E-04
9.5	1.36E-04	1.78E-04	1.49E-04	1.25E-04	6.27E-03	1.41E-04	1.33E-04	1.21E-04
17.5	4.70E-05	6.13E-05	5.15E-05	4.31E-05	2.15E-03	4.87E-05	4.58E-05	4.19E-05
37.5	1.67E-05	2.18E-05	1.83E-05	1.53E-05	7.58E-04	1.74E-05	1.63E-05	1.49E-05




PC COSYMA: Worst case: Organ Dose
Dose (Sv)
6.00E-02
4.00E-02
2.00E-02
0.00E+00
1
4
7
10
13
16
19
Distance (km)
EFFECTIVE
THYROID
EYE LENS
OVARIES
LUNG
B. MARROW
GI-TRACT


2.00
1.50
1.00
0.50
0.00
0.1
0.6
1.25
2.25
3.25
4.25
5.25
6.5
8.5
17.5
Series1

Annexure 7

PC COSYMA: Most probable case: Organ dose

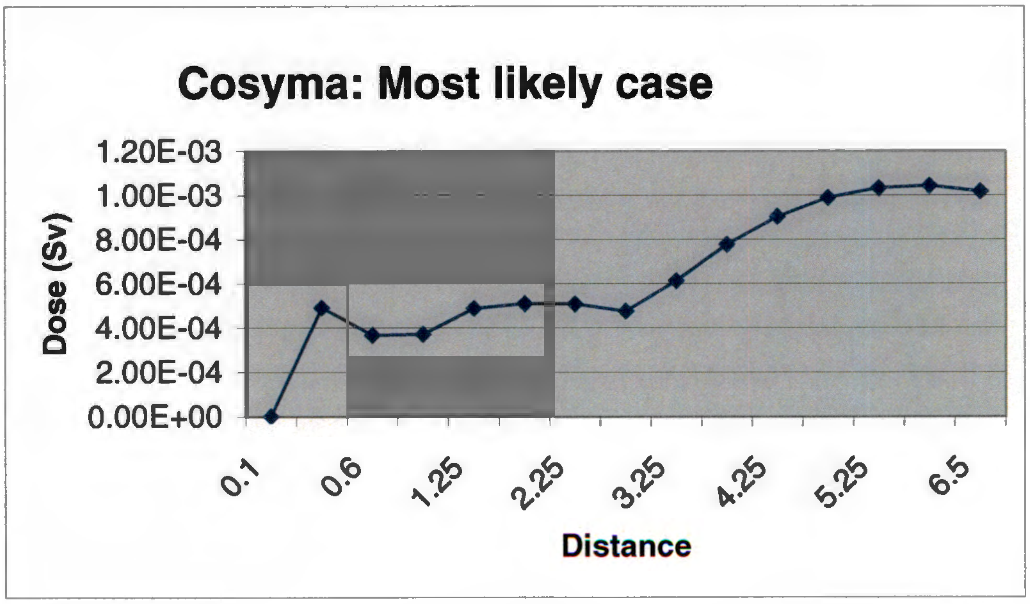
PC COSYMA output for different organs for the most likely case

2830 D25'

Mean individual 1 day dose

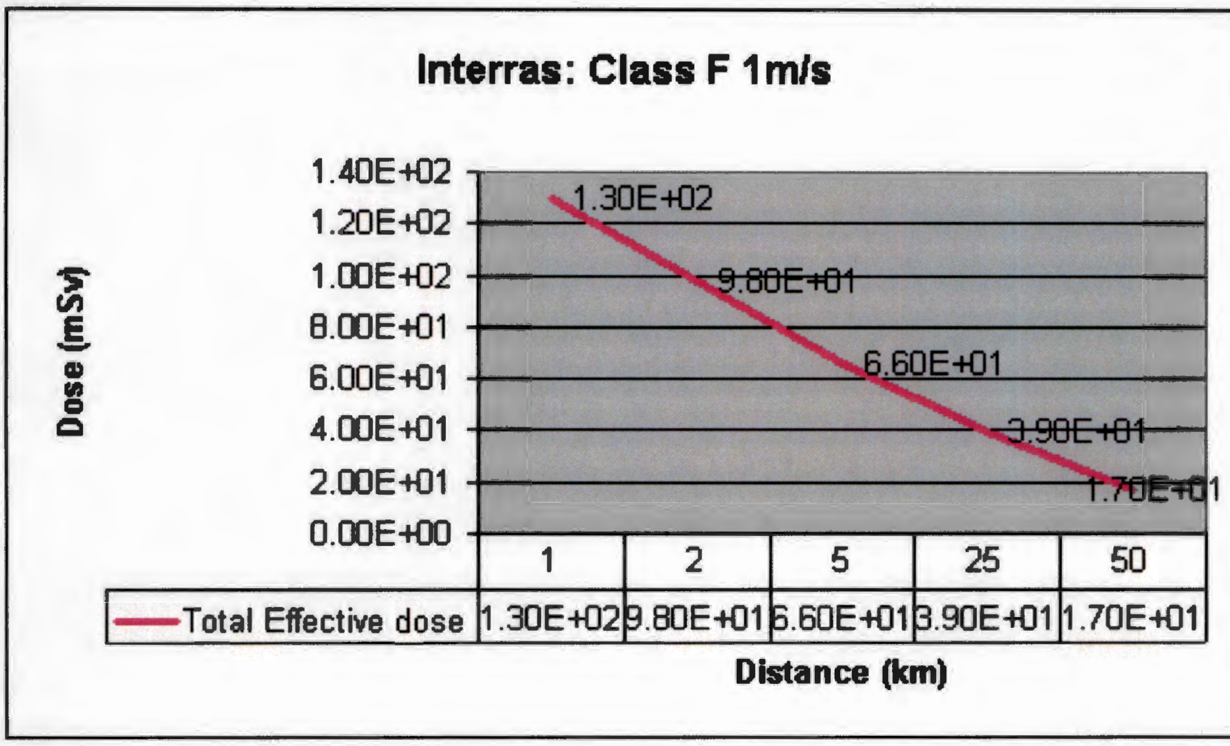
Dose (Sv)

Distance	Distance	Effective	Thyroid	Eye lens	Ovaries	Skin	Lung	B Marrow	GI Track
	0.1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	0.35	4.91E-04	5.62E-04	5.47E-04	4.12E-04	3.12E-04	5.05E-04	4.61E-04	4.38E-04
	0.6	3.67E-04	4.32E-04	4.07E-04	3.13E-04	3.73E-03	3.80E-04	3.47E-04	3.27E-04
	0.85	3.72E-04	4.55E-04	4.11E-04	3.26E-04	8.70E-03	3.89E-04	3.56E-04	3.32E-04
	1.25	4.87E-04	6.05E-04	5.37E-04	4.32E-04	1.46E-02	5.12E-04	4.68E-04	4.34E-04
	1.75	5.09E-04	6.41E-04	5.60E-04	4.56E-04	1.76E-02	5.37E-04	4.91E-04	4.53E-04
	2.25	5.08E-04	6.41E-04	5.58E-04	4.56E-04	1.81E-02	5.36E-04	4.90E-04	4.52E-04
	2.75	4.76E-04	6.02E-04	5.22E-04	4.27E-04	1.75E-02	5.02E-04	4.59E-04	4.23E-04
	3.25	6.13E-04	7.85E-04	6.72E-04	5.55E-04	2.54E-02	6.49E-04	5.93E-04	5.45E-04
	3.75	7.78E-04	1.00E-03	8.52E-04	7.08E-04	3.44E-02	8.26E-04	7.55E-04	6.91E-04
	4.25	9.04E-04	1.17E-03	9.89E-04	8.25E-04	4.12E-02	9.60E-04	8.78E-04	8.03E-04
	4.75	9.88E-04	1.28E-03	1.08E-03	9.03E-04	4.58E-02	1.05E-03	9.60E-04	8.78E-04
	5.25	1.03E-03	1.34E-03	1.13E-03	9.44E-04	4.83E-02	1.10E-03	1.00E-03	9.17E-04
	5.75	1.04E-03	1.35E-03	1.14E-03	9.53E-04	4.92E-02	1.11E-03	1.01E-03	9.25E-04
	6.5	1.02E-03	1.32E-03	1.11E-03	9.32E-04	4.85E-02	1.08E-03	9.89E-04	9.04E-04
	7.5	9.44E-04	1.23E-03	1.03E-03	8.65E-04	4.54E-02	1.01E-03	9.18E-04	8.38E-04
	8.5	8.52E-04	1.11E-03	9.31E-04	7.81E-04	4.11E-02	9.07E-04	8.29E-04	7.57E-04
	9.5	7.58E-04	9.87E-04	8.29E-04	6.95E-04	3.66E-02	8.07E-04	7.37E-04	6.73E-04
	17.5	3.09E-04	4.01E-04	3.38E-04	2.83E-04	1.44E-02	3.29E-04	3.00E-04	2.75E-04
	37.5	5.84E-05	7.53E-05	6.38E-05	5.31E-05	2.63E-03	6.23E-05	5.65E-05	5.18E-05



Annexure 8
nterras: Stability class F 1 m/s

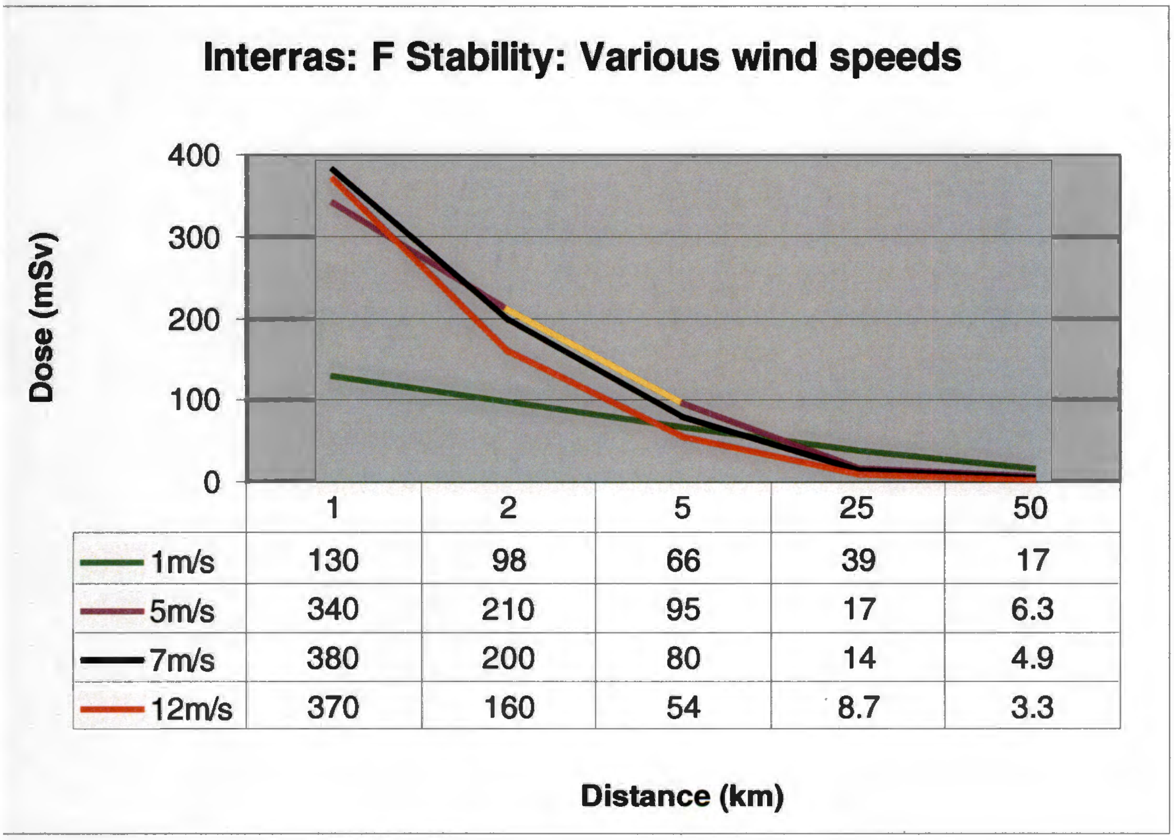
2830A					2003/11/03 10:29
istance	Maximum EARLY Doses (mSv)				
istance	1	2	5	25	50
otal Effective	1.30E+02	9.80E+01	6.60E+01	3.90E+01	1.70E+01
hyroid	1.50E+03	1.20E+03	1.00E+03	3.70E+02	1.40E+02
loud Shine	4.40E+01	3.50E+01	3.00E+01	1.90E+01	9.60E+00
round Shine	1.60E+01	1.20E+01	1.10E+01	3.90E+00	1.40E+00
ff. Inhalation	6.60E+01	5.10E+01	4.50E+01	1.60E+01	5.90E+00



nnexure 9
nterras: Worst case: Varying wind speeds

terras output Stability Category F

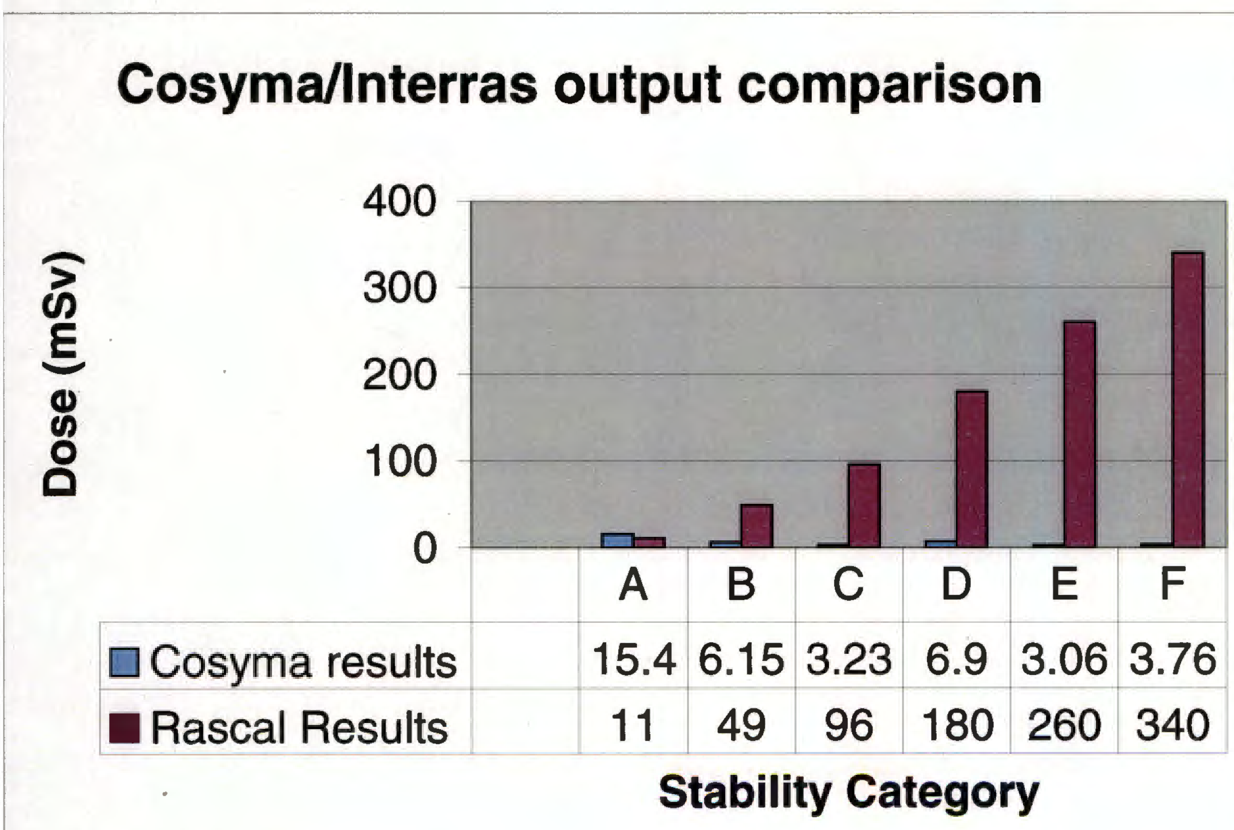
istance (km)	1	2	5	25	50
ind speed (m/s)					
1	130	98	66	39	17
3	250	170	110	24	8.7
5	340	210	95	17	6.3
7	380	200	80	14	4.9
8	380	200	73	12	4.5
9	380	190	67	11	3.9
10	380	180	62	10	3.8
12	370	160	54	8.7	3.3



Annexure 10
PC COSYMA/Interras comparison: Stability classes

Summary of the comparison between PC COSYMA results and Interras results for different stability classed

Stability category	COSYMA results (mSv)	Rascal Results (mSv)	Mixing height Cosyma (m)
A	15.44	11	1600
B	6.15	49	1200
C	3.23	96	800
D	6.9	180	560
E	3.06	260	320
F	3.76	340	200



Annexure 11

PC COSYMA/Interras comparison: Stability classes

Summary of the comparison between PC COSYMA results and Interras results for different stability classed

Stability category	1	3	5	7	8	9	15	
A	1.88	6.49	15.44	18.09	18.22	17.99	14.71	Cosyma
A	28	17	11	7.9	6.9	6.2	3.7	Interras