SOURCE TERM AND RADIOLOGICAL CONSEQUENCES OF THE CHERNOBYL ACCIDENT

TERME-SOURCE ET CONSÉQUENCES RADIOLOGIQUES DE L'ACCIDENT DE TCHERNOBYL

by

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Abstract

This report presents the results of a study of the source term and radiological consequences of the Chernobyl accident.

The results consist of two parts. The first part was performed during the first 2 months following the accident and dealt with the evaluation of the source term and an estimate of individual doses in the European countries outside the Soviet Union. The second part was performed after August 25-29, 1986 when the Soviets presented in a IAEA Conference in Vienna detailed information about the accident, including source term and radiological consequences in the Soviet Union. The second part of the study reconfirms the source term evaluated in the first part and in addition deals with the radiological consequences in the Soviet Union. Source term and individual doses are calculated from measured post-accident data, reported by the Soviet Union and the European countries, such as radiation fields, concentration of radionuclides in air and on the ground, and meteorological data. The simulation uses the microcomputer program PEAR (Public Exposure from Accident Releases) (Reference 1).

The main findings from the fallout pattern are:*

i) The reactor was effectively at low power for about 12 hours prior to the accident.

ii) Releases of radioactive material started on April 26 and ceased around May 05. Releases in the first two days were relatively high, followed by lower almost constant releases during the next 3 days, followed by relatively high releases, respecially of non-volatiles, during the 6-10th day.

iii) Releases of Sr-89, Sr-90, Ru-103, Ru-106, Te-132, I-133, Cs-134 and Cs-137 over the course of the accident were between 10 and 20 percent of the respective core inventories at the time of the accident. About 40% of the I-131 inventory was released.

iv) In Europe, outside the U.S.S.R., the maximum hypothetical individual doses (effective and committed dose equivalents to individuals exposed to radiation for the first 10 years) assuming no mitigation are in the range of 0.1 to 28 mSv. The highest predicted doses are encountered in Poland, Finland and Sweden and the lowest predicted doses are in Greece, Albania, Belgium and Denmark. External dose from ground deposition and internal dose from inhalation and food ingestion are the main exposure pathways considered in the analysis.

Variations within each country and between countries are largely due to changes in the trajectories of the plume, changes in the releases and local effects of deposition. The given doses are maximum values and do not necessarily apply to any real individual as they are derived using the maximum reported concentrations and without allowing for any shielding, attenuation or protective actions. A summary of the maximum individual doses is given in Table 1 (rounded to one significant digit).

v) In the Soviet Union, the individual doses in 10 locations are in the range of 3-300 mSv. In towns within the 30 km zone, it is assumed that people are exposed to radiation for 2 days and in towns outside the 30 km zone, people are exposed to radiation for 50 years. Exposure from the food pathway, and thyroid blocking due to administration of KI tablets are not considered in the analysis. A summary of the individual doses is given in Table 2 (rounded to one significant digit).

*The first 4 findings, largely from calculations done prior to the IAEA Post Accident Review meeting on August 25-29, are consistent with the sequence of events presented by the Soviets.

Table 1 Summary of Maximum Hypothetical Individual Doses (mSv to the Whole Body)**

Poland/Finland/Sweden	20
Hungary/Romania	10
Germany/Yugoslavia/Austria	6
Italy/Switzerland/Czechoslavakia	3
United Kingdom/Netherlands	1
Greece/Albania	0.3
Belgium	0.2
Denmark	0.1

**These are not necessarily the doses for any real individual as they exclude shielding, attenuation and protective action and are based on maximum concentrations

Table 2 Individual Doses in the Soviet Union (mSv) (mSv to the whole body)

Pripyat	3	KM	300
Chistogolovka	5.5	KM	100
Chernobyl	15	KM	50
Narovlja	60	KM	90
Oster	70	KM	60
Kiev	110	KM	10
Baryshevska	160	KM	50
Cherkassy	270	KM	30
Minsk	320	KM	3
Kaliningrad	730	KM	20

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Résumé

Le présent rapport donne les résultats d'une étude du terme-source et des conséquences radiologiques de l'accident de Tchernobyl.

Les résultats sont divisés en deux parties. La première partie a été établie pendant les deux premiers mois suivant l'accident, et ont porté sur l'évaluation du terme-source et sur une estimation des doses individuelles dans les pays européens en dehors de l'U.R.S.S. La deuxième partie a été établie après la période du 25 au 29 août 1986, lorsque les Soviétiques ont présenté, lors d'une Conférence de l'AIEA à Vienne, des informations détaillées sur l'accident, comprenant le terme-source et les conséquences radiologiques de l'accident en U.R.S.S. La deuxième partie de l'étude confirme à nouveau le terme-source évalué dans la première partie et, en outre, traite des conséquences radiologiques en U.R.S.S. Le terme-source et les doses individuelles sont calculés à partir des données post-accidentelles, notifiées par l'U.R.S.S. et les pays européens, comme les champs de rayonnement, la concentration de radionucléides dans l'air et sur le sol, ainsi que les données météorologiques. On a recours au programme de micro-ordinateur PEAR (Public Exposure from Accident Releases) pour la simulation (référence 1).

Les principales conclusions tirées des retombées sont les suivantes* :

i) Le réacteur a fonctionné effectivement à faible puissance pendant environ 12 heures avant l'accident

ii) Les rejets de matières radioactives ont commencé le 26 avril et se sont arrêtés vers le 5 mai. Les rejets des deux premiers jours ont été relativement élevés, suivis par des rejets inférieurs de façon presque constante pendant les 3 jours suivants, puis par des rejets relativement élevés, spécialement non volatils, entre le 6^{e} et le 10^{e} jour.

iii) Des rejets de ^{89}Sr, ^{90}Sr, ^{103}Ru, ^{106}Ru, ^{132}Te, ^{133}I, ^{134}Cs et ^{137}Cs pendant le déroulement de l'accident, correspondaient à entre 10 et 20 % des charges du coeur respectives au moment de l'accident. Environ 40 % de la charge de ^{131}I ont été libérés.

iv) En Europe, en dehors de l'U.R.S.S., les doses individuelles hypothétiques maximales (équivalents de dose efficaces et engagés pour les individus exposés aux rayonnements pendant les 10 premières années) en supposant aucune atténuation, sont de l'ordre de 0,1 à 28 mSv. Les doses prévues les plus élevées ont été trouvées en Pologne, Finlande et Suède et les doses prévues les plus faibles ont été trouvées en Grèce, Albanie, Belgique et Danemark. La dose externe provenant des dépôts sur le sol et la dose interne provenant de l'inhalation et de l'ingestion d'aliments constituent les voies d'exposition principales prises en compte dans l'analyse.

Les variations à l'intérieur d'un même pays et entre divers pays sont importantes en raison des changements de trajectoire du panache, des changements dans les rejets et des effets locaux des dépôts. Les doses données correspondent aux valeurs maximales mais ne s'appliquent pas nécessairement à une personne réelle, car elles sont dérivées en utilisant les concentrations notifiées maximales et ne tiennent pas compte du blindage, de l'atténuation ou des mesures de protection. On trouvera un résumé des doses individuelles maximales au tableau 1 (arrondies à un chiffre significatif).

v) En U.R.S.S., les doses individuelles en 10 points différents vont de 3 à 300 mSv. Dans les localités situées dans la zone de 30 km, on suppose que le public est exposé aux rayonnements pendant 2 jours et dans les villes à l'extérieur de la zone de 30 km, le public est exposé aux rayonnements pendant 50 ans. L'exposition à partir de la chaîne alimentaire et le blocage de la thyroïde en raison de l'ingestion de pilules de KI ne sont pas prises en compte dans l'étude. On trouvera au tableau 2 un résumé des doses individuelles (arrondies à un chiffre significatif).

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*Les quatre premières conclusions, provenant principalement des calculs effectués avant la Réunion d'analyse de l'accident du 25 au 29 août, sont conformes à la séquence d'événements présentée par les Soviétiques.

Tableau 1 Résumé des doses individuelles hypothétiques maximales (mSv au corps entier)**

Pologne/Finlande/Suède	20
Hongrie/Roumanie	10
Allemagne/Yougoslavie/Autriche	6
Italie/Suisse/Tchécoslovaquie	3
Royaume-Uni/Pays-Bas	1
Grèce/Albanie	0,3
Belgique	0,2
Danemark	0,1

**Ces doses ne s'appliquent pas nécessairement à une personne réelle, étant donné qu'elles ne comprennent pas le blindage, l'atténuation et les mesures de protection et se fondent sur les concentrations maximales.

Tableau 2 Doses individuelles en U.R.S.S. (mSv) (mSv au corps entier)

Pripyat	3	KM	300
Chistogolovka	5,5	KM	100
Tchernobyl	15	KM	50
Narovlja	60	KM	90
Oster	70	KM	60
Kiev	110	KM	10
Baryshevska	160	KM	50
Cherkassy	270	KM	30
Minsk	320	KM	3
Kaliningrad	730	KM	20

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CONTENTS

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1. INTRODUCTION

1.1 Background

On Saturday, April 26, around 1:23 a.m. local time (21:00 hours G.M.T.), Unit 4 of the Chernobyl nuclear station, located 130 km north of Kiev, suffered a reactivity excursion leading to destruction of the reactor core. The Chernobyl reactors are light-water cooled, graphite moderated, pressure tube reactors. They are 1000 MW(e) plants and are called RBMK-1000 by the Soviets.

The graphite burned, and because of the continuing intense heat released, radioactive material from the core was discharged upwards reaching an elevation of hundreds of meters. The fire continued for about 10 days during which significant amounts of fission products and some activation products and actinides were released to the atmosphere. The winds carried the releases in the first 2 days mainly to the North-west parts of the Soviet Union and towards the Scandinavian countries, and later releases were carried to the rest of Europe and to the Soviet Union.

Finland was the first country outside the Soviet Union to detect high radiation. Levels of six times the normal background were recorded in Helsinki and Kajaani on the afternoon of April 27 and ten times the normal background the next day. Sweden broke the news to the world on the morning of April 28. Radiation levels at the Forsmark nuclear power plant and at the Studsvik research center were about 10 times the normal levels. On April 29 the Polish authorities reported that a radioactive cloud had passed over northwest Poland. On April 30 and later on, radiation levels higher than normal were reported by all the countries of western Europe, by the Soviets and by other countries outside Europe.

The Russians confirmed on April 28 that they had an accident at Unit 4 of the Chernobyl reactor and that on the afternoon of April 27, 30,000 residents of the towns close to the site had been forced to leave an area of about 10 km radius around Chernobyl. On May 2nd, a 30 km zone was evacuated involving another 60000 people. Evacuees were taken to villages located 60 km south of Chernobyl and west of Kiev. The evacuation effort had been enlarged later on to include hundreds of thousands of children from as far away as Kiev. Potassium iodide (KI) tablets were widely distributed inside as well as outside the 30 km zone.

1.2 Objectives and Approach

The objective of this report is to estimate the source term and to evaluate the maximum hypothetical individual doses in 17 European countries outside the Soviet Union and individual doses in 10 locations in the Soviet Union through the analyses of measurements of meteorological data, and airborne and deposited activity. Applying the information on weather, radiation fields and radionuclide concentrations on the ground and in air to deduce the source term involves a reversal of the techniques of nuclear accident analyses which estimate the offsite consequences of postulated accidents. In this study we simulate quantities of the radionuclides that if released at Chernobyl and following the calculated trajectories, would explain the observed radiation levels and radionuclides concentrations as measured by the European countries and as reported by the Soviets. The simulation of the data is done by using the microcomputer program PEAR (Ref. 1) which uses the methodology as described in CSA N288.2 (Ref. 2). The assessment of the magnitude and characteristics of the source term and of the individual doses is made using the following data:

(i) Meteorological data and trajectory patterns.

(ii) External radiation field, concentration of radionuclides on the ground and time-integrated concentration in air.

Radioisotopes of Sr, Ru, I, Te and Cs are considered in this report. The data used in the first part is derived from references 3 to 19 of the following countries: Sweden, Finland, Poland, Hungary, Romania, Germany, Yugoslavia, Austria, Italy, Switzerland, Czechoslovakia, United

Kingdom, Netherlands, Greece, Albania, Belgium and Denmark. The data used in the second part is derived from reference 22.

Individual doses (effective and committed dose equivalents) resulting from exposure to the Chernobyl fallout in the first 10 years are assessed for the European countries outside the Soviet Union. The exposure pathways considered are given below in order of decreasing importance:

(i) Food ingestion.

(ii) External irradiation from contamination deposited on the ground.

(iii) Immersion in the radioactive cloud, i.e. through inhalation and external irradiation.

Individual doses are evaluated using the maximum radiological measurements reported by the European countries and without allowing for any shielding, attenuation or protective actions and as such, the calculated doses are an upper limit for the individual doses in the referenced countries and do not necessarily reflect the dose to any real individual.

Individual doses (effective and committed dose equivalents) resulting from exposure to the Chernobyl fallout in the first 50 years are assessed for 10 locations in the Soviet Union. For people in the 30 km zone, the exposure to fallout is taken as two days only. The exposure pathways considered are external irradiation from contamination deposited on the ground and immersion in the cloud (items (ii) and (iii) above).

Individual doses to the Soviet population are calculated for 10 locations only due to the limited information provided by the Soviets. In the 30 km zone for instance, there are 71 populated areas of which the Soviets gave data for only 3 (Chernobyl, Pripyat and Baryshevska). The Soviets provided data for a total of 31 locations. A few of these could not be identified on the maps (such as Rudki and Orevichi), others had incomplete data. Most of the 31 locations, addressed by the Soviets, were located in a few precise directions (or sectors) such as Southeast, Northeast, and North of the Chernobyl plant. All these restrictions limited the number of addressed locations in this report to 10.

The scope of this work does not cover the following issues.:

i) The inclusion of other radionuclides, such as noble gases and actinides, H-3, C-14, and radioisotopes of Ce, Ba, Zr, and Mo, which are likely to increase the doses by a factor of 2 at the most.

ii) The inclusion of the protective actions undertaken by the authorities outside the Soviet Union and of natural shielding and attenuation which are likely to decrease the doses by a factor of 2 at the least.

iii) The evaluation of individual doses at the Chernobyl site, and outside Europe.

iv) The evaluation of the average individual doses and of global long-term health effects. In the European countries the average dose is likely to be lower than the maximum dose by a factor between 2 and 50.

2. MODELS AND PARAMETERS USED FOR THE PREDICTION OF THE SOURCE TERM AND DOSES

2.1 Introduction

One of the major problems in the assessment of the transport and deposition of radioactive material, especially when transported over a few hundreds of kilometers, is to determine its pathway, i.e., to track the releases. In this analysis, "tracking of the cloud" is not considered a problem as it can be extracted for the many post-accident measurements. In Europe, the cloud activity and deposition on the ground were monitored under the extended monitoring program undertaken there. Measurements of radioactivity in Europe usually were reported as "maximum" values and therefore these measurements together with meteorological data, have defined the trajectory of the releases from Chernobyl. In the Soviet Union however, the reported data was more general, so it is assumed in this report that the data represents "average" values in the different locations.

The objective of this analysis is, based on the assessed trajectories and on the measured radioactive concentrations, to estimate the source term, i.e., those releases that, if transported under the measured meteorological conditions and trajectories, would give concentrations close to the observed values. The objective is to also assess the maximum doses to hypothetical individuals in the European countries projected for 10 years exposure with no consideration for natural shielding and protection and for any protective actions, and finally to assess the "average" dose to individuals in the Soviet Union considering the evacuation of the 30 km zone. Individual doses are calculated from the following exposure pathways:

1. Exposure from the radioactive cloud as external irradiation directly from the cloud and internal irradiation as a result of inhalation of radioactive material from the cloud.

2. Exposure to radiation as a result of deposition of radioactive material on the ground. The exposure pathways are external irradiation directly from the ground and internal irradiation from the food chain. As the extent of the food banning undertaken by the Soviets is unknown the last pathway is not considered in the dose calculation in the Soviet Union.

Deposition on the ground together with the Time Integrated Concentration in air (T.I.C.) provide a rational and scientific basis for estimating the above exposure pathways and the resulting doses. The models used to calculate the T.I.C. and the concentrations on the ground are given in References 1 and 2 and are briefly described in Sections 2.2 and 2.3 respectively.

2.2 Time Integrated Concentration (T.I.C.)

The T.I.C. at the centre of the plume is calculated using the puff-trajectory model equation (Ref. 20):

$$\text{T.I.C.} = \int_0^\infty \chi(t)dt = \int_0^\infty \frac{Q}{2\pi\sigma_H^2 L}\,dt$$

where: Q is the release in Bq

L is the mixed layer depth in meters

σ_H is the horizontal standard deviation of the puff in meters

When σ_H is assumed to be comparable to Σ_x and Σ_y in the Gaussian puff model, and L comparable to Σ_z, the puff-trajectory and the Gaussian-puff equations become identical. Following the recommendations in Reference 2, the T.I.C. for a release that lasts a day or so is calculated using the prolonged-term release Gaussian plume formula, i.e.:

$$\text{T.I.C.} = \frac{Q}{\Sigma_z\ \bar{u}\ x}$$

where: x is the trajectory length

$\bar{u}$ is the average wind speed over the trajectory

Σ_z is the modified vertical standard deviation of the plume.

2.3 Fallout

Depletion of the plume due to deposition of radioactive material during the travel time and deposition on the ground are treated using the "high-low" deposition velocities approach recommended in Reference 2. The "low value" (V_{dL}) of deposition velocity is used when plume depletion is calculated and the "high value (V_{dH}) when deposition on the ground is calculated. Depletion of the plume and concentration on the ground are calculated using the following formulae:

$$\text{Depletion of the plume} = \exp\left(-\alpha \int \frac{dx'}{\Sigma_z(x')}\right)$$

where: $\alpha = \dfrac{0.8V_{dL}}{\bar{u}}$, and

$$\text{Concentration on the ground} = \text{T.I.C.} \times V_{dH}$$

2.4 Doses

Doses from external irradiation directly from the cloud, internal irradiation due to inhalation of radioactive material and external irradiation directly from deposition on the ground are calculated using the methods and radiological data in Reference 2.

Dose from food ingestion is not thoroughly treated in Reference 2. A simple approach is used in this report to determine the dose from the food pathway. Dosimetric conversion factors for the food pathway are calculated based on work by Koch and Tadmor (Reference 21). The derived conversion factors give the committed effective dose equivalent that an individual will receive if he lives for 10 years in an area initially contaminated at a level of 1 Bq. m^{-2}. The conversion factors are given in Table 4.1. The food chain exposure pathway is considered only for the European countries and is not considered in the dose evaluation in the Soviet Union.

Table 2.1: Food Pathway Conversion Factors*

Radionuclide	Conversion Factor Sv per Bq/m^2
Sr-89	6×10^{-10}
Sr-90	10^{-8}
Ru-103	2×10^{-9}
Ru-106	10^{-8}
I-131	10^{-9}
I-133	2×10^{-10}
Te-132	2×10^{-10}
Cs-134	10^{-7}
Cs-137	10^{-7}

* Give the committed effective dose equivalent that an individual will receive if he lives for 10 years in an area contaminated at a level of 1 Bq. m^{-2}.

3. FIRST PART - THE EUROPEAN COUNTRIES OUTSIDE THE SOVIET UNION

3.1 Data and Measurements

3.1.1 Weather and Terrain Data

3.1.1.1 Wind Data and Trajectories

Weather conditions near the surface in the vicinity of the site at the starting time of the accident and also during the period of April 26-28 were characterized by generally low wind speeds and variable wind directions. Winds aloft (between 300 and 1000 metres above the surface), which are more representative for transport conditions over long distances (over 500 km) and at high elevation of releases (more than 500 metres), were generally from the southeast with wind speeds between 5 to 10 m/s. Higher in the atmosphere (higher than 1000 m), the wind field was even clearer and at a height of 1500 m the wind speeds were 8 to 10 m/s blowing from the southeast or the south. During the period of April 28-30, more easterly winds prevailed with the same wind speeds. On May 1st and 2nd, winds transported the releases to the south and southwest. During the period of May 3rd to May 5th the winds were generally from the south and/or east.

Meteorological conditions at high elevations (700 to 1500 metres) are used to describe the transport of the releases during April 26 - May 5 over Europe. Wind data (speeds and direction) are used to define the trajectories that releases have taken. It appears that there were two major release components; one source, between 1.5 and 4 km, was transported in the upper levels of the troposphere to Japan, and the other, below 1.5 km, meandered in Europe. It is assumed therefore that the releases that affected Europe have an effective height of release of less than 1.5 km.

Figures 3.1 and 3.2 show some of the results obtained from a trajectory analysis, which represents the general pattern as agreed by most of the analyses done in Europe, the U.S.A. and Canada.

The radiation measurements performed in Europe have also confirmed, at least partially, the trajectory analyses; the highest activity detected first was in Sweden, at Oskarshamn. Therefore, the trajectory of the plume centre line was, initially, over the Chernobyl-Oskarshamn axis. This defines quite well the trajectory of the "first day" release. Later releases went across Poland and central Europe to Britain. The location of the maximum activity as measured in the European countries defined quite well the actual trajectories.

Also, the time that the radioactivity reached a certain country, together with the trajectory length, defined an "average wind speed" of the release. The average wind speed, calculated for the trajectories is found to be in the range 7±2 m/s. A value of 7 m/s is used for all the releases and trajectories.

3.1.1.2 Atmospheric Stability

At site, probably stable conditions prevailed during the first hours after the accident started, with an inversion at a relatively high altitude (about 2 km). Normally, the capping inversion, under stable conditions, is at a lower altitude but in this case, there was a much deeper layer through which the release could mix below the inversion.

The radioactive material released to the atmosphere, during the period April 26 to May 05, obviously went through a series of changes in atmosphere stabilities ranging from high stability to neutral and unstable conditions and the releases were subject to large scale changes.

It is simply assumed that all the releases were subject to a neutral atmospheric stability (Pasquill D) on the average, with an elevated capping inversion at a height of 10 km.

3.1.1.3 Precipitation Conditions

Precipitation conditions over the course of the accident played a key role in determining the radiological consequences. Countries that were subjected to heavy rains experienced high fallout of radioactive material and hence a relatively high estimate for the maximum individual doses. For these countries, we used a relatively high value for the deposition velocities for the evaluation of deposition on the ground.

There was no rainfall at site and in the vicinity over the course of the accident. Also, there was no noticeable precipitation in the U.S.S.R. during the period April 26 - May 05. On the other hand, there was quite a widespread precipitation throughout Europe causing "patches" of relatively high deposition. During the first two days, April 28-29, some rain was measured over Scandinavia. From April 30 to May 1st, heavy rain was measured in southeastern France, in Switzerland, southern Germany, Austria and Czechoslavakia. On May 2nd, heavy rains moved to various parts of Europe. In general, heavy scattered rains fell across western Europe while the radioactive cloud from Chernobyl passed over.

3.1.1.4 Terrain Data

Terrain data is important to consider when air and ground concentrations are evaluated for nearby locations to the release source. For larger distances its effect is small. The closest country to the Chernobyl site, outside the Soviet Union and treated in this report, is Poland, located 600 km away. For these large distances, the results are insensitive to the terrain data.

3.1.2 Release Characteristics

3.1.2.1 Effective Height of Release

Due to the burning graphite, the radioactive material was released to the atmosphere with an intense heat content of the order of 500 MW. The decay heat of the reactor at the time of the accident was much less (about 30 MW). The warm air would rise to considerable heights between 500 meters and 2 km under neutral and stable conditions.

The effect of the height of the release on the dilution factor at ground level, for distances over 600 km, is extremely small for effective heights of releases less than 3 km. The smallest length of trajectory treated in this part of the report is 600 km. It is concluded, therefore, that the results of this part of the study are insensitive to the effective height of release.

3.1.2.2 Release Rates

It is assumed that activity is released at a fairly constant rate in the first 2 days, drops to a lower constant rate in the next 3 days and increases again to a higher constant rate in the last 5 days. Daily releases during the course of the accident as calculated are given in Table 3.1.

3.1.3 Radiation Measurements

Radiological measurements provided by the European countries are given in References 3 to 19. The data is in the form of activity in the air, on the ground, in rainwater, drinking water, food, milk and external radiation levels.

Variations within each country and between countries are large due to local effects of deposition by rain. A first preliminary try to sort and merge all the data into a coherent database is presented here. It permits us to present the data in a way which indicates, for each country, maximum values of radiation levels and concentrations.

The data is in the following form:

(i) Ru-103, I-131 and Cs-137 concentrations in air presented in Figures 3.3 through 3.5.

(ii) Ru-103, I-131 and Cs-137 Time Integrated Concentration (T.I.C.) in the European countries. These T.I.C.'s are calculated from the concentration values with time and are given in Figures 3.3 through 3.5.

(iii) Ru-103, I-131 and Cs-137 concentrations on the ground are given in Figures 3.6 through 3.8.

(iv) External radiation levels, 1 metre above the ground as measured in the different countries on different dates are given in Figure 3.9.

In this part of the study, the maximum reported values are used. A summary of the maximum values of the T.I.C., of concentration on the ground and of the radiation levels is given in Figure 3.10.

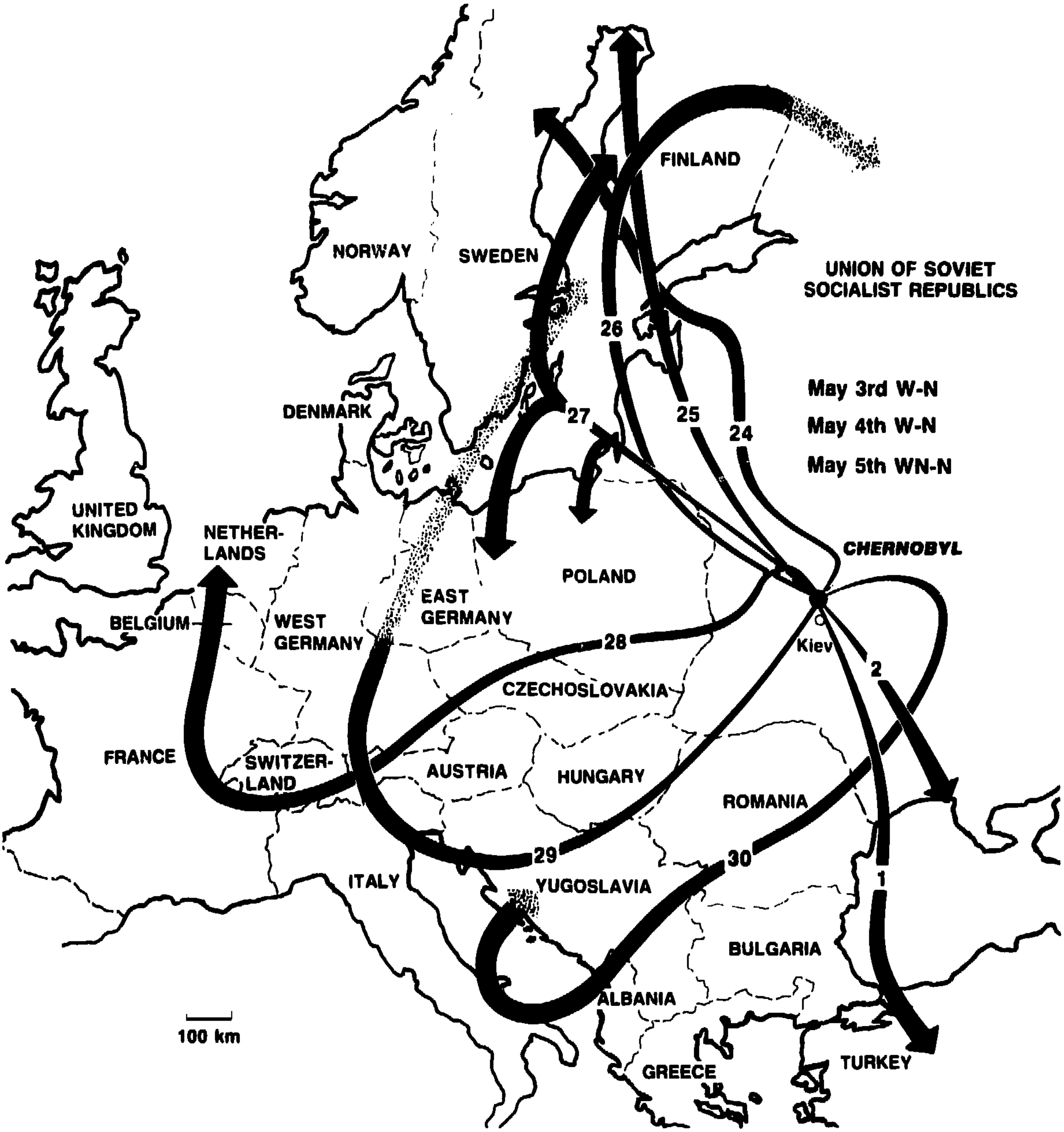
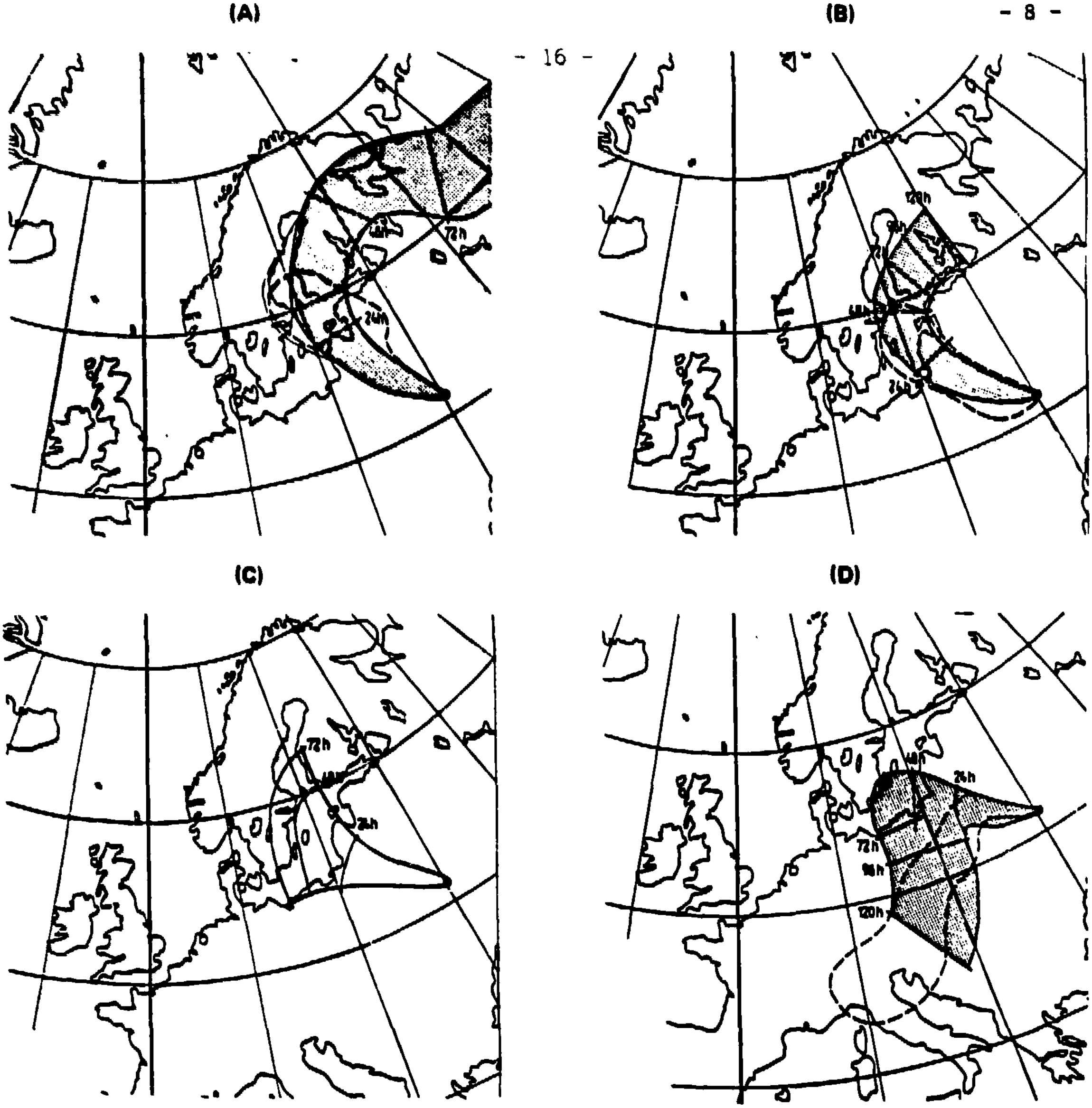


FIGURE 3.1 TRAJECTORIES STARTING ON APRIL 24 THROUGH MAY 5 (FROM SURFACE TO 4 km) (ONLY THOSE AREAS WEST OF CHERNOBYL ARE SHOWN)



Figures 3.2,A,B,C and D illustrate the movement in the atmosphere of any radioactive material that might have been released from the Chernobyl reactor during the first days after the accident. The approximate location of plumes originating at Chernobyl at various times have been calculated from the meteorological information by the Swedish Meteorological and Hydrological Institute. The four diagrams represent the following assumed emission times at Chernobyl:

(A) Saturday, 26 April, 00.00 hours GMT
(B) Saturday, 26 April, 12.00 hours GMT
(C) Saturday, 26 April: transition stage 12 - 24 GMT
(D) Sunday, 27 April, 00.00 hours GMT

Full lines indicate the level 1500 m, dashed lines 750 m. The transport time is indicated for the level 1500 m. The thin line in Figure 3.2A indicates an uncertainty area due to weak and variable winds.

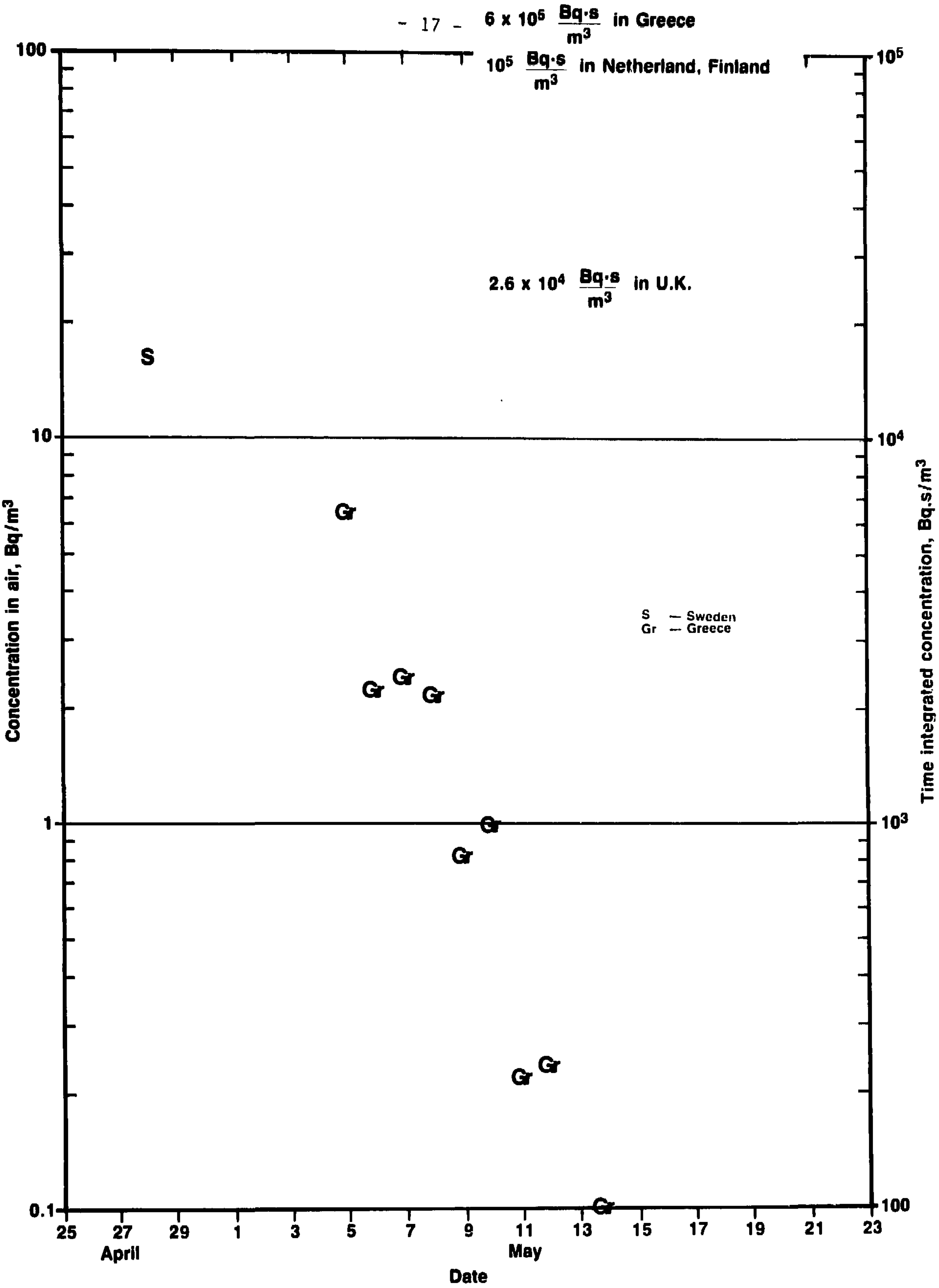


FIGURE 3.3: Ru-103 CONCENTRATION IN AIR AND TIME INTEGRATED CONCENTRATION

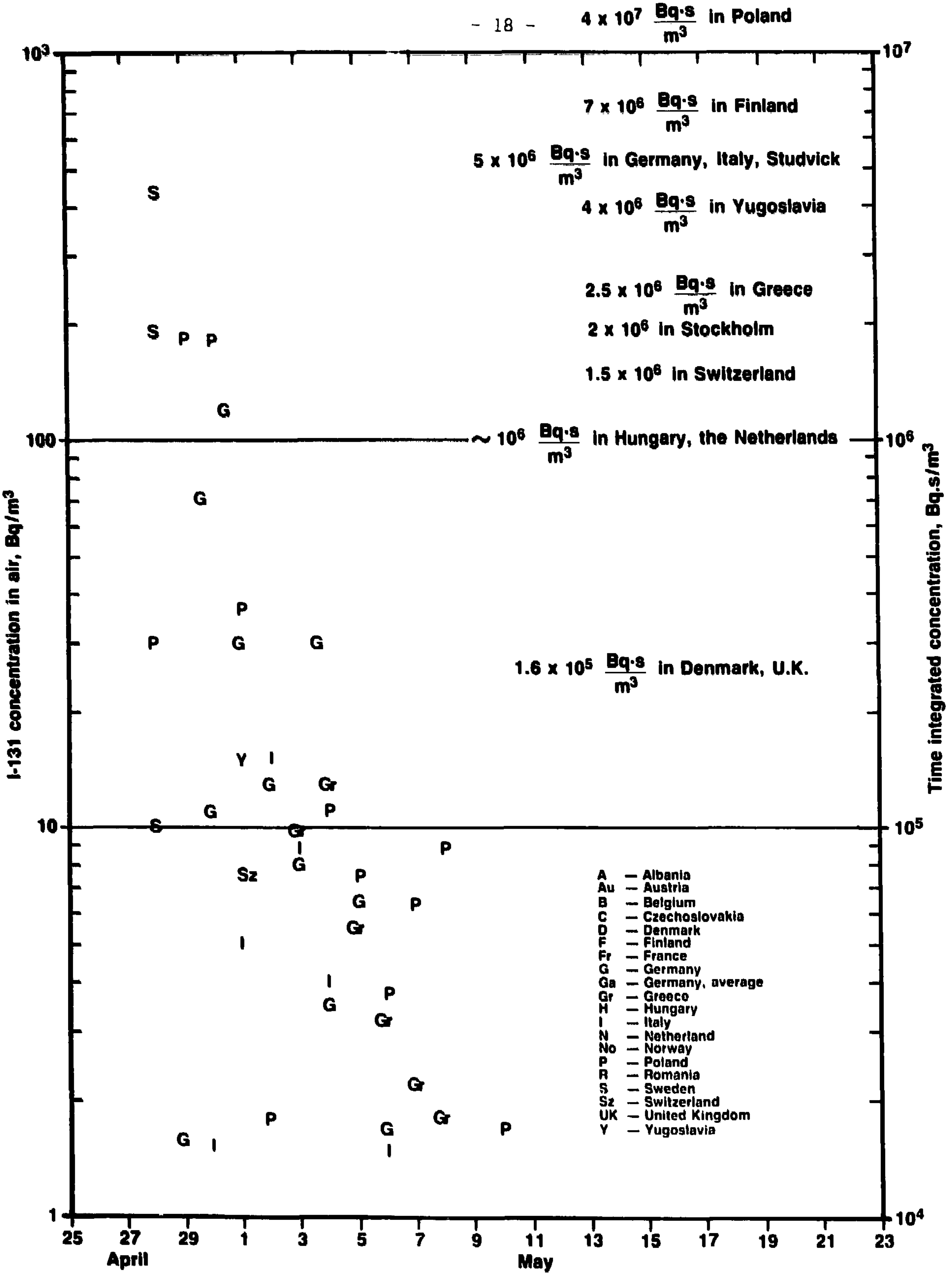


FIGURE 3.4: I-131 CONCENTRATION IN AIR AND TIME INTEGRATED CONCENTRATION

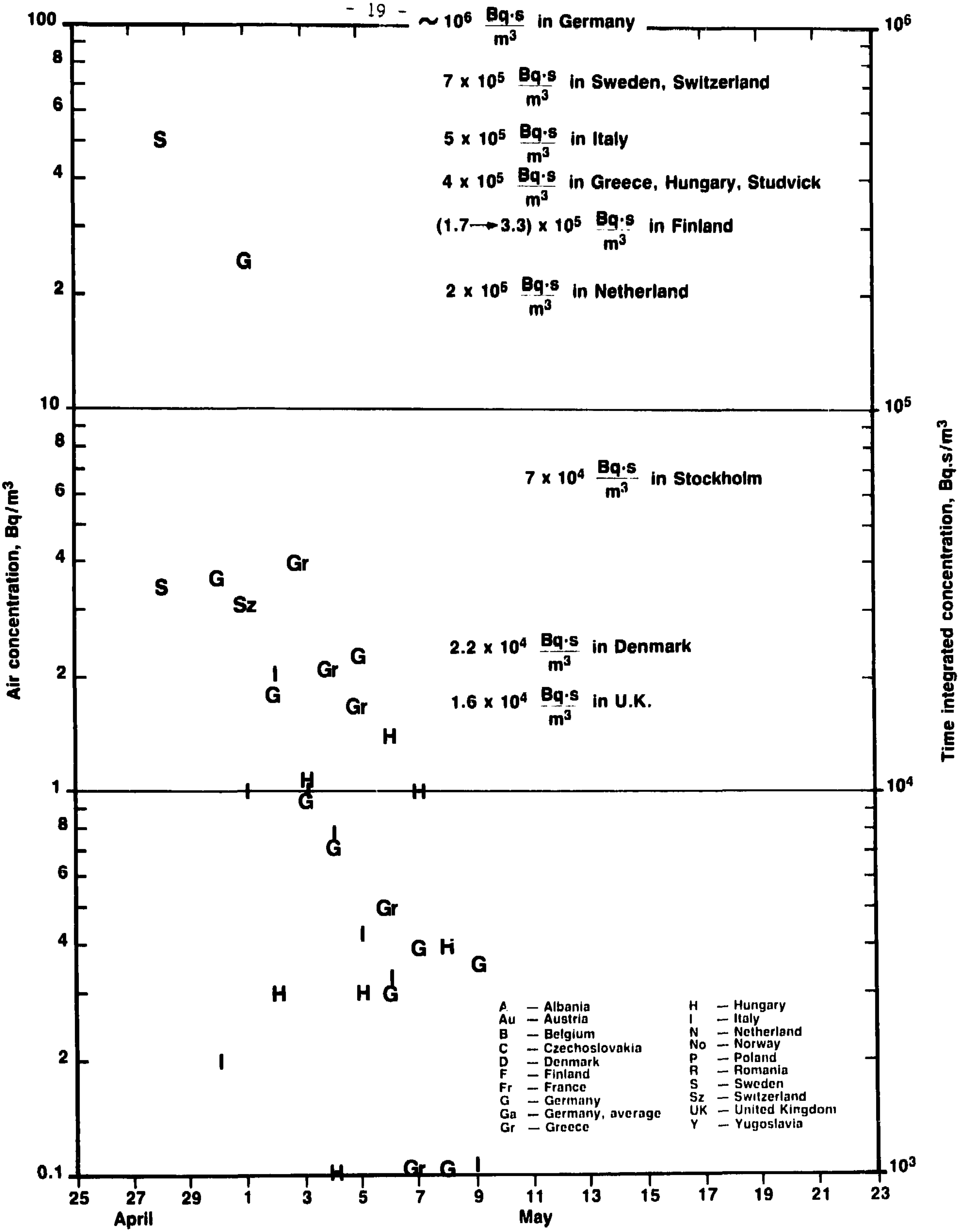


FIGURE 3.5: Cs-137 CONCENTRATION IN AIR AND TIME INTEGRATED CONCENTRATION

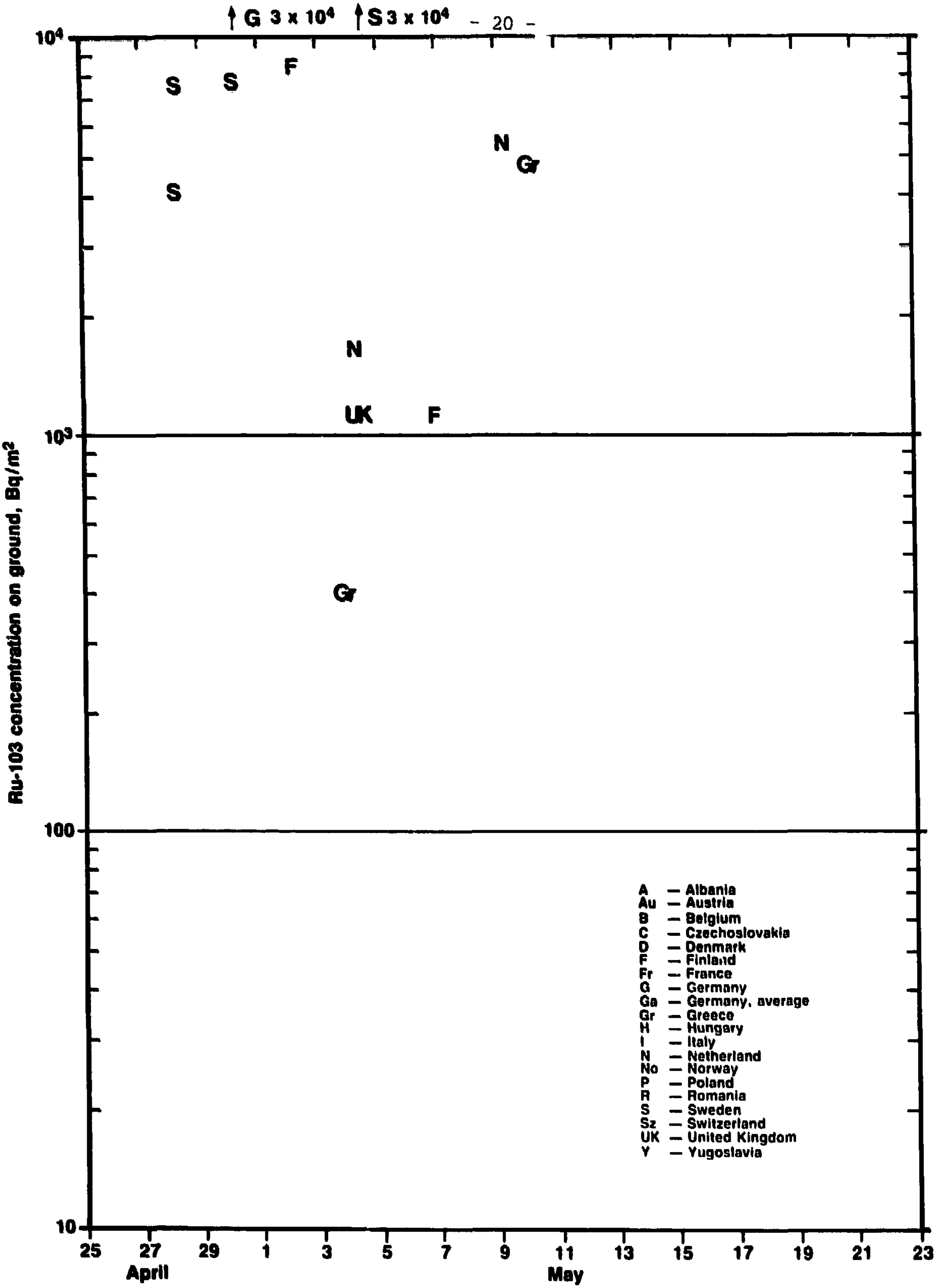


FIGURE 3.6: Ru-103 CONCENTRATION ON THE GROUND

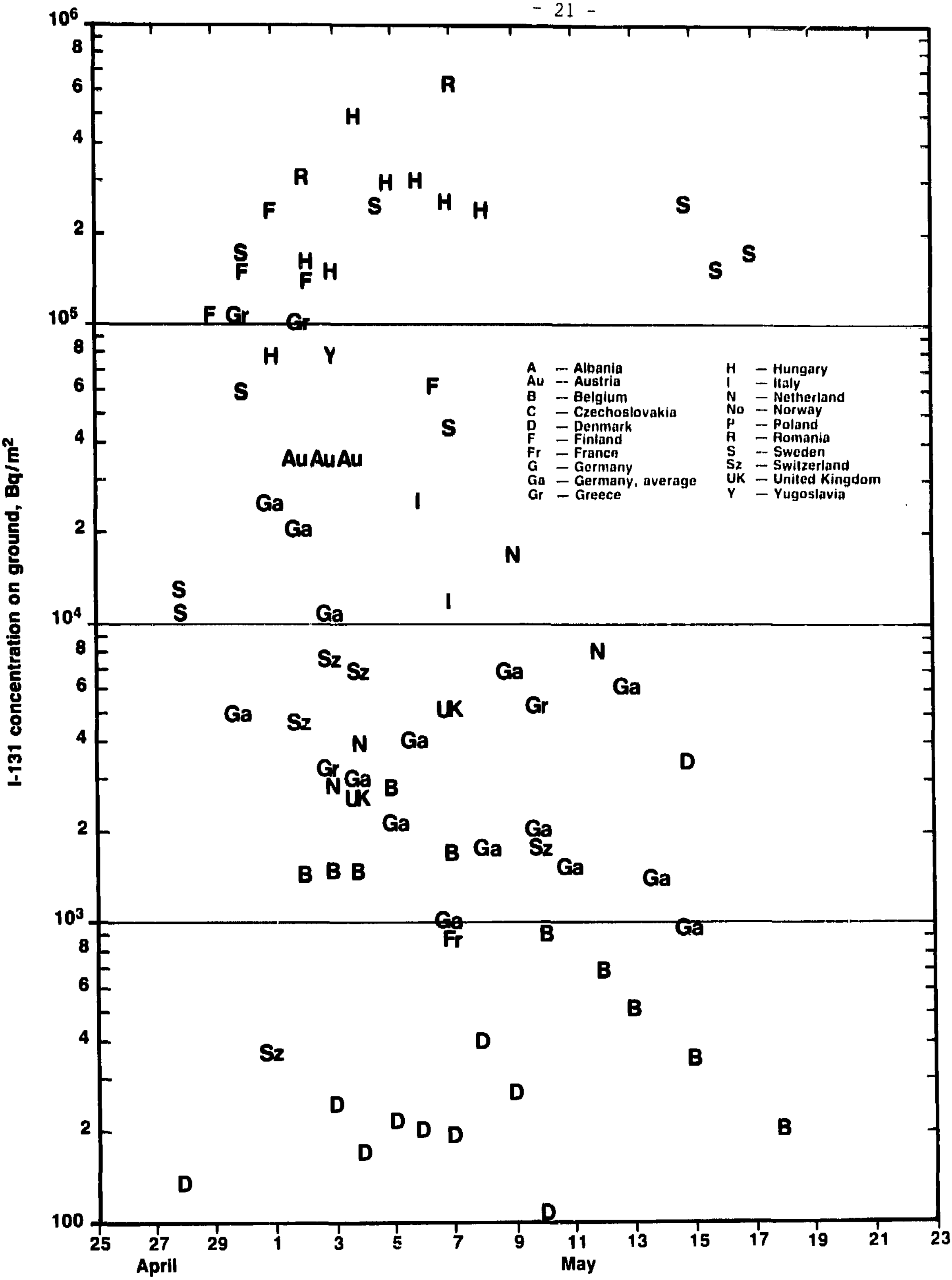


FIGURE 3.7: I-131 CONCENTRATION ON THE GROUND

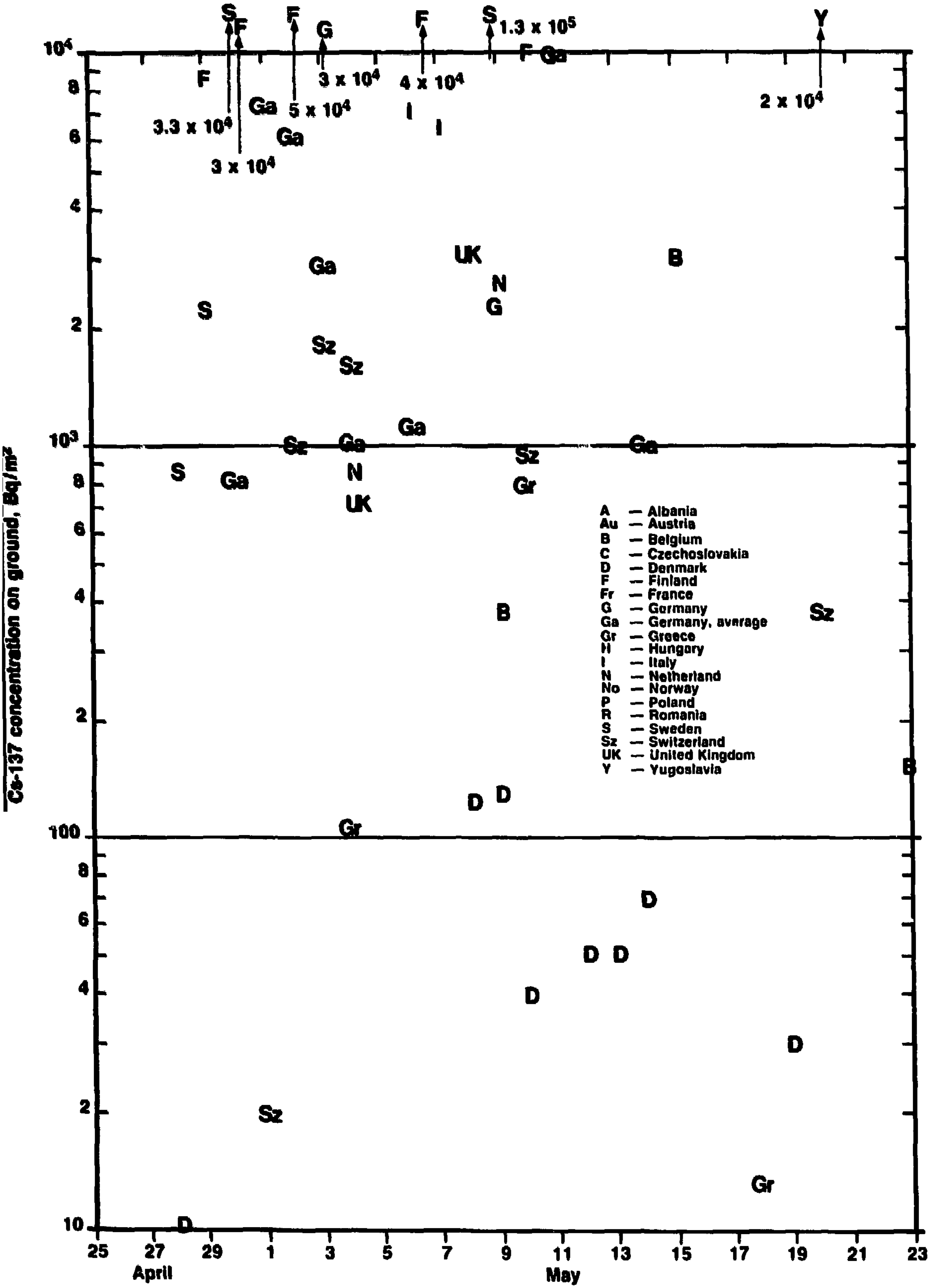


FIGURE 3.8: Cs-137 CONCENTRATION ON THE GROUND

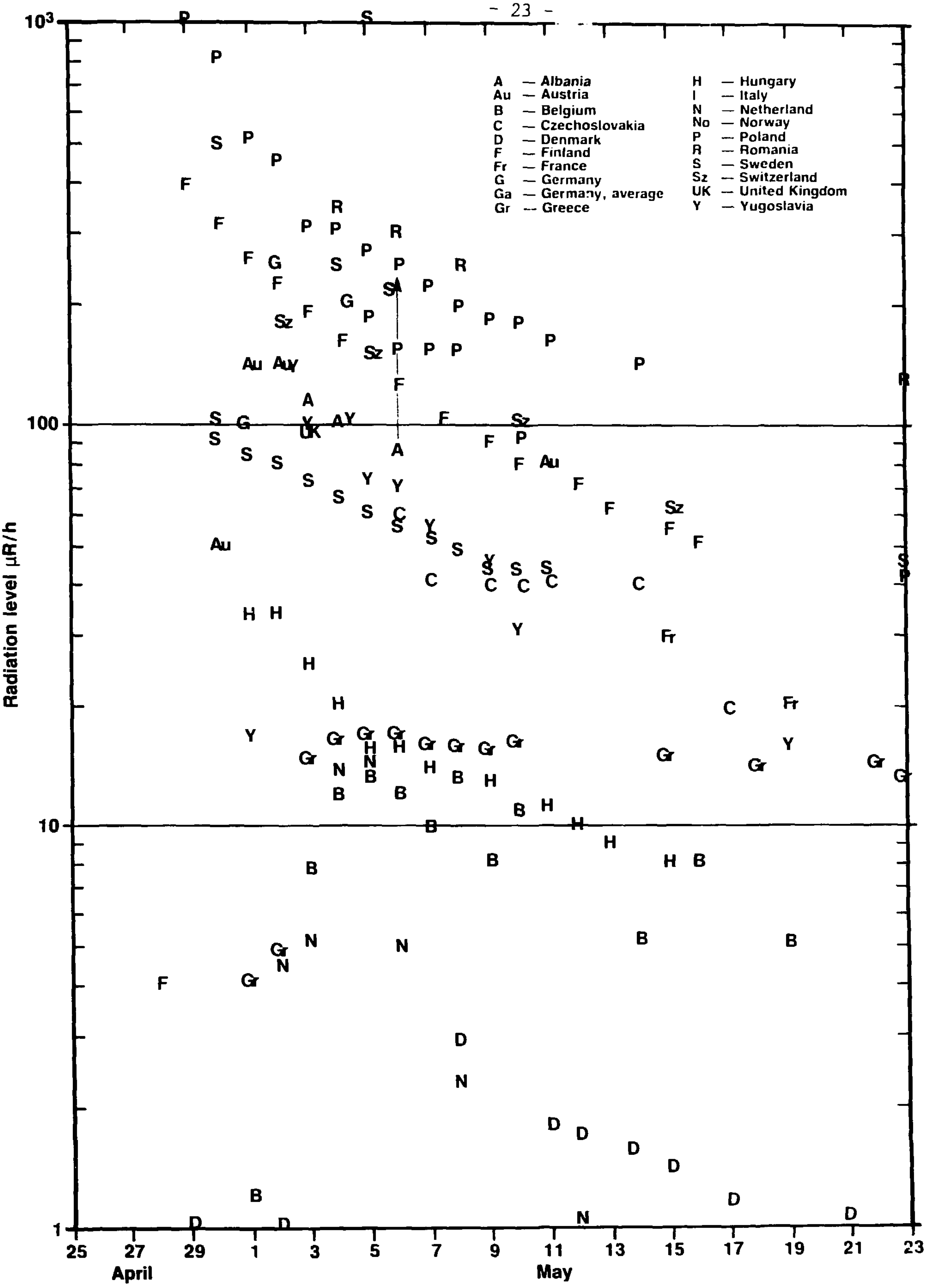


FIGURE 3.9: EXTERNAL RADIATION LEVELS, 1m ABOVE GROUND (ABOVE NATURAL BACKGROUND)

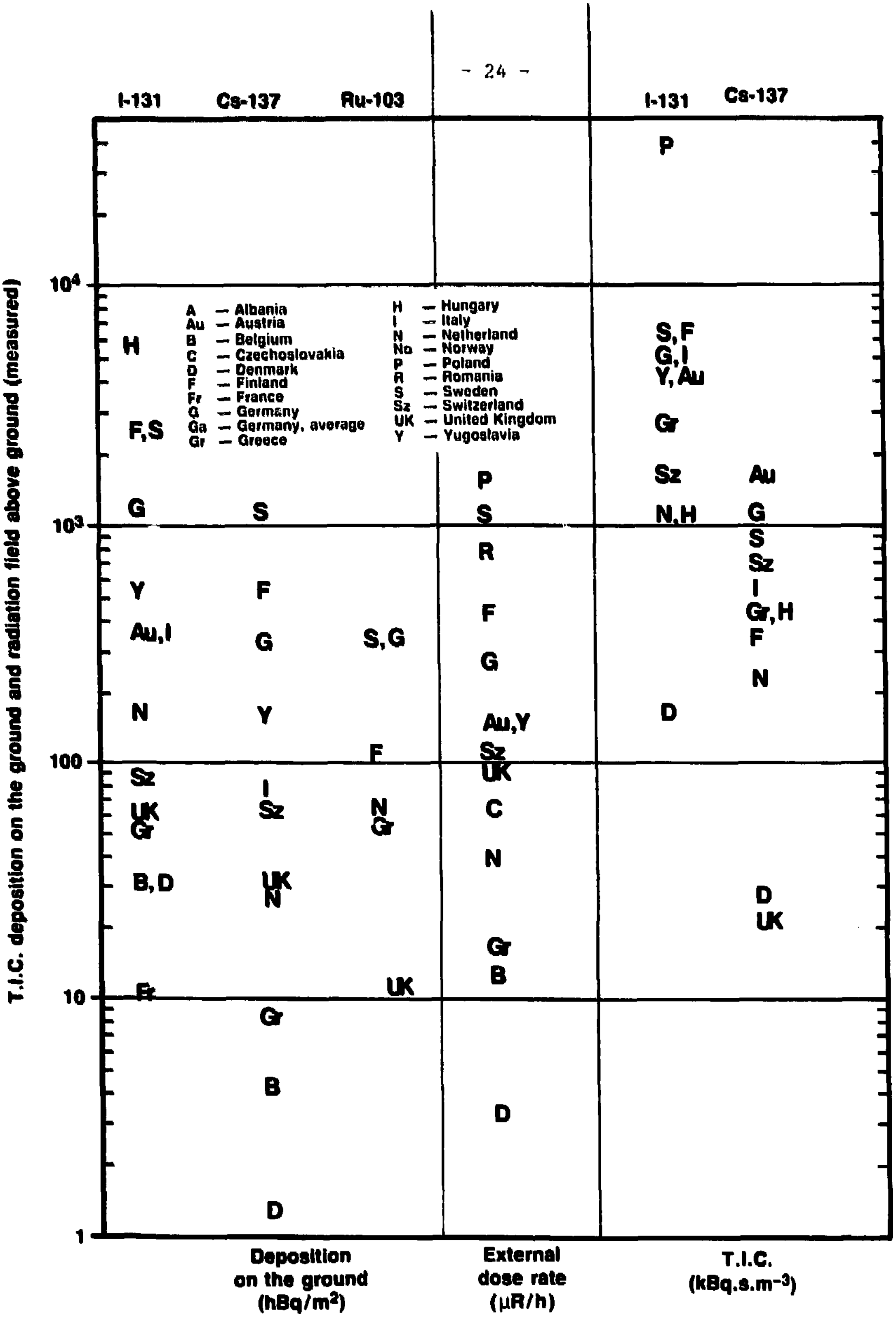


FIGURE 3.10: MAXIMUM RADIATION LEVELS IN EUROPE

3.2. Findings

(i) Values of I-133 to I-131 ratios observed from air and fallout samples in Finland, Sweden, Poland and the Netherlands indicate that the reactor was effectively at low power for about 12 hours prior to the accident.

Figure 3.11 shows the ratios of I-133 to I-131 activities corrected from the measurement time back to the time of the accident (April 26, 1:30 a.m.) taking into account the decay of the two radioiodines. The average ratio has a value of 1.4. The ratio of I-133 to I-131 activities in CANDU fuel (and also in Chernobyl fuel) at equilibrium is 2.0. This clearly indicates that the I-131 and I-133 activities were not at their maximum values in the Russian reactor at the time of the accident and that the reactor was effectively at low power for 12 hours.

(ii) Values of Cs-137 to I-131 ratios observed from air and fallout samples from all locations, indicate that radioisotopes of iodine and caesium behaved in a similar way in terms of their releases from the core, transport in the atmosphere and fallout behaviour.

Figure 3.12 gives the ratios of Cs-137 to I-131 activities found in air and ground samples, corrected for I-131 decay from time of sampling back to the time of the accident. The average ratios in air, vegetables and surface samples, as calculated from the data in the figure, are 0.10, 0.19 and 0.10 respectively. The ratio of Cs-137 to I-131 activities in the RBMK reactor is 0.12, which, when compared to the calculated average ratios, indicates that the two elements behaved almost the same.

(iii) Non-volatiles such as Ru, Te and Sr were, relative to I-131, preferentially released from the core to the atmosphere in particular in the post May 30 releases. This indicates that the iodines were significantly released in the first few days and also that the temperature of the fuel had significantly increased a few days after the accident to a value which did not affect the iodine release rate but did strongly affect the release rate of the "non-volatiles".

Figure 3.13 gives the ratios of Ru-103 to I-131 activities measured in air and surface samples, corrected for decay of the two radionuclides. The ratios are relatively low in Sweden and Finland (affected by early releases) and high in Greece and the Netherlands which are affected by later releases. The ratio of Ru-103 to I-131 activities in the RBMK reactor is 1.25.

(iv) Air concentrations and fallout on the ground indicate that releases were almost constant in the first 2 days, slightly decreased in the next few days and followed by a relatively high release on May 1st. This release characteristic is confirmed by the simulation of the measured data by the code PEAR. Releases started on April 26 and ended on May 5th. The inventory of the Chernobyl reactor at the time of the accident and the daily releases of the radionuclides treated in this report during the period April 26 until May 5th are calculated and given in Table 3.1. Releases of Sr-89, Sr-90, Ru-103 Ru-106, Te-132, I-133, Cs-134 and Cs-137 over the 10 day period are between 10 to 20 percent of the respective core inventories and the I-131 release is about 40% of the core inventory.

(v) The Time Integrated Concentration (T.I.C.) in air varies slightly in the different countries in Europe while the deposition on the ground and the external radiation fields vary widely (see Figure 3.10). This indicates that local precipitation conditions had a strong effect on the deposition and fallout patterns in Europe. To simulate the measured T.I.C., the deposition on the ground and the radiation fields, two different values of deposition velocities are used: a low value is used to deplete the cloud on the average during the travel time and a high value is used to calculate local deposition on the ground. This method of low and high deposition velocities is described in References 1 and 2.

Table 3.2 gives for each daily release, the main countries affected and the values of the low-high deposition velocities used for I and for Cs in PEAR simulation. These low-high deposition velocities are 0.15 to 0.4 and 1 to 40 cm/s respectively for the radioiodines and 0.2 to 0.4 and 0.3 to 20 cm/s for caesium.

(vi) External dose from ground deposition and committed doses from food ingestion are found to have almost the same value and to be the major contributors to the individual doses. Doses from inhalation are less significant and external doses from the cloud are negligible.

Table 3.3 gives the breakdown of the total hypothetical individual maximum doses in the different countries as evaluated by PEAR. The maximum hypothetical individual doses are in the range of 0.07 to 28 mSv.

Individual doses are calculated assuming that people live for 10 years in an area initially contaminated with the maximum values reported by the European countries and without allowing for any shielding, filtration or any protective action. The individual doses, as given in this report, should be looked upon therefore, as an upper value of the individual doses in the referenced countries and not necessarily as a dose received by any one person. The average doses are lower by a factor between 2 and 50.

Table 3.1: Core Inventory and Daily Releases

Radionuclide	Inventory(1) (TBq)	RELEASES (TBq)											Percentage of total Inventory Released(2) (%)
		APRIL					MAY						
		26	27	28	29	30	1	2	3	4	5	Total	
Sr-89	$2x10^6$ (2E6)	$3x10^4$	$3x10^4$	10^4	10^4	10^4	$5x10^4$	$5x10^4$	$5x10^4$	$5x10^4$	$5x10^4$	$3x10^5$	15 (4)
Sr-90	$2x10^5$ (2E5)	$3x10^3$	$3x10^3$	10^3	10^3	10^3	$5x10^3$	$5x10^3$	$5x10^3$	$5x10^3$	$5x10^3$	$3x10^4$	15 (4)
Ru-103	$4x10^6$ (4E6)	$9x10^3$	$9x10^3$	$6x10^3$	$6x10^3$	$6x10^3$	$7x10^4$	$7x10^4$	$7x10^4$	$7x10^4$	$7x10^4$	$4x10^5$	10 (3)
Ru-106	$2x10^6$ (2E6)	$5x10^3$	$5x10^3$	$3x10^3$	$3x10^3$	$3x10^3$	$3.5x10^4$	$3.5x10^4$	$3.5x10^4$	$3.5x10^4$	$3.5x10^4$	$2x10^5$	10 (3)
I-131	$3x10^6$ (3E6)	$3x10^5$	$3x10^5$	$9x10^4$	$9x10^4$	$7x10^4$	$7x10^4$	$7x10^4$	7.10^4	$7x10^4$	$7x10^4$	$1.2x10^6$	40 (20)
I-133	$4x10^6$ –	$4x10^5$	$2x10^5$	$2x10^4$	10^4	$5x10^3$	$2x10^3$	10^3	$5x10^2$	$3x10^2$	10^2	$6x10^5$	15 –
Te-132	10^6(2.5E6)	$4x10^4$	$3x10^4$	$9x10^3$	$7x10^3$	$6x10^3$	$2x10^4$	10^4	10^4	10^4	10^4	$1.5x10^5$	15 (15)
Cs-134	$2x10^5$ (2E6)	$4x10^3$	$4x10^3$	10^3	10^3	10^3	$6x10^3$	$6x10^3$	$6x10^3$	$6x10^3$	$6x10^3$	$4x10^4$	20 (10)
Cs-137	$4x10^5$ (3E5)	$8x10^3$	$8x10^3$	$2x10^3$	$2x10^3$	$2x10^3$	$1.2x10^4$	$1.2x10^4$	$1.2x10^4$	$1.2x10^4$	$1.2x10^4$	$8x10^4$	20 (13)
Total Releases All N.G.		8E5 (9E5)	6E5 (3E5)	1.3E5 (2E5)	1.2E5 (1.7E5)	1.0E5 (1.3E5)	2.6E5 (1.2E5)	2.5E5 (2.3E5)	2.5E5 (2.6E5)	2.5E5 (3.2E5)	2.5E5 (3.2E5)		

(1) At the time of the accident, on April 26, 1:30 a.m.

(2) Total releases divided by the inventory.

( ) Soviet data or derived therefrom.

Table 3.2: Deposition Velocities used in the Simulation, Calculated Dilution and Depletion Factors in the European Countries

Date of Release	Country affected and its trajectory distance from Chernobyl		Deposition velocity (cm/s)				Dilution factor (s.m^{-3})	Depletion factors	
			low		high				
		(km)	I	Cs	I	Cs		I	Cs
April 26	Finland	1200	0.4	0.3	4	10	1.5×10^{-10}	0.07	0.15
	Sweden	1200	0.4	0.25	4	10	1.5×10^{-10}	0.07	0.20
April 27	Finland	1200	0.4	0.3	4	10	1.5×10^{-10}	0.07	0.15
	Sweden	1200	0.4	0.25	4	10	1.5×10^{-10}	0.07	0.20
	Netherlands	1600	0.43	0.22	2	1.5	10^{-10}	0.03	0.15
	Poland	600	0.4	0.4	2	2	4×10^{-10}	0.2	0.20
April 28	Austria	1600	0.4	0.23	2.5	10	10^{-10}	0.07	0.22
	Belgium	2200	0.34	0.23	1.3	1.4	6×10^{-11}	0.035	0.10
	Czechoslavakia	1200	0.5	0.25	20	10	1.5×10^{-10}	0.038	0.20
	Denmark	2600	0.34	0.23	1.8	0.7	5×10^{-11}	0.023	0.08
	Germany	1400	0.34	0.25	4	4	1.2×10^{-10}	0.08	0.16
	Netherlands	1600	0.43	0.22	2	1.5	10^{-10}	0.03	0.15
	Poland	600	0.4	0.4	2	2	4×10^{-10}	0.2	0.2
	Switzerland	1600	0.34	0.23	1	10	10^{-10}	0.07	0.16
	United Kingdom	2200	0.4	0.3	40	20	6×10^{-11}	0.02	0.05
	Yugoslavia	1600	0.4	0.23	2.5	10	10^{-10}	0.07	0.22
April 29	Austria	1600	0.4	0.23	2.5	10	10^{-10}	0.07	0.22
	Belgium	2200	0.34	0.23	1.3	1.4	6×10^{-11}	0.035	0.10
	Denmark	2600	0.34	0.23	1.8	0.7	5×10^{-11}	0.023	0.08
	Germany	1400	0.34	0.25	4	4	1.2×10^{-10}	0.08	0.16
	Hungary	700	0.5	0.25	20	10	3×10^{-10}	0.10	0.32
	Romania	700	0.5	0.25	20	10	3×10^{-10}	0.10	0.32
	Switzerland	1600	0.34	0.23	1	10	10^{-10}	0.07	0.16
	United Kingdom	2200	0.4	0.3	40	20	6×10^{-11}	0.02	0.05
	Yugoslavia	1600	0.4	0.23	2.5	10	10^{-10}	0.07	0.22
April 30	Albania	1800	0.15	0.2	0.3	0.3	8×10^{-11}	0.27	0.18
	Greece	1800	0.15	0.2	0.3	0.3	8×10^{-11}	0.27	0.18
May 1st	Italy	1800	0.20	0.07	0.7	2	8×10^{-11}	0.2	0.57
Beyond May 1									
May 3-4	Poland	600	0.4	0.4	2	2	4×10^{-10}	0.2	0.2
May 4	Germany	1400	0.35	0.25	4	4	1.2×10^{-10}	0.08	0.16
May 5	Finland	1200	0.4	0.3	4	10	1.5×10^{-10}	0.07	0.20
	Sweden	1200	0.4	0.25	4	10	1.5×10^{-10}	0.07	0.20

Table 3.3: Maximum Radiation Doses to Individuals in Europe (effective/committed dose in mSv)

Exposure Pathway / Country	External dose from Ground Deposition	Internal Dose		Total Dose
		Inhalation	Ingestion	
Sweden	15	0.06	13	28
Finland	11	0.06	9	20
Poland	10	0.5	7.5	18
Hungary or Romania	6	0.025	5	11
Yugoslavia or Austria	3.3	0.016	2.9	6.2
Germany	3	0.037	2.9	5.9
Italy	1.8	0.044	1.8	3.6
Switzerland	1.6	0.008	1.4	3
Czechoslavakia	1.5	0.004	1.3	2.8
United Kingdom	0.7	0.002	0.6	1.3
Netherlands	0.4	0.001	0.4	0.8
Greece or Albania	0.14	0.02	0.16	0.32
Belgium	0.09	0.0025	0.08	0.17
Denmark	0.03	0.001	0.04	0.07

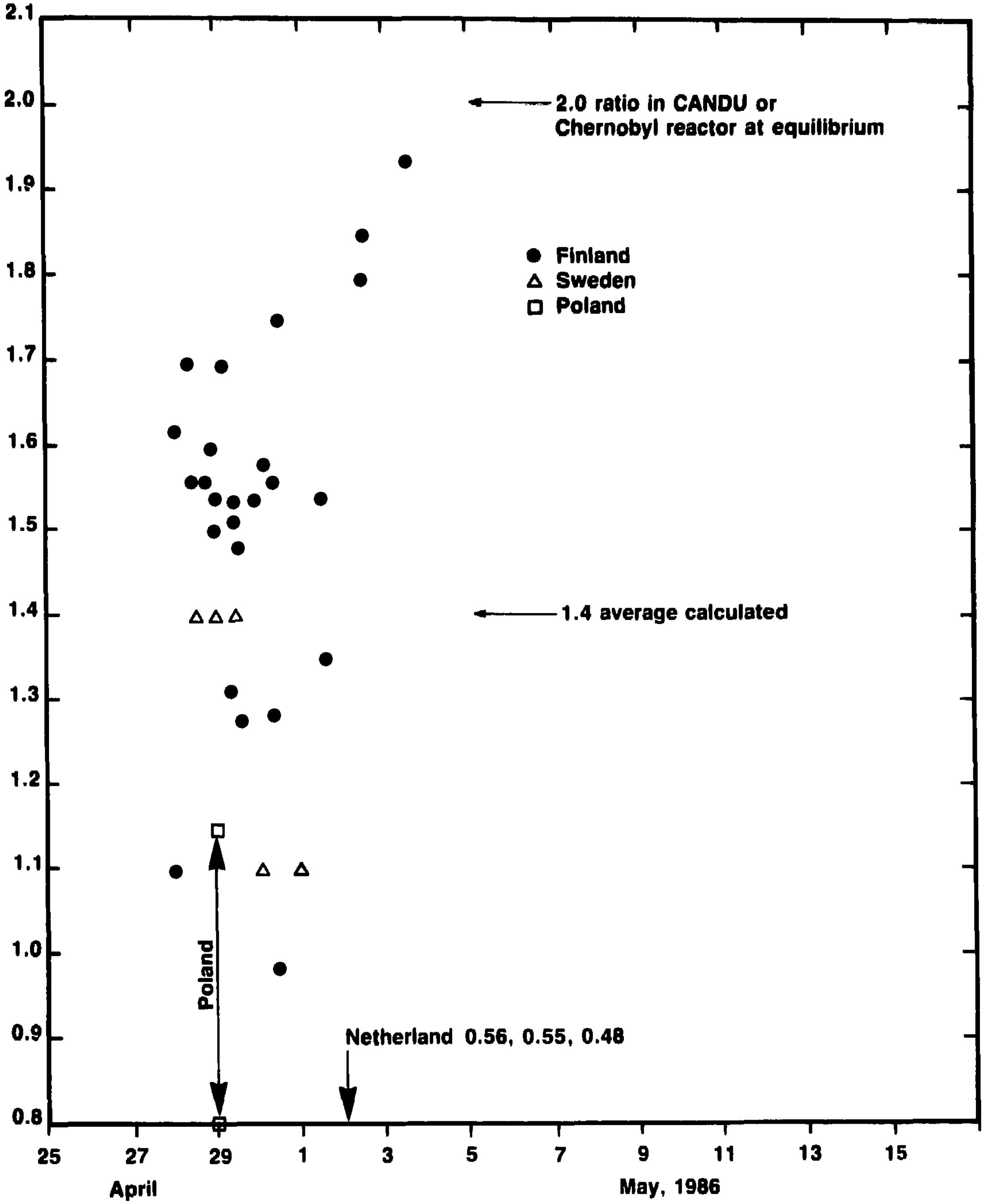


FIGURE 3.11: RATIOS OF I-133 TO I-131 ACTIVITES IN AIR SAMPLES (CORRECTED FOR DECAY BACK TO APRIL 26, 1:30 a.m.)

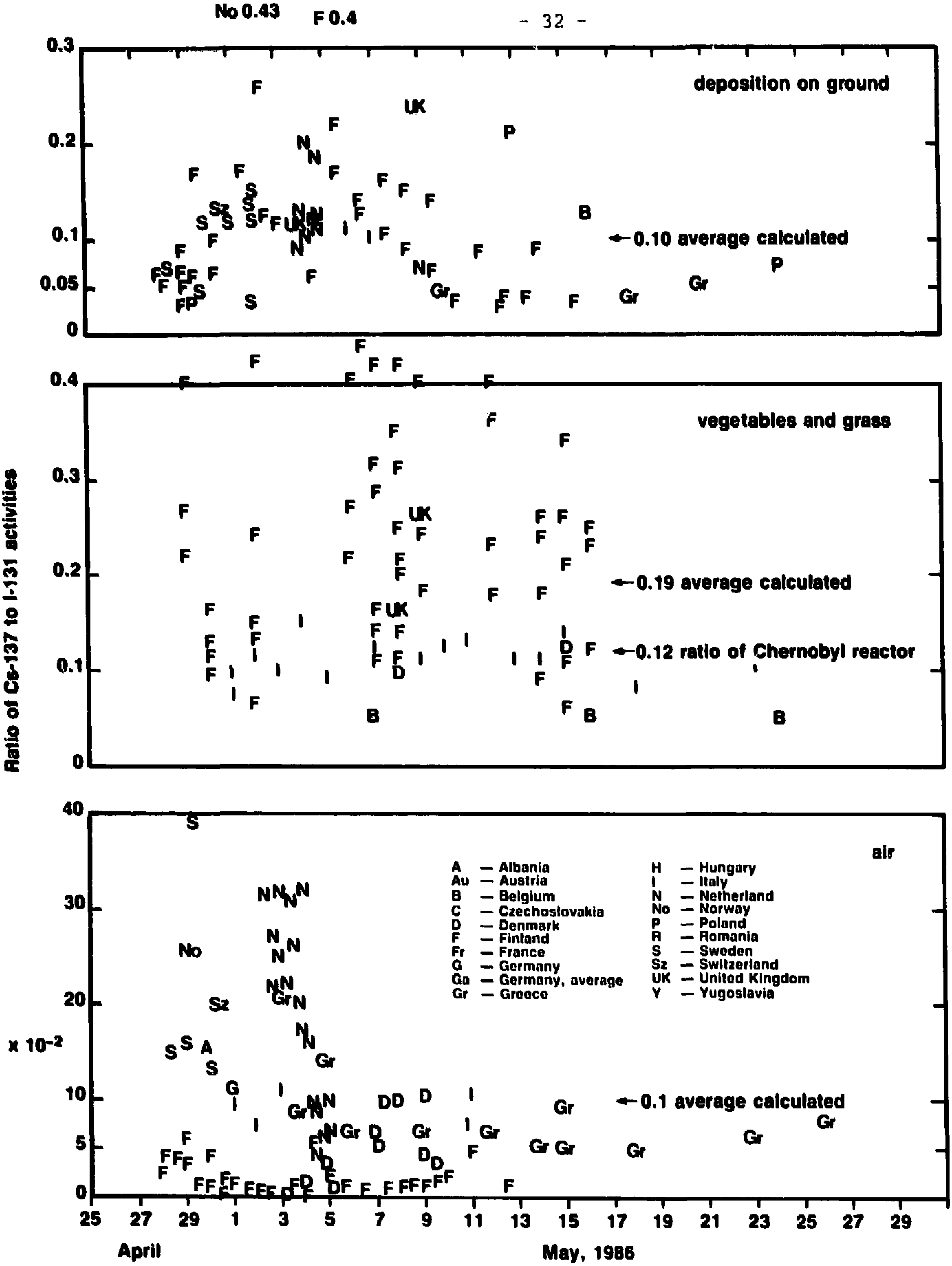


FIGURE 3.12: RATIOS OF Cs-137 TO I-131 ACTIVITES IN AIR SAMPLES, VEGETABLES AND GRASS AND DEPOSITION ON THE GROUND (CORRECTED FOR I-131 DECAY BACK TO APRIL 26, 1:30 a.m.

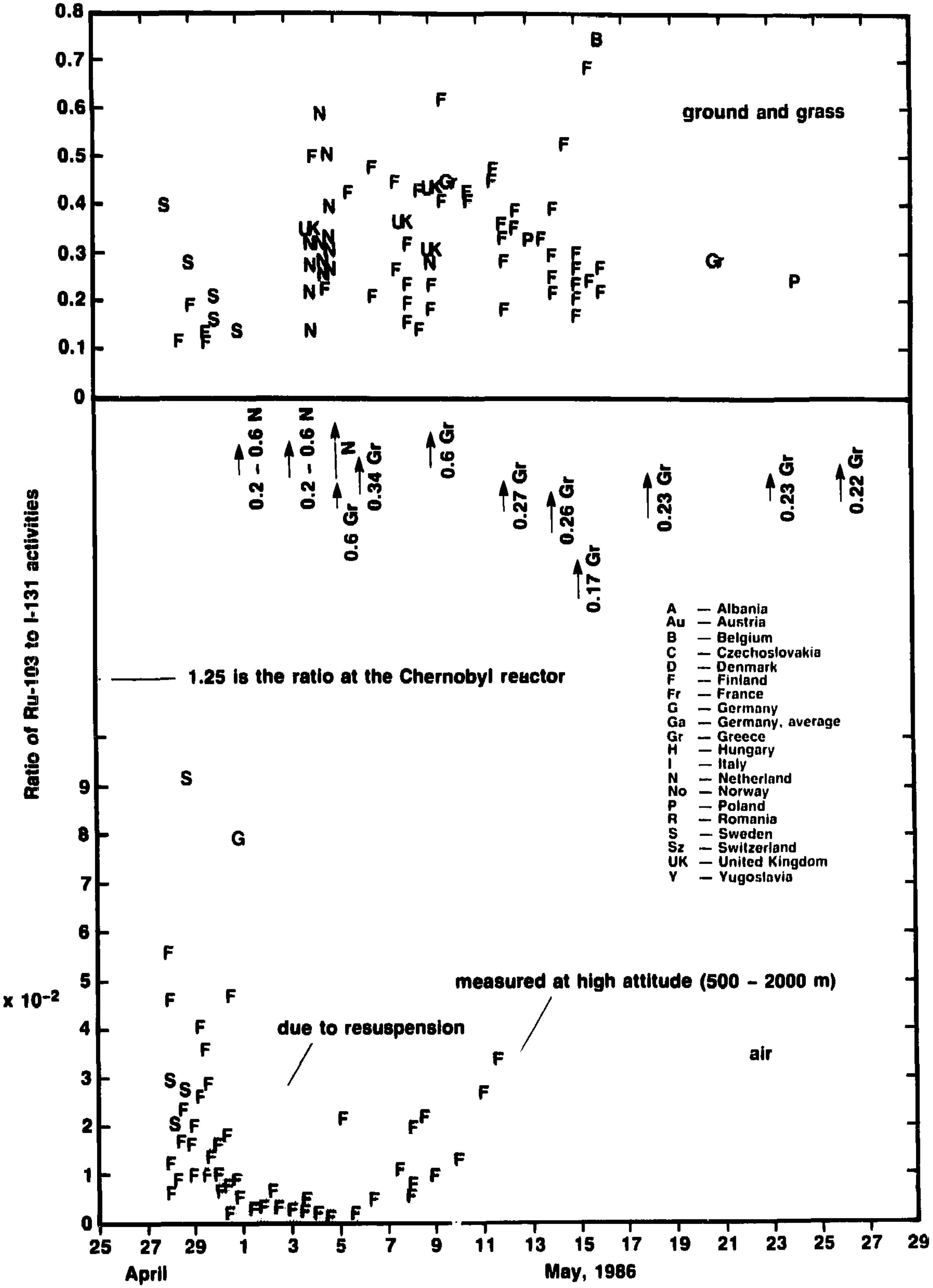


FIGURE 3.13: RATIOS OF Ru-103 TO I-131 ACTIVITIES IN AIR AND GROUND (ALSO GRASS) SAMPLES. (CORRECTED FOR DECAY BACK TO APRIL 26 1:30 a.m.)

3.3 RESULTS AND DISCUSSION

3.3.1 Results

Our simulation gives the following results:

(i) Source Term

Releases, of the 9 radionuclides treated in this report, during the period April 26 to May 05 are given in Table 3.1. Their inventories in the Chernobyl reactor at the time of the accident are also shown. I-131 releases are about 40% of the core inventory and for the other 8 radionuclides, the releases are between 10 and 20% of the respective core inventory. The uncertainty associated with the source term is unlikely to exceed a factor of 3.

(ii) Time Integrated Concentration (T.I.C.), concentration on the ground and external radiation fields

T.I.C. in air and concentration on the ground of the 9 radionuclides and radiation fields at one metre above ground are calculated. Figure 3.14 gives the T.I.C. of I-131 and of Cs-137, concentration on the ground of I-131, Cs-137 and Ru-103 and also the radiation fields as calculated for the different countries. A comparison between the calculated and the measured/reported data is shown in Figure 3.15.

(iii) Individual Doses

Table 3.3 gives the calculated effective/committed doses to hypothetical individuals in the different countries for 3 exposure pathways. The "External dose from the cloud" contribution to the dose is found to be extremely small and therefore it is not shown in Table 3.3.. The total hypothetical individual effective dose in the different countries is shown in Figure 3.16.

3.3.2 Discussion

The countries that are treated in this part of the report are far away from the source, between 600 and 2200 km from Chernobyl (see Table 3.2). At these distances, the dilution of the releases in the atmosphere is high and the values of the dilution factors in the different countries in Europe do not vary by much. The values of the dilution factors are in the range 6×10^{-11} to 4×10^{-10} $s.m^{-3}$ (see Table 3.2). Time Integrated Concentrations are proportional to the dilution factors and also to the magnitude of the release and to the depletion of the cloud due to decay and deposition of the radioactive material on the ground. As a result, T.I.C. of I-131 and Cs-137 as shown in Figure 3.14, vary within a wider range than the dilution factors. Figure 3.14 also shows that deposition on the ground within the European countries varies even more than the T.I.C. values. The heavy rains that fell across western Europe after the accident caused significant high ground-level readings in some areas. To simulate the measured T.I.C., the deposition on the ground and radiation fields, different depletion and deposition mechanisms and parameters were required in the analyses of this report. A "wise" choice of the values of the V_{dL} and V_{dH} was very important.

The maximum individual doses, as evaluated in this report, are proportional to the deposition on the ground and almost insensitive to the T.I.C. in air. Average individual doses in the referenced countries on the other hand, depend on the values of the T.I.C. and are much lower than the calculated doses by a factor of the order of magnitude of V_{dH}/V_{dL}.

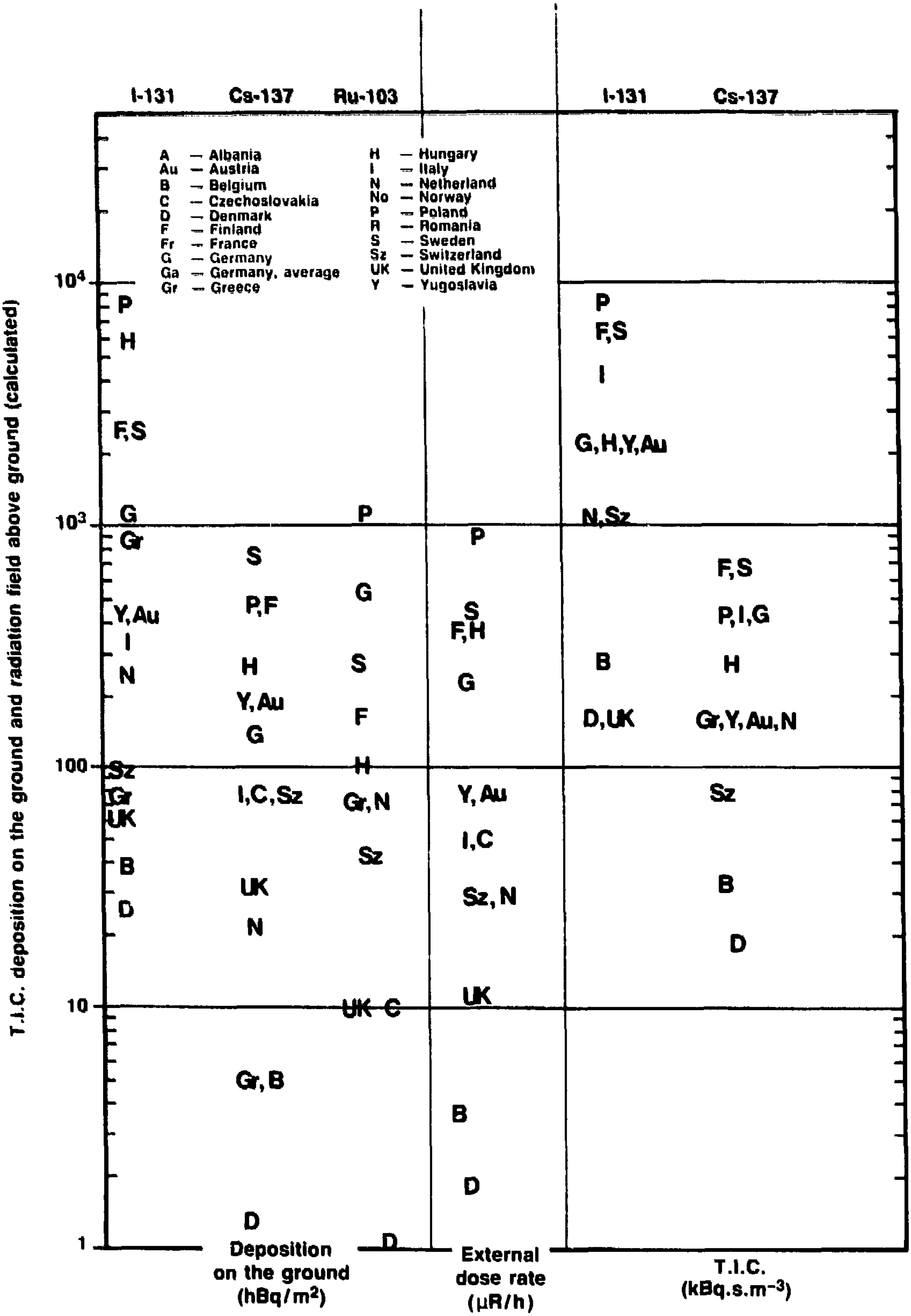


FIGURE 3.14: CALCULATED TIME INTEGRATED CONCENTRATION OF I-131 AND OF Cs-137 CONCENTRATION OF I-131, Cs-137 AND Ru-103 ON THE GROUND AND RADIATION FIELD 1m ABOVE GROUND

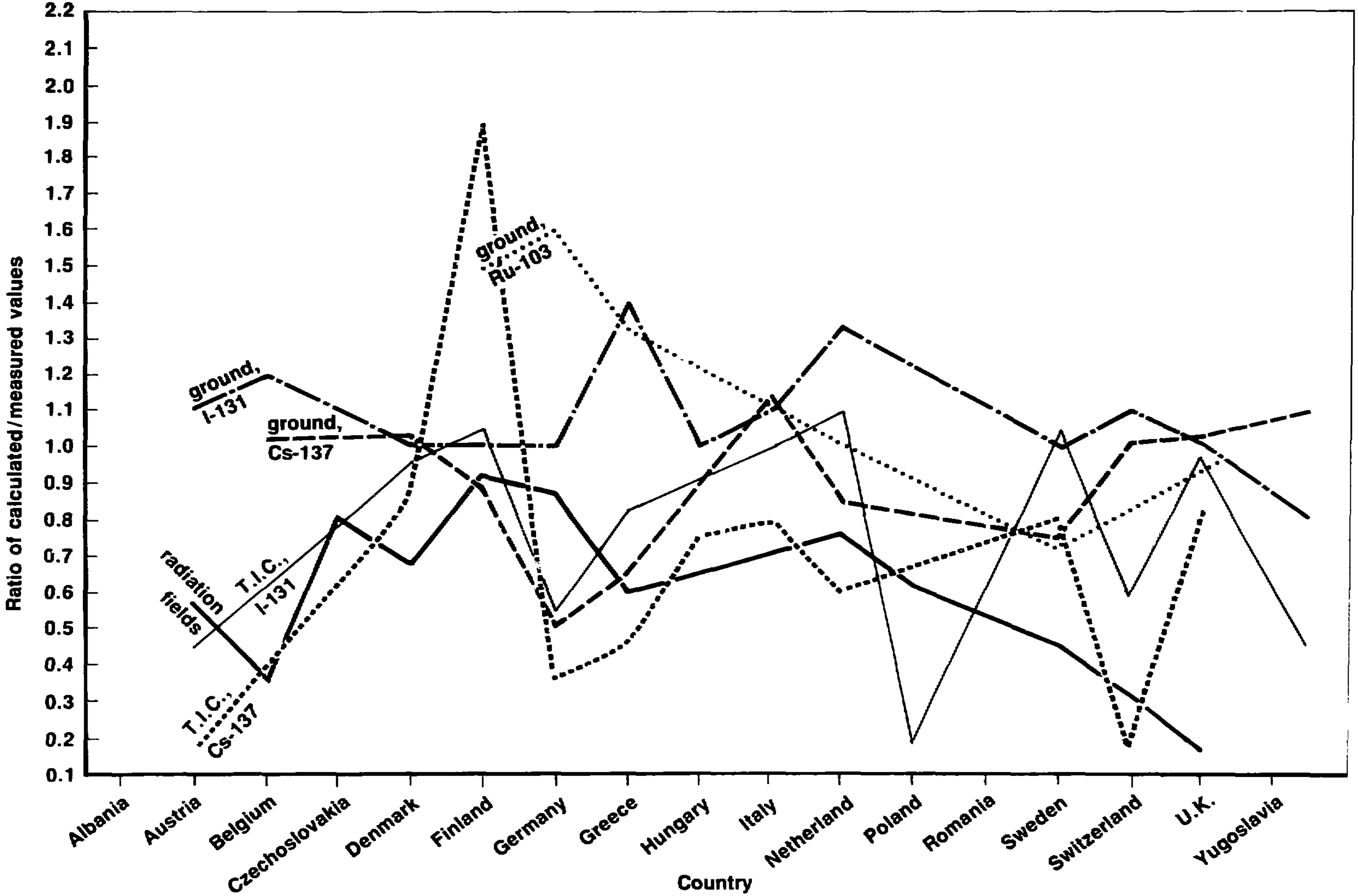


FIGURE 3.15: T.I.C.,CONCENTRATION ON THE GROUND AND RADIATION FIELDS —
COMPARISON WITH MEASUREMENTS

FIGURE 3.16: MAXIMUM CALCULATED WHOLE BODY DOSES (mSv)

4. SECOND PART - THE SOVIET UNION

4.1 Data and Measurements

4.1.1 Weather and Terrain Data

4.1.1.1 Wind Data and Trajectories

Prevailing weather conditions are described in 3.1.1.1. Meteorological conditions at 700 m elevation are used to describe the transport of the releases during April 26 - May 5 over the Soviet Union. The source of release, between 0 and 200 m appears to be the major component that affected the nearby area and the source of release, between 0 and 2 km was the major component that affected more distant areas.

Figure 4.1 shows some of the results obtained from a trajectory analysis. An average value of 7 m/s for wind speed is used for all the releases and trajectories calculated in the Soviet Union.

4.1.1.2 Atmospheric Stability

Prevailing stability conditions at site and far away are partially described in 3.1.1.2.

It is assumed that all the releases were subject to a neutral atmospheric stability (Pasquill D) on the average, with a capping inversion at 400 metres at distances less than 30 km and 1000 m at farther distances.

4.1.1.3 Precipitation Conditions

There was no rainfall at site and in the vicinity of the Chernobyl site over the course of the accident. Also, there was no noticeable precipitation in the U.S.S.R. during the 10 day releases.

In the analysis, all the releases are assumed to be subject to dry deposition alone. The "average" deposition velocities approach is used, see References 1 and 2.

4.1.1.4 Terrain Data

The terrain around the Chernobyl reactor is assumed to be grass or water covered.

4.1.2 Release Characteristics

4.1.2.1 Effective Height of Release

This parameter, which was not significant in the evaluation of the consequences in Europe outside the Soviet Union, becomes extremely important in handling locations in the U.S.S.R., especially those which are in the close vicinity of the plant. Therefore, effective height of release is an important parameter to model.

Due to the burning graphite, the radioactive material was released to the atmosphere with a relative high heat of content of the order of a few hundred MW (∿500). The decay heat right after the accident was about 20 MW only.

Under neutral stable conditions, the warm exhaust air rises to a considerable height, calculated between 500 meters (Pasquill C or D) and 2000 meters (for Pasquill E and F). Obviously, a small portion of the release did not reach that height and diffused in the 0-200 m first layer of the atmosphere. Also the plume reached its final rise only at distances of a few kilometers from the plant. As a result, the nearby locations (at distances less than 20 km) were mainly affected by radioactive material that was transported in the 0-200 meters layer.

An effective height of 700 metres is used in the analysis for the main stream on April 26, 27 and 28 and 400 meters for the following days.

For the closer locations (in the 30 km zone) it is assumed that 3 to 10% of the total releases were transported at an average height of 100 metres.

4.1.2.2 Release Rates

Daily releases during the course of the accident are given in Table 3.1.

4.1.3 Radiation Measurements

Radiological measurements provided by the Soviets are given in Reference 22. The data is in the form of activity in the air, on the ground, water, milk and external radiation levels. The Soviets also gave some estimates for individual doses in the Soviet Union.

The Soviets address in total 31 locations. These, together with the type of data provided by the Soviets are given in Table 4.1. Figure 4.2 is a map which shows the Chernobyl site and a few of these 31 locations. Most of these locations are in a few precise directions such as SE, N and NE direction.

In the 30 km zone, there are about 70 populated areas of which the Soviets gave some data for only six. Three of these (Lelev, Rudki and Orevichi) couldn't be found in the available maps and therefore were not included in the study.

Figure 4.4 shows the gamma - field distribution in the 30 km zone around the Chernobyl site.

In the report, 10 locations, out of the 31 addressed by the Soviets, are found to have adequate data to be included in the study. The 10 locations are identified in Figure 4.3. Radiological data for the 10 locations, as reported by the Soviets, are shown in Table 4.2. Data on ground concentration of I-131, Ru-103, Cs-137, total β-γ and time integrated concentration for I-131, Ru-103 and Cs-137, and the dose rate from ground deposition are shown in the table.

4.2 Findings and Results

4.2.1 Values of Te-132 to I-131 ratios observed from air and fallout samples within the 30 km zone indicate that Te, relative to I, was equally or even preferentially released from the core to the atmosphere.

Figure 4.5 shows the ratios of Te-132 to I-131 activities corrected from the measurement time back to the time of the accident (April 26, 1:30 a.m.) taking into account their decay. Most of the ratios are higher by a factor 1 to 4 from the ratio of Te-132 to I-131 activities in the Chernobyl fuel at equilibrium.

4.2.2 A comparison between the source term evaluated by the Soviets and by PEAR is shown in Table 4.3. PEAR predictions, based on measurements in Europe alone, are comparable or slightly higher than the Soviets estimates.

4.2.3 Using the source term, evaluated in section 3 and shown in Table 3.1, and the approach described in 4.1, concentration on the ground, time integrated concentration and external radiation at one meter above ground are calculated for the 10 locations and shown in Table 4.2. A comparison between the calculated and the measured/reported data is shown in Figure 4.6. The discrepancy between the values is in most cases within a factor of 3 at the most.

4.2.4 Table 4.4 gives the individual doses in the 10 addressed locations as estimated by the Soviets and as evaluated by PEAR. A comparison between the Soviets and PEAR predictions is given in Figure 4.7. The effective committed dose equivalents to individuals in the 10 locations are calculated taking into account all the exposure pathways excluding the food pathway. The doses are in the range 3-300 mSv. The inclusion of the food chain pathway is likely to increase the dose by a factor of two and inclusion of other radionuclides such as noble gases, short and long-lived radionuclides, is likely to increase the individual doses by a factor of 3.

4.3 Conclusions

(i) We have established and reconfirmed the values of high releases we had predicted a few weeks after the Chernobyl accident based on radiological data from Europe. Our calculations are comparable to the Soviet estimates of source terms, published in August 1986, in Vienna, which are based on more local measurements.

(ii) PEAR predictions of the radiological consequences in the environment and of the individual doses in the Soviet Union are comparable to those provided by the Soviets.

(iii) We have demonstrated that the source term and the analytical methods used in the report can handle measurements both very close and far away from the source of the release. This clearly indicates that our method is a reliable way of integrating, and making sense of, diverse measurements.

TABLE 4.1

LOCATION AND DATA PROVIDED BY THE SOVIETS

Location, distance and direction	Air Concentration	Ground Concentration	Individual Doses: Rate from Ground	Individual Doses: Total	Individual Doses: Thyroid	Individual Doses: From Cloud	Individual Doses: From Ground
1 Baryshevska, 160, SE	✓						
2 Bragin, 40, N			✓				
3 Brest, 440, WNW			✓				✓
4 Briansk, 350, NE			✓				✓
5 Cherkassy, 270, SE			✓				✓
6 Chernigov, 90, E			✓				✓
7 Chernobyl, 15, SSE	✓	✓	✓		✓	✓	✓
8 Chistogolovka, 5.5, WSW		✓	✓		✓	✓	✓
9 Donetsk, 690, SE			✓				
10 Gomel, 130, NNE			✓				✓
11 Kaliningrad, 730, NW		✓					✓
12 Kharkov, 480, ESE			✓				✓
13 Kechenev, 500, SSW			✓				✓
14 Kiev, 120, S		✓	✓				
15 Lelev, 9,		✓	✓		✓	✓	✓
16 Leningrad, 940, N			✓				
17 Minsk, 320, NNW	✓		✓				
18 Mogilev, 270, N			✓				✓
19 Narovlja, 60, NW			✓				

TABLE 4.1 (CONTINUED)

LOCATION AND DATA PROVIDED BY THE SOVIETS (Continued)

Location, distance and direction	Air Concentration	Ground Concentration	Individual Doses				
			Rate From Ground	Total	Thyroid	From Cloud	From Ground
20 Orel 450, ENE			✓				✓
21 Orevichi, 29,		✓	✓		✓	✓	✓
22 Oster, 70, SE			✓				
23 Poltava, 380, SE			✓				✓
24 Pripyat, 3, NW	✓	✓	✓	✓		✓	✓
25 Rudki 22,			✓		✓	✓	✓
26 Smolensk, 400, NNE							✓
27 Tula, 600, NE			✓				✓
28 Vinnitsa, 270, SW			✓				
29 Viteksk, 420, N			✓				
30 Voroshetovgrad,720,SE			✓				
31 Zhitomir, 150, SW			✓				✓
Within 30 km zone		✓		✓	✓		✓
Ukraine				✓	✓		

TABLE 4.2

RADIOLOGICAL DATA PROVIDED BY THE SOVIET UNION AND EVALUATED BY PEAR(1)

LOCATION	PRIPYAT		CHISTOGOLOVKA		CHERNOBYL		NAROVLJA		OSTER	
QUANTITY	S.U	PEAR	S.U	PEAR	S.U	PEAR	S.U	PEAR	S.U	PEAR
· GROUND CONC. $Bq.m^{-2}$										
I-131	$>2\times10^{7}$	10^{9}	$>2\times10^{7}$	4×10^{8}	$>2\times10^{7}$	10^{8}	-	8×10^{6}	-	2×10^{6}
Ru-103	$>2\times10^{7}$	2×10^{8}	$>2\times10^{7}$	3×10^{7}	$>2\times10^{7}$	5×10^{7}	-	5×10^{5}	-	2×10^{6}
Cs-137	$>10^{7}$	3×10^{7}	$>10^{7}$	10^{7}	$>10^{7}$	10^{7}	-	2×10^{5}	-	10^{5}
TOTAL β,γ	$>2\times10^{8}$	3×10^{9}	$>2\times10^{8}$	7×10^{8}	$>2\times10^{8}$	3×10^{8}	-	2×10^{7}	-	6×10^{6}
· T.I.C. $Bq.s.m^{-3}$										
I-131	-	2×10^{10}	-	9×10^{9}	-	2×10^{9}	-	10^{9}	-	4×10^{8}
Cs-134	-	3×10^{8}	-	9×10^{7}	-	10^{8}	-	2×10^{7}	-	10^{7}
Cs-137	-	6×10^{8}	-	2×10^{8}	-	2×10^{8}	-	5×10^{7}	-	2×10^{7}
· DOSE RATE FROM GROUND, mR/H	1000	2500/ 450	20	360/27	15	150/ 30	1	18/ 2.6	0.33	5/0.5

TABLE 4.2 (CONTINUED)

RADIOLOGICAL DATA PROVIDED BY THE SOVIET UNION AND EVALUATED BY PEAR(1) (CONTINUED)

Location	Kiev		Baryshevska		Cherkassy		Minsk		Kaliningrad	
Quantity	S.U	PEAR	S.U	PEAR	S.U	PEAR	S.U	PEAR	S.U	PEAR
· Ground Conc. $Bq.m^{-2}$										
I-131	$6x10^5$	10^6	-	10^6	-	$7x10^5$	-	$3x10^5$	$8x10^5$	10^6
Ru-103	-	10^5	-	10^6	-	$6x10^5$	-	$2x10^4$	-	$8x10^4$
Cs-137	$2x10^4$	$2x10^4$	-	$7x10^4$	-	$5x10^4$	-	$5x10^3$	$8x10^3$	$3x10^4$
Total β,γ	-	$2x10^6$	-	$3x10^6$	-	$2x10^6$	-	$7x10^5$	-	$3x10^6$
· T.I.C. $Bq.s.m^{-3}$										
I-131	-	$3x10^8$	$5x10^7$	$2x10^8$	-	$2x10^8$	$5x10^7$	$5x10^7$	-	$3x10^8$
Cs-134	-	$3x10^6$	-	10^7	-	10^7	10^6	10^6	-	$5x10^6$
Cs-137	-	$6x10^6$	10^7	$2x10^7$	-	$2x10^7$	$2x10^6$	$2x10^6$	-	$9x10^6$
· Dose rate from (2) ground, mR/h	0.2	1.5/ 0.2	-	3/0.4	0.1	2/0.2	0.2	0.7/ 0.1	-	2/0.4

(1) Soviet data is for the month of May, 1986. PEAR values are maximum.

(2) PEAR predictions for skin and effective respectively.

TABLE 4.3

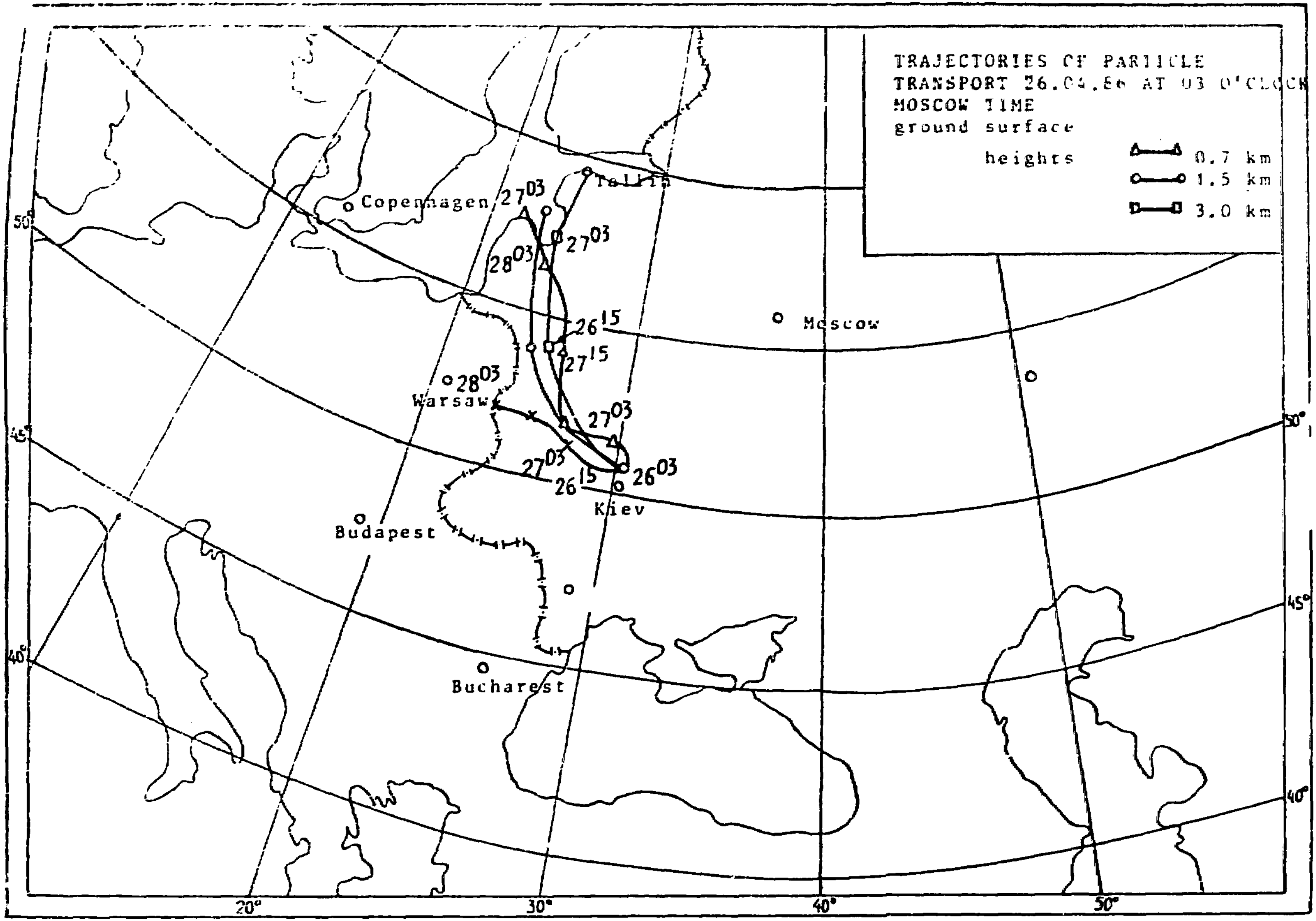
COMPARISON OF THE TOTAL RELEASES (SOURCE TERM) EVALUATED BY THE SOVIET UNION AND BY PEAR

	% of Total Inventory Released	
Radionuclide	Soviet Union	PEAR
Sr-89	4	10
90	4	10
Ru-103	3	10
106	3	10
I-131	20	40
133	--	15
Te-132	15	15
Cs-134	10	20
137	13	20

INDIVIDUAL DOSES IN THE SOVIET UNION (mSv)

Location and Distance	Thyroid (cloud)		Effective							
			Cloud + Ground		Ground Only					
			2 Days		One Month		In 1986		In 50 Years	
	S.U	PEAR	S.U	PEAR	S.U	PEAR	S.U	PEAR	S.U	PEAR
Pripyat, 3 km	-	4800	60-200	300	1300*	1200*	3000*	2600*	-	-
Chistogolovka, 5.5 km	1200	1500	60-200	100	200*	160*	600*	450*	-	-
Chernobyl, 15 km	800	360	60-200	50	20-1200*	110*	40-2500*	500*	-	-
Narovlja, 60 km	-	360	-	-	-	3.3	-	8.2	-	90
Oster, 70 km	-	-	-	-	-	-	-	6	-	-
Kiev, 110 km	-	49	-	-	-	0.35	-	-	-	-
Baryshevska, 160 km	-	40	-	-	-	-	-	4	-	-
Cherkassy, 270 km	-	26	-	-	-	-	2.7	2.7	8	28
Minsk, 320 km	-	12	-	-	-	-	-	0.29	-	-
Kaliningrad, 730 km	-	50	-	-	-	0.9	0.12	1.3	0.4	16

* Hypothetical values



TRAJECTORIES OF PARTICLE TRANSPORT 26.04.86 AT 03 O'CLOCK MOSCOW TIME

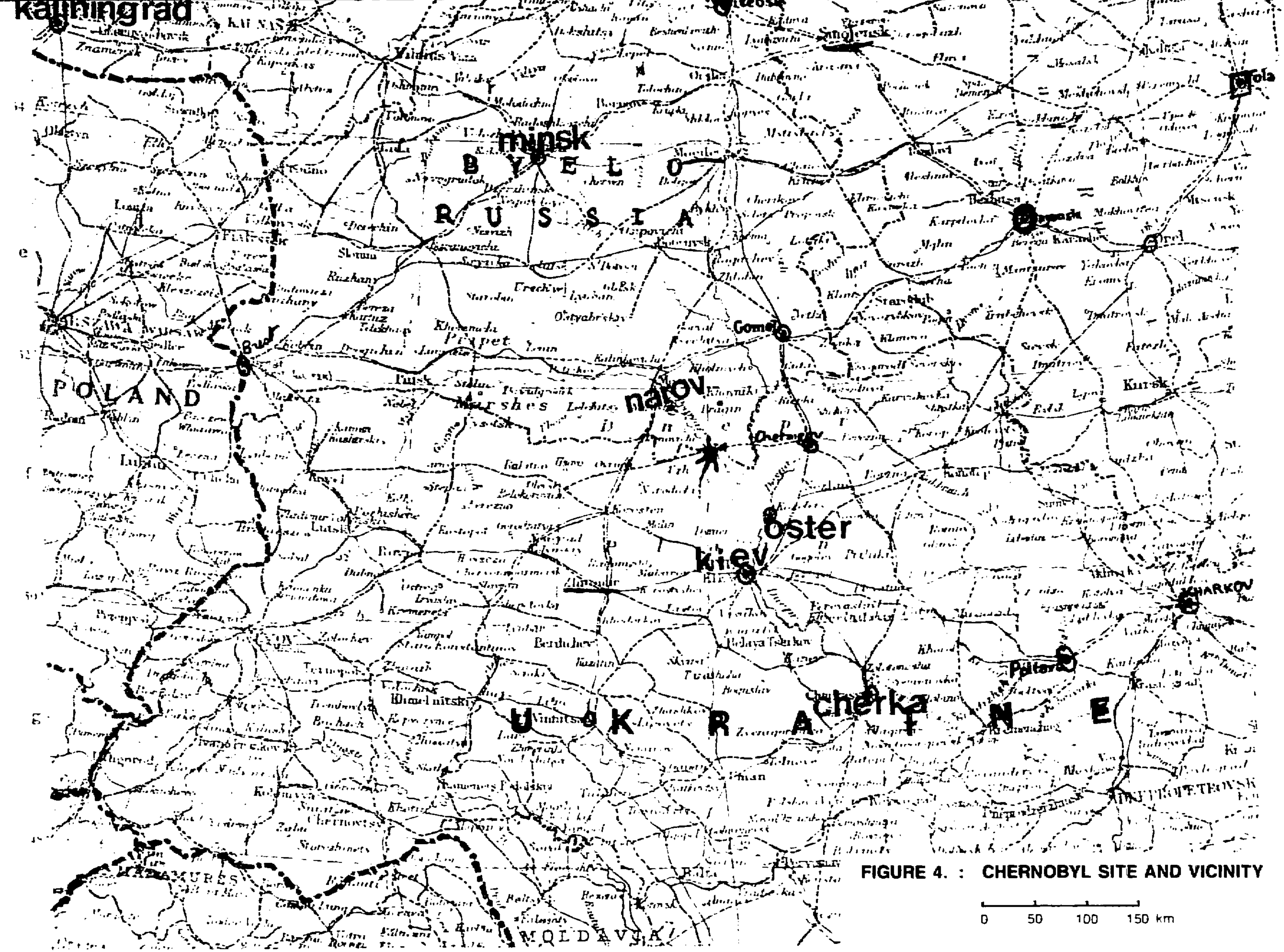


FIGURE 4. : CHERNOBYL SITE AND VICINITY

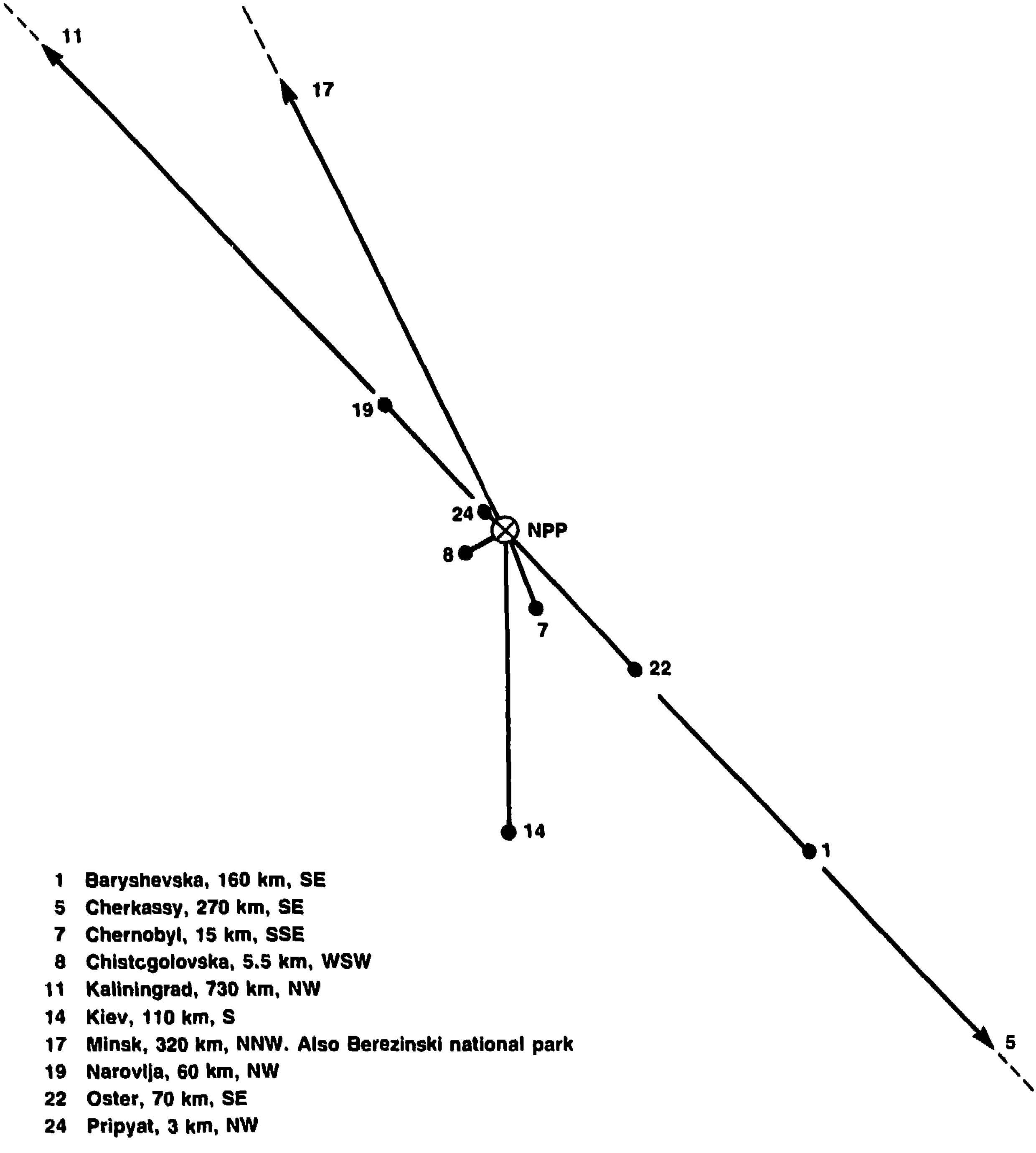


FIGURE 4.3: LOCATIONS EVALUATED IN THE SOVIET UNION

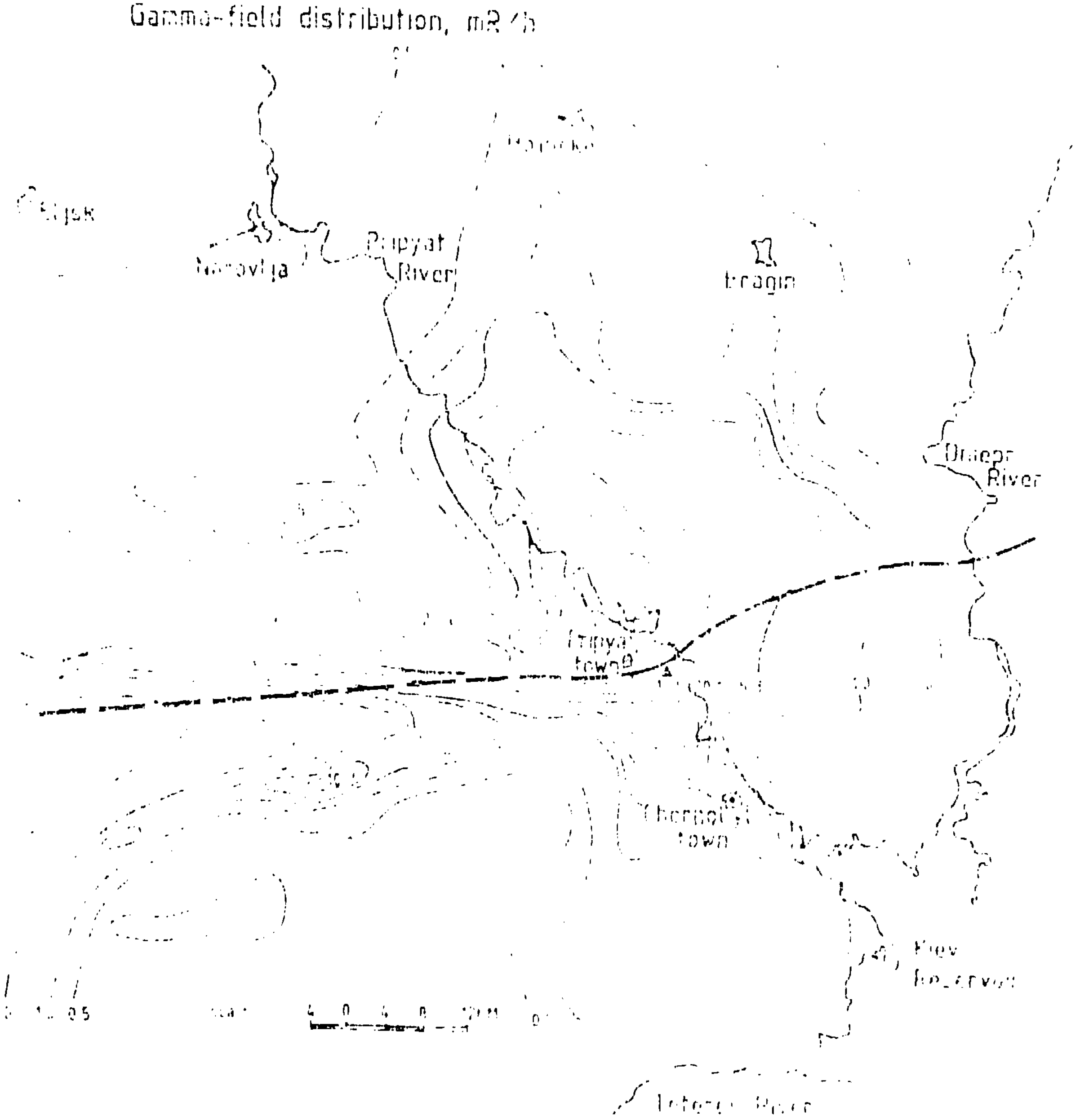


FIGURE 4.4: GAMMA FIELD DISTRIBUTION, mR/h

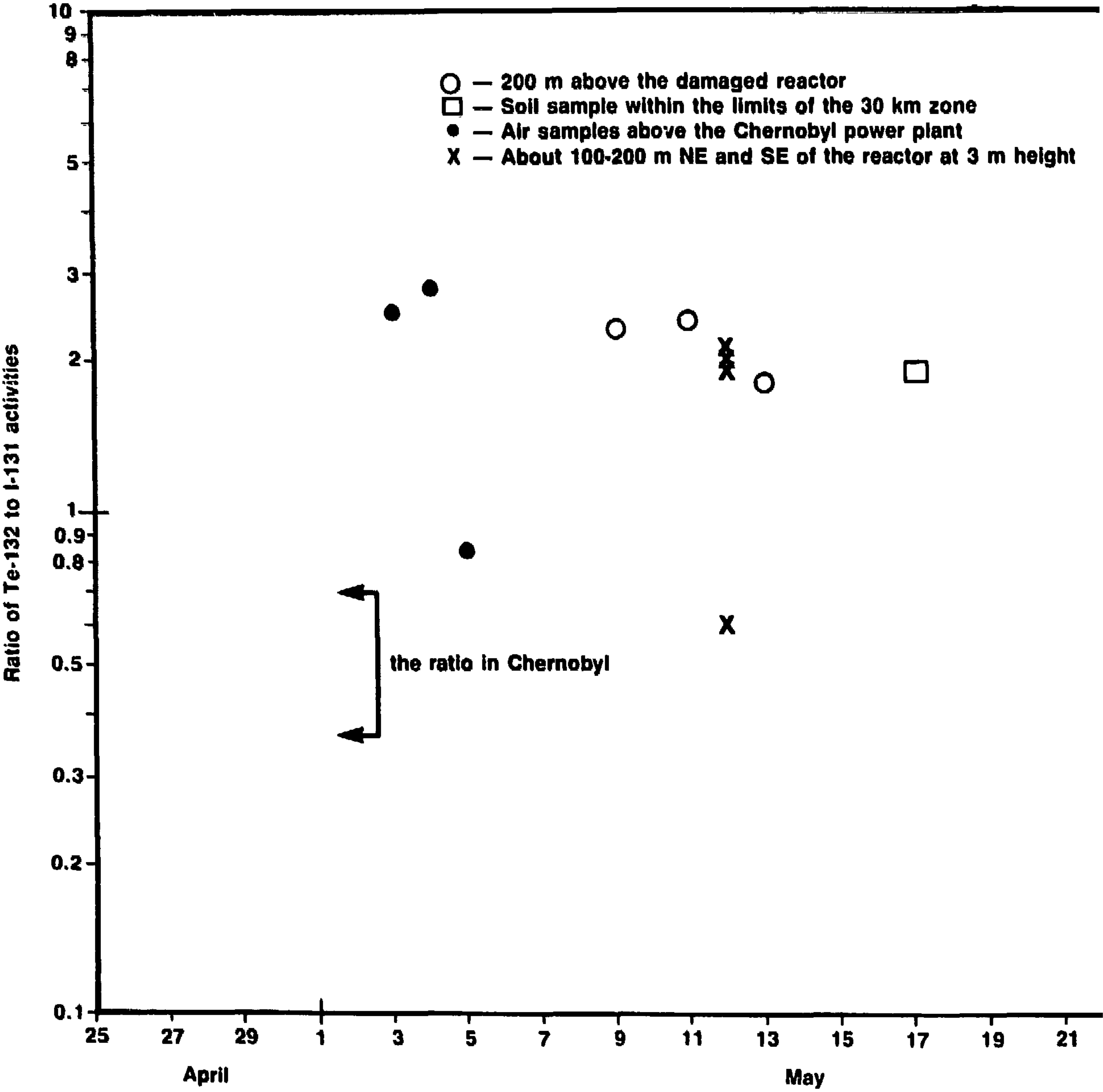


FIGURE 4.5: RATIOS OF TE-132 TO I-131 ACTIVITIES IN AIR AND SURFACE SAMPLES (Corrected for decay back to April 26, 1.30 AM)

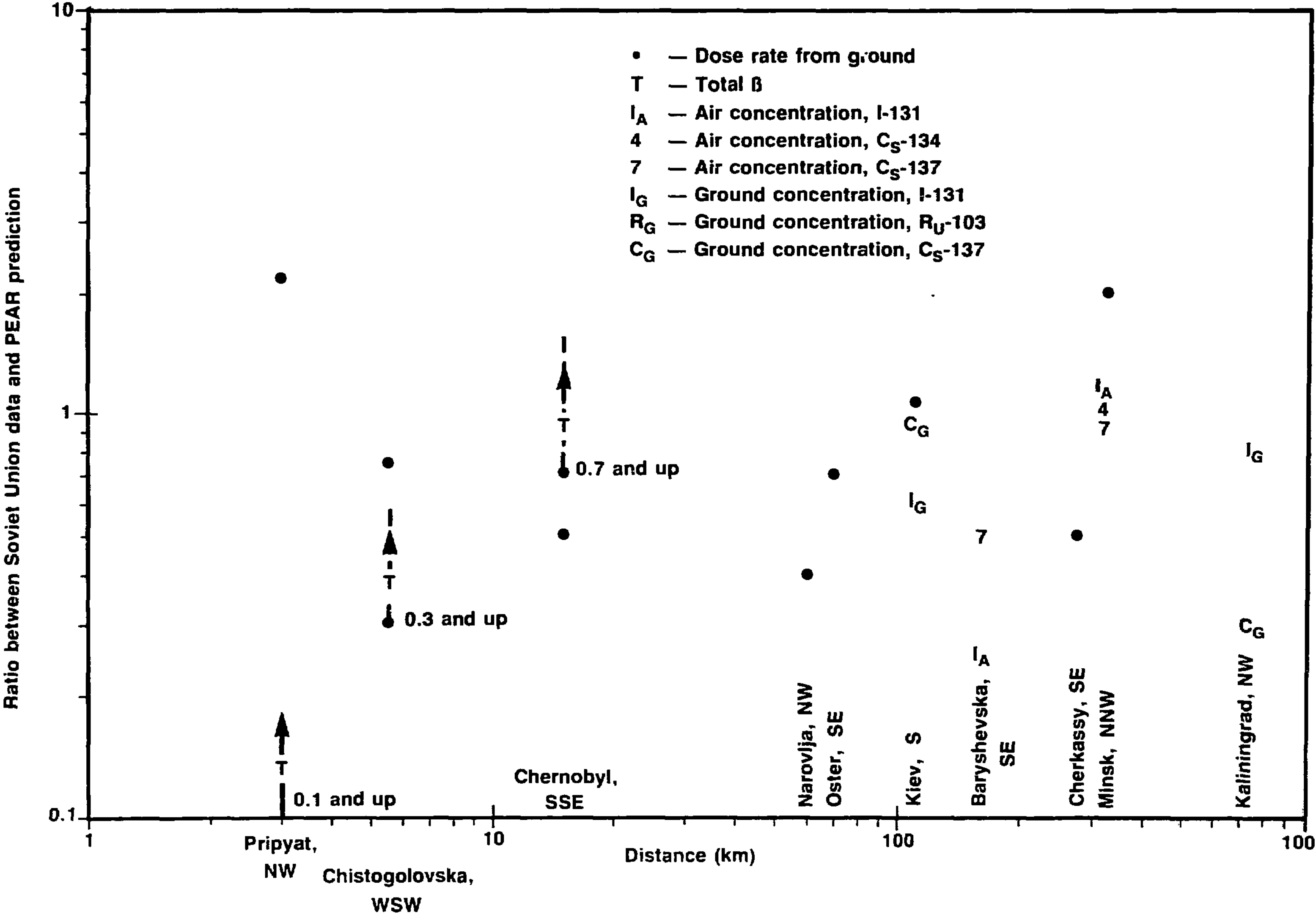


FIGURE 4.6: GROUND AND AIR CONCENTRATIONS

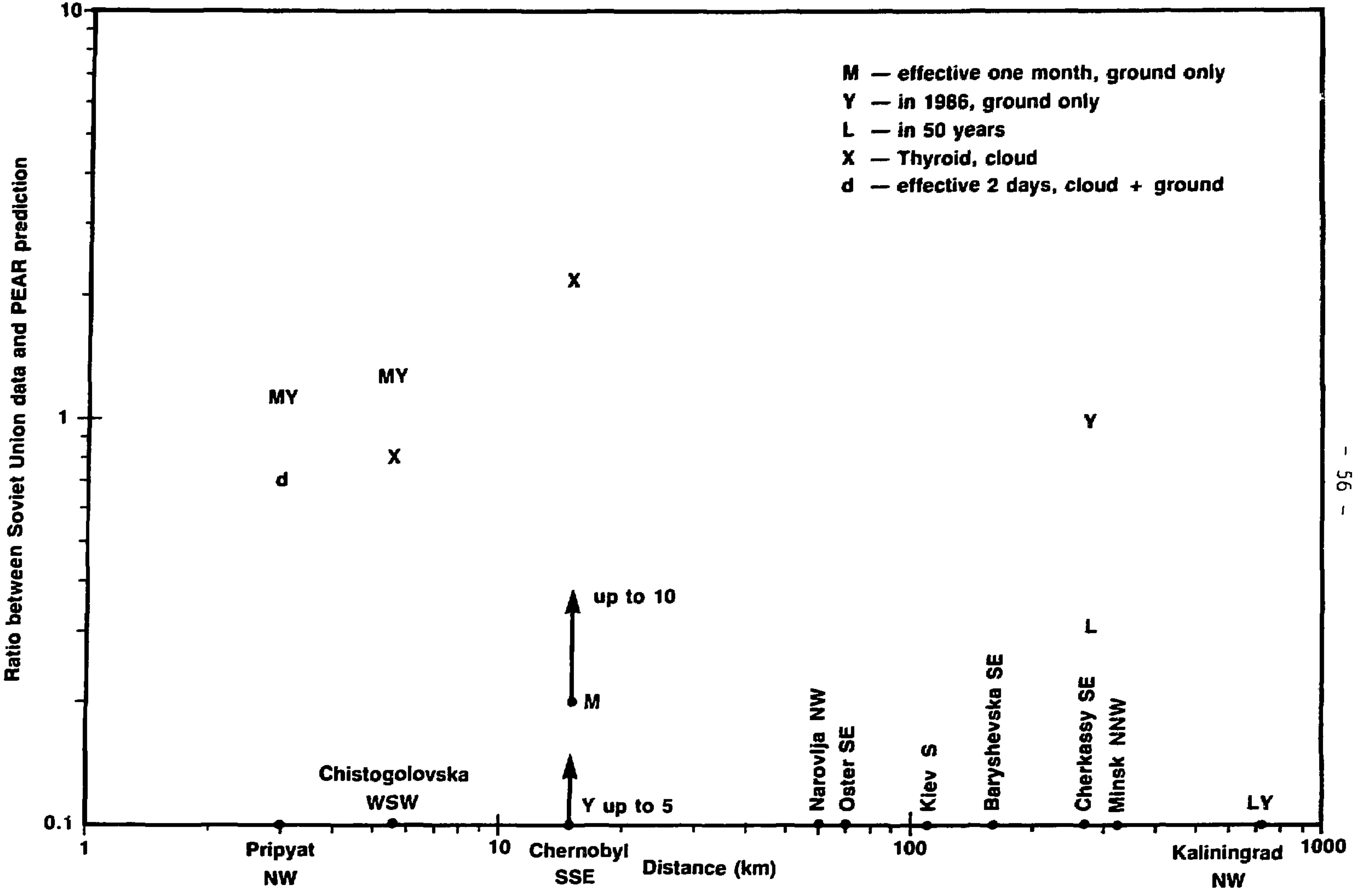


FIGURE 4.7: INDIVIDUAL DOSES

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