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Dit nummer bevat de teksten van de uiteenzettingen gedaan in Brussel op 23 april 1996 ter gelegenheid van de gemeenschappelijke vergadering van de Belgische Vereniging voor Stralingsbescherming, de Belgian Nuclear Society, de International Union of Radioecology en Women in Nuclear, gewijd aan:

CHERNOBYL, ECOLOGICAL AND HEALTH IMPACT: TEN YEARS OF OBSERVATION

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THE CHERNOBYL REACTOR ACCIDENTE SOURCE TERM

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Presented at a Belgian Nuclear Society seminar April 23, 1996 in Brussels

Abstract

Initial observations of enhanced radioactivity at the Studsvik site in Sweden one day before the announcement of the Chernobyl accident were the start of extensive further efforts to characterize the release and fallout.

Measurements and subsequent analyses at Studsvik discovered the hot fuel particles and ruthenium particles in the fallout and that iodine was transported in both particulate and gaseous form. Further, iodine and cesium were found not to have combined in any chemical form but were transported separately. Ruthenium and molybdenum were more abundant compared to fuel material in the late emission period, which was interpreted as more extensive release due to the prevailing oxidizing conditions.

Initiatives from NEA and support from e.g. the Swedish Nuclear Power Inspectorate have encouraged the author and colleagues to summarize what we now know about the source term from results obtained by scientists in a number of countries.

The initial estimates of total releases presented in August 1986 by USSR were based on integration of ground deposition within USSR only. Addition of materials dispersed abroad and analysis of core debris within the reactor building now allow us to estimate the cesium release to about one third of the core inventory. About half of the iodine is thought to have been released.

Introduction

Ladies and gentlemen. I would like to thank Mr Maurice Roch, the president of your society for the invitation to share with you the experience and information about the Chernobyl source term. I am pleased to be with you today.

Since April 28 1986 I have now and then been involved in the assessment and characterization of the release and fallout from the accident at Unit 4 of the Chernobyl NPP. The accident started the first

hours on April 26.
Before I go into the technical matters about the source term I would like to tell you my personal experience of our first findings at Studsvik in Sweden about the Chernobyl accident.

During morning hours Monday 28th of April 1986 I worked in my office at Studsvik. At that time I had, among other duties, the responsibility for actions in case of emergency situations at the Studsvik site.

The radiation protection officer came to my office and told me that we had got a severe contamination at the site. The monitor for checking the personnel at the hot cell laboratory gave the first alarm signals and all over the site we had increased radiation. The first reaction was to identify what we thought was a local source for the contamination.

In a phone call from the Nuclear Inspectorate a few minutes later, they asked us about the situation at Studsvik and informed us that the NPP at Forsmark also had increased radiation level. Part of the emergency response organisation at Studsvik went into operation. Thus air filters from the environmental control stations were analysed immediately by gamma spectrometry. We observed high concentrations of fission products and actinides. From the ratio Cs 134 to Cs 137 which was about 0.5 we could exclude a nuclear weapon as the source, because in that case the ratio would have been only of the order of 0.01. Cars coming from outside areas were also contaminated so we excluded a local source.

Around lunch time the same day the national authorities could trace the source to areas south-east of Sweden by use of wind trajectories. The same evening the accident was announced from the Soviet side on TV.

Many activities were started in all European countries to measure and assess the fallout and radiation doses. The activities at Studsvik were focused on three objectives

- characterization of the release and fallout
- validation of models for radiation exposure and pathways
- increase of measurement capacity for national radiation protection purposes.

In the May 15 issue of Nature 1986 we could in a letter to the editor [1] inform about our initial observations and could include measurements up to May 9 after the passage of a second plume. At Studsvik we collected different types of samples and analysed them by gamma spectrometry. Many of these results have been evaluated and published and I will give you some examples.

Further I will give you a summary of what we think is the international consensus of our present knowledge about the source term.

Release estimates

At the IAEA Post-Accident Review Meeting in Vienna 25-29 August 1986, Academician Legasov and his colleagues presented, very impressively, information on the accident and initial estimates of the source term [2]. It was made clear at the meeting in Vienna by USSR representatives that the quantitative estimate of release was based on the integration of ground deposition within the territories of the Soviet Union. In the discussions it was accordingly suggested that the total release of volatile and radiologically important nuclides like cesium and iodine therefore must be significantly higher if one considers also the deposition outside the former Soviet Union.

The release pattern according to the initial estimates is shown in Figure 1. We observe the release peak during the first violent excursion and then a decrease of the release rate during some days and then a second increased release period about a week after the first peak. There are more than one set of release pattern published so there are some uncertainties about the day to day release pattern. The extended release period is one of the unexpected features of the accident. Another special feature was the extensive release of fuel material.

Ten years have elapsed since the accident. A great deal more data is available concerning the events, phenomena and processes that took place. In a recent NEA-report and a poster paper [3] to the IAEA conference this month, my co-authors and I have summarized the present knowledge about the source term.

In Table 1, the initial release estimates as well as our current estimates are presented. Now I would like to give my comments to these figures.

The noble gases were initially estimated to have been released to 100 %of the core inventory and there are no results or discussion objecting to this estimate. For the volatile elements iodine, tellurium and cesium the initial estimates varied between 10 and 20 %. When the globally dispersed cesium 137 was added the release estimate increased from about 40 PBq to about 70 PBq for cesium 137 according to the UNSCEAR 1988 report.

Russian analysis of core debris and deposited material inside the reactor building have made it possible to carry out an independent estimate of the release of cesium to the environment.

> They arrived at 33 ± 10 % release of the core inventory of cesium to the environment which means 90 ± 30 PBq of cesium 137.

For the iodine release the best estimate from Russian scientists is 50-60 % of the core inventory.

Fuel material was dispersed as fuel fragments to 3,5 %, most of the material was deposited within the borders of former Soviet Union but could also be detected and studied for example in Poland, Greece and the Nordic countries. The fuel particles contained non-volatile elements such as cerium, zirconium and the actinides in the same proportions as in the core. The fuel particles were, however, more or less depleted in more volatile elements such as cesium, strontium and ruthenium.

Our current estimate for the strontium release is 3.5-4.5 %.

The release of ruthenium increased substantially compared to cesium and the fuel material in the late phase of the accident as can be seen from Figure 2. The reason is probably more oxidizing condition in the core region and the formation and release of the volatile ruthenium oxides. The Studsvik group also reported radioactive particles containing only the ruthenium isotopes 103 and 106. By comparing the ratio between ruthenium and cerium isotopes as well as cesium isotopes in air samples and in the ground deposition we have estimated the release of ruthenium. The total release seems to fall in the range 3.5-6 % of the core inventory.
The tellurium release is more uncertain and there are various estimates in the range 10-60 %.

The release of radioactive material from the reactor dispersed by the winds all over Europe and even further. There were of course more pronounced tracks in some directions and heavy rain deposited much more activity than under dry conditions. In Figure 3 the pattern of spatial dispersion is shown over Europe at various times during the release period.

Physical and chemical forms

The physical and chemical forms of the released radioactive material affected dispersion and deposition. The forms also affected solubility and transport in the food chains.

The washout of cesium was much more efficient in heavy rain compared to that of zirconium embedded in fuel particles as can be seen in Figure 4.

Dry deposition was different for the various elements. For the elements neptunium (Np), cerium (Ce), zirconium (Zr) and niobium (Nb) which were embedded in fuel particles the deposition was much higher than for cesium which was carried by other types of aerosols which can be seen in Figure 5. It has been shown that only a fraction of cesium was soluble in water. A major fraction was in colloid form and not easily soluble. Cesium is also known to be trapped in clay material in contrast to strontium.

Iodine appeared in both gaseous and particulate form. Figure 6 shows that the gaseous form dominated over the particulate form. Analysis in Germany has shown that a fraction of the gaseous iodine was in organic form.

Several groups have measured the particle sizes of the aerosols which carried the condensed radionuclides. Table 2 gives a résumé. Fuel particles were generally larger.

Some conclusions

o The total release of the various radioactive elements form Chernobyl is now better known due to several reasons.

- Firstly, world wide integration of deposited cesium is available and adjusts the initial estimates based on integration within the borders of the former Soviet Union.

- Secondly, analysis of core material and deposition within the reactor building supports the estimate that about one third of the core inventory of cesium was released to the environment.

- Thirdly, extended number of analysis of samples from the environment have confirmed the estimate of 3.5 % release of fuel material.

- Fourthly, comparisons between individual elements in environ-mental samples with cesium and non-volatile elements in dis-persed fuel material have given additional information for the tellurium, strontium and ruthenium release.

o Russian scientists have estimated the total iodine release to 50-60 % of the core inventory. Iodine appeared in both gaseous and particulate form. Special analyses revealed that a significant fraction consisted of organicforms of iodine. There were no observations of any cesium iodide or other compounds of cesium and iodine in the plume.

o The release duration was about ten days and started with a violent eruption which lofted much radioactive material to a height of more than one kilometre. After about a week a second release peak occurred but the plume lift was less than 400 m.

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[2] USSR State Committee on the Utilization of Atomic Energy
The accident at the Chernobyl Atomic Energy Power Plant and its Consequences.
IAEA translation Vienna, Austria, August 1986

[3] DEVELL L., GÜNTAY S., POWERS D.A
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NEA/CSNI/R (95) 24, 1995; also as a shorter and updated version in IAEA Conference. One decade after Chernobyl. Vienna 8-12 April 1996

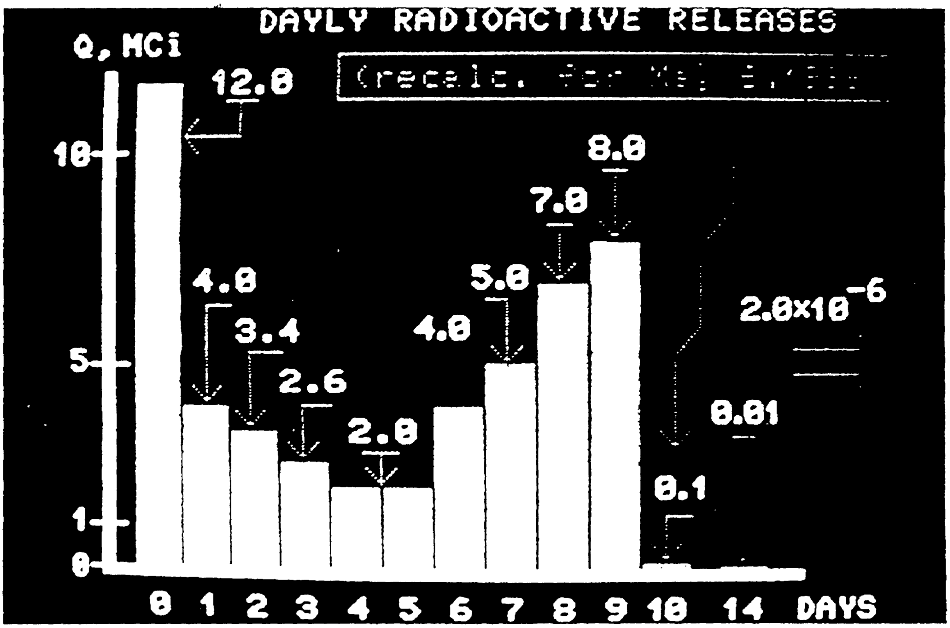
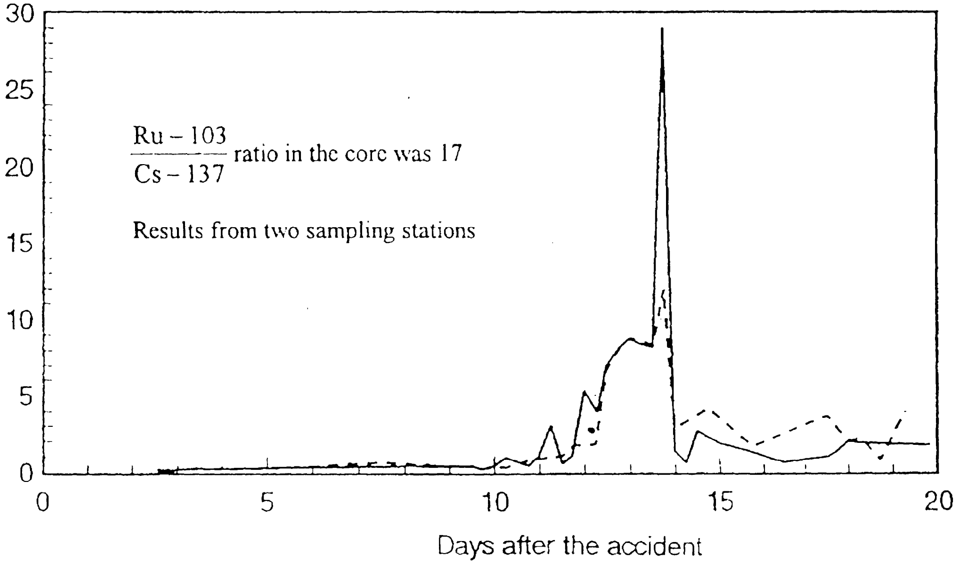


Figure 1
Initial estimate of daily releases. USSR 1986 [Ref 2]


$\frac{Ru-103}{Cs-137}$ ratio in the core was 17

Results from two sampling stations

Figure 2
Radioactivity ratio Ru-103/Cs-137 in air samples at Studsvik corrected for decay.

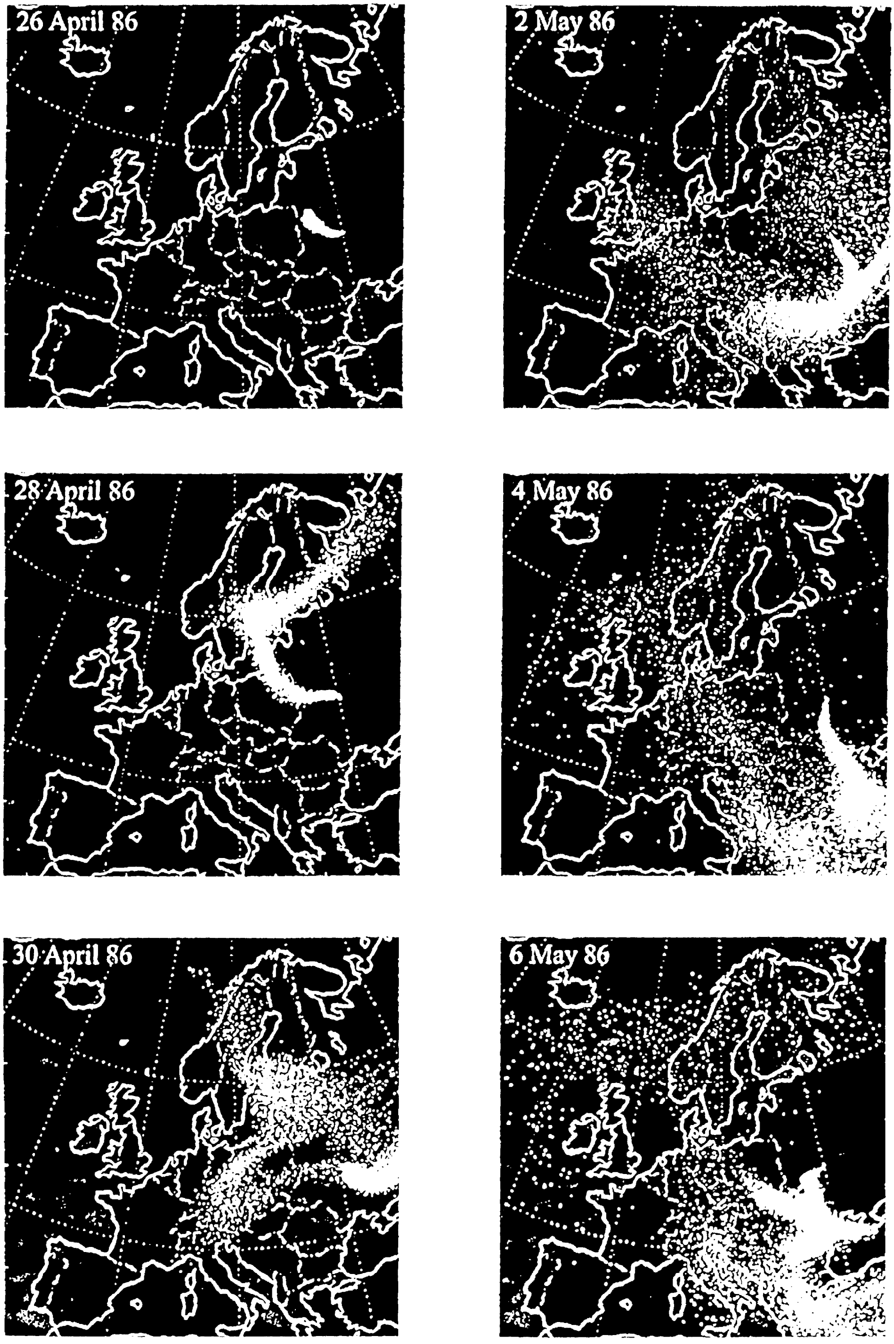


Figure 3
Areas covered by the main body of the radioactive cloud on various days during the release (NEA and ARAC).

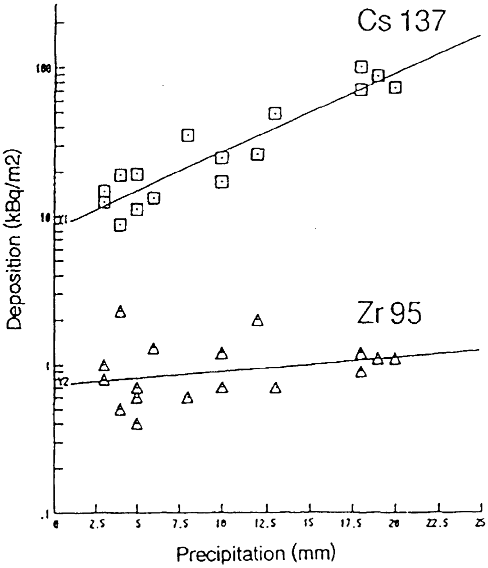


Figure 4
Deposition versus precipitation for Cs-137 and Zr-95.(The latter nuclide appeared in fuel particles in contrast to Cs-137)

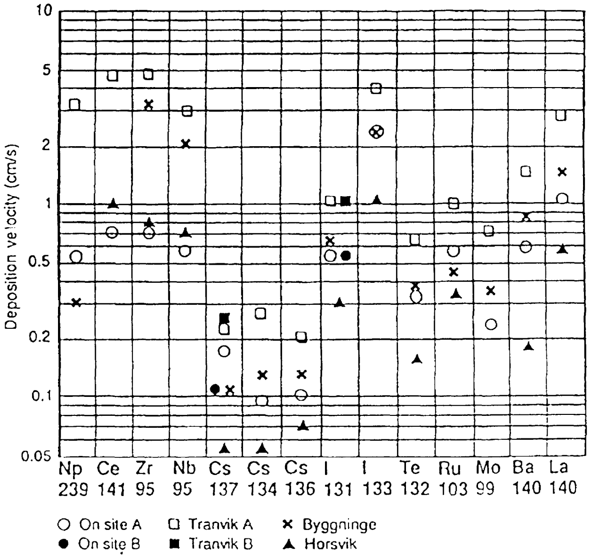


Figure 5
Dry deposition velocities on grass surfaces for various nuclides.

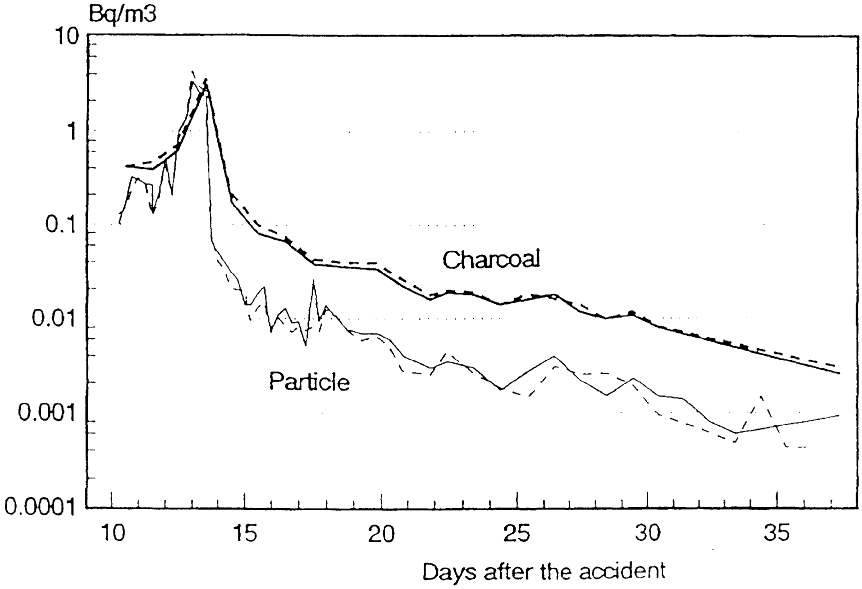


Figure 6
Iodine-131 in air, sampled by charcoal or particle filters.

Table 1

Estimates of Radionuclide Releases During the Chernobyl Accident

Nuclide	***Core Inventory*** 26 April 1986 (Pbq*)	***Initial Estimate***	***Current Estimate***
		(percent of core inventory)	
^{85}Kr	33	100	100
^{133}Xe	6300	100	100
^{131}I	3200	20	50-60
^{132}Te	4000	15	10-60
^{134}Cs	180	10	33±10
^{137}Cs	280	13	33±10
^{140}Ba	4800	5.6	3.5-6
^{95}Zr	5600	3.2	3.5
^{99}Mo	4800	2.3	3.5-6
^{103}Ru	4800	2.9	3.5-6
^{106}Ru	2100	2.9	3.5-6
^{141}Ce	5600	2.3	3.5
^{144}Ce	3300	2.8	3.5
^{89}Sr	3500	4	3.5-4.5
^{90}Sr	200	4	3.5-4.5
^{239}Np	27000	3	3.5
^{238}Pu	1	3	3.5
^{239}Pu	0.85	3	3.5
^{240}Pu	1.2	3	3.5
^{241}Pu	170	3	3.5
^{242}Cm	26	3	3.5

* 1 PBq = 10^{15} Bq

Table 2
Particle size measured in air samples from the Chernobyl plume (note that fuel particles were larger and are not included in the table).

Location	**Period**	**Median diameter* (mm)**	**Nuclide**	**Ref**
Helsinki	May 7-14	0.33-0.57 0.65-0.93	I-131 Ru-103, Te-132,Cs-137	a)
Göttingen	May-June	0.6 0.7-1	I-131 Ru-103,Cs-137	b)
Munich	April 30-May 7	0.35-0.6 0.5-0.85	I-131 Ru-103,Cs-137	c)
Neuherberg	May 1-10	0.5-0.8	I-131,Cs-137,Ru-103, Te-132, Sr-90	d)
Studsvik	May 7-9	0.7	Cs-137	e)

*Aerodynamic equivalent diameter.
a) Kaupinen et al
b) Porstendörfer and Reineking
c) Tschiersch and Georgi
d) Winkelmann et al
e) Chyssler and Devell

Résumé

Des observations initiales d'une augmentation de la radioactivité sur le site de Studsvik en Suède le jour précédant l'annonce de l'accident de Chernobyl furent le départ d'efforts étendus en vue de caractériser le relâchement et les retombées.

Les mesures et les analyses subséquentes à Studsvik décelèrent des particules de combustible et de ruthénium dans les retombées et de l'iode transporté sous forme de particules et de gaz. Par ailleurs, l'iode et le césium n'étaient pas combinés chimiquement mais étaient transportés séparément. Le ruthénium et le molybdène étaient plus abondants comparés au combustible, en fin d'émission, ce qui fut interprété comme un relâchement plus important à cause des conditions d'oxydation.

Des initiatives de l'AEN et le soutien de l' Inspection de l'Energie Nucléaire Suédoise ont encouragé l'auteur et ses collègues à rassembler ce que nous savons à présent du terme source à partir de résultats obtenus par des scientifiques dans quelques pays.

Les estimations initiales du total des relâchements présentées par l' URSS en août 1986 étaient basées sur l'intégration des dépôts au sol à l'intérieur de l' URSS uniquement. L'addition des matériaux dispersés à l' étranger et l' analyse des débris du coeur à l' intérieur du bâtiment du réacteur nous permettent d ' estimer l' échappement du césium au tiers de l' inventaire du coeur. Pratiquement la moitié de l'iode semble avoir été relâchée.

Samenvatting

Initiële observaties van verhoogde radioactiviteit in het Studsvik gebied in Sweden een dag voor de bekendmaking van het Chernobyl ongeval gaven de start voor verdere inspanningen om ontsnapping en fallout te kenmerken.

Metingen en verdere ontledingen in Studsvik ontdekten brandstof deeltjes en ruthenium deeltjes in de fall out en Iodium vervoerd zowel in deeltjes vorm als gasvorm. Verder Iodium en Cesium werden niet gecombineerd maar afzonderlijk vervoerd. Ruthenium en Molybdeen waren meer aanwezig als brandstof materiaal in de late emissie periode wat geïnterpreteerd werd als een uitgebreide ontsnapping omwille van heersende oxydatie condities.

Initiatieven van NEA en steun van het toezicht van het Sweedse Kernenergie Inspectoraat hebben de auteur en collega's aangemoedigd om een samenvatting op te stellen van wat wij nu weten van de bron volgens de resultaten van wetenschappers uit verschillende landen.

De initiële schattingen van de totale emissie als voorgesteld in augustus 1986 door de USSR berustten op de integratie van de gronddepositie enkel binnen de USSR. De samenstelling van materialen verspreid en de ontleding van de fragmenten van de kern binnen de omheining laten ons toe de Cesium ontsnapping te schatten op ongeveer een derde van de kern inventaris. Men schat de ontsnapping van Iodium op ongeveer de helft.

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CHERNOBYL, ECOLOGICAL AND HEALTH IMPACT:
10 YEARS OF OBSERVATION
STATUS OF THE SARCOPHAGUS

Bernard Jampsin
European Commission, Directorate General IA

Brussels- April 23, 1996

Abstract

On the 26th of April, 1986, a major nuclear accident occured at the Chernobyl Nuclear Power Plant in the Ukraine, destroying reactor n°4 and releasing a considerable amount of radioactive material into the environment. The debris of the reactor and of its enclosure were encased into a Shelter, or " Sarcophagus ", built in haste and under extremely arduous conditions. It is now known that this structure is unstable, has more than 1000m^2 of voids and can no more be considered as safe. Actions are currently under way to remedy this situation, through the stabilization of the existing shelter and the erection of a new encasement. These actions are now placed within the broader framework of the G7 Action Plan for the Ukraine's Energy Sector

1. The accident.

In 1986, there were six reactor blocks at the Chernobyl site. Four were operational, and two units, 5 and 6, were under construction. On the 26 of April 1986, an explosion and fire severely damaged reactor 4 at Chernobyl Nuclear Power Plant, whole site and surrounding areas were contaminated by a mixture of radioactive materials.

The accident arose from an enormous power surge which caused local fuel melting and disintegration. It is technically defined as a voiding induced super prompt critical power excursion that triggered a fuel-coolant interaction steam explosion. As a result, the reactor core was completely destroyed and the 2000 tonnes upper biological shield was displaced and rotated 105° so that it now stands some 15° from the vertical while the reactor base was displaced some 4 meters downwards. The reactor building itself, especially above the floor of the reactor hall suffered extensive damage, the roof and upper building structures were destroyed. Other major components of the unit, including the emergency core cooling system, dearerator system, steam drums, main coolant pumps and primary piping were destroyed or severely damaged. Hot core materials and debris expelled by the explosion caused heavy damage to the roof that covers the turbogenerators, causing significant damage to the equipment below. The explosion pressure wave compromised the building's structural integrity.

2. Distribution of radioactive material after the explosion.

From an initial inventory of 190 tonnes of fuel material, approximately 135 tons melted and flowed into the lower parts of the reactor building. Another 38 tonnes ± were scattered in the upper levels and in the immediate vicinity of the building. Approximately 6.7 tonnes were expelled and released high into the atmosphere in form of aerosolized particles. 11 tonnes are unaccounted for, most probably located in the building or in the sarcophagus.

At the moment of the explosion, the fuel load contained 6000 MCi of fission products. 53% of the initial inventory of ^{131}I was released, as 33% of the ^{137}Cs and 4% of the ^{90}Sr.

3. The construction of the Shelter, or " Sarcophagus ".

The debris of the reactor and its enclosing structure were encased into a shelter, otherwise known as "the Sarcophagus" or " Ukritiye ", erected in great haste and under extremely arduous conditions. It was completed in October 1986. It can be briefly described as follows:

On the East side, a dividing wall constructed as a combination of existing structures and newly erected walls or concrete filler separates Unit 4 from the auxiliary system building " V ". The western wall, relatively undamaged, was lined on the inside by a buttress concrete shielding wall and on the outside by a contraforce wall made of metal and concrete. On the northern side, radioactive material thrown out from the roof and other debris are covered by concrete forming the so-called cascade wall. In the upper parts, two metallic beams support a roofing made of 27 steel pipes over which a roof of specially made steel plates was placed. Over the southern part and the dearator, a roofing of steel plates is supported by the so called mammoth beam resting on two concrete columns which were strengthened by remotely poured concrete.

4. Present situation of the sarcophagus.

4.1 Radiological and nuclear safety situation.

The radiation situation in the shelter can be summed up as follows:

Point of measurement	exposure dose rate (Rem/h)	
	average	maximum
Reactor Hall	30 to 600	1800 to 2400
Shelter premises	1 to 800	1800 to 4800
Shelter roof	1 to 4	5 to 20

The average concentration of aerosols in the Shelter premises subject to monitoring are:
from 1.0×10^{-11} to 3.3×10^{-10} Ci/m^3 of beta/gamma radionuclides
from 1.0×10^{-13} to 1.4×10^{-12} Ci/m^3 of alpha radionuclides

Investigations performed so far indicate that the risk of a criticality accident is very low but cannot be excluded. In this regard, the water which penetrates into the shelter is a major source of danger.

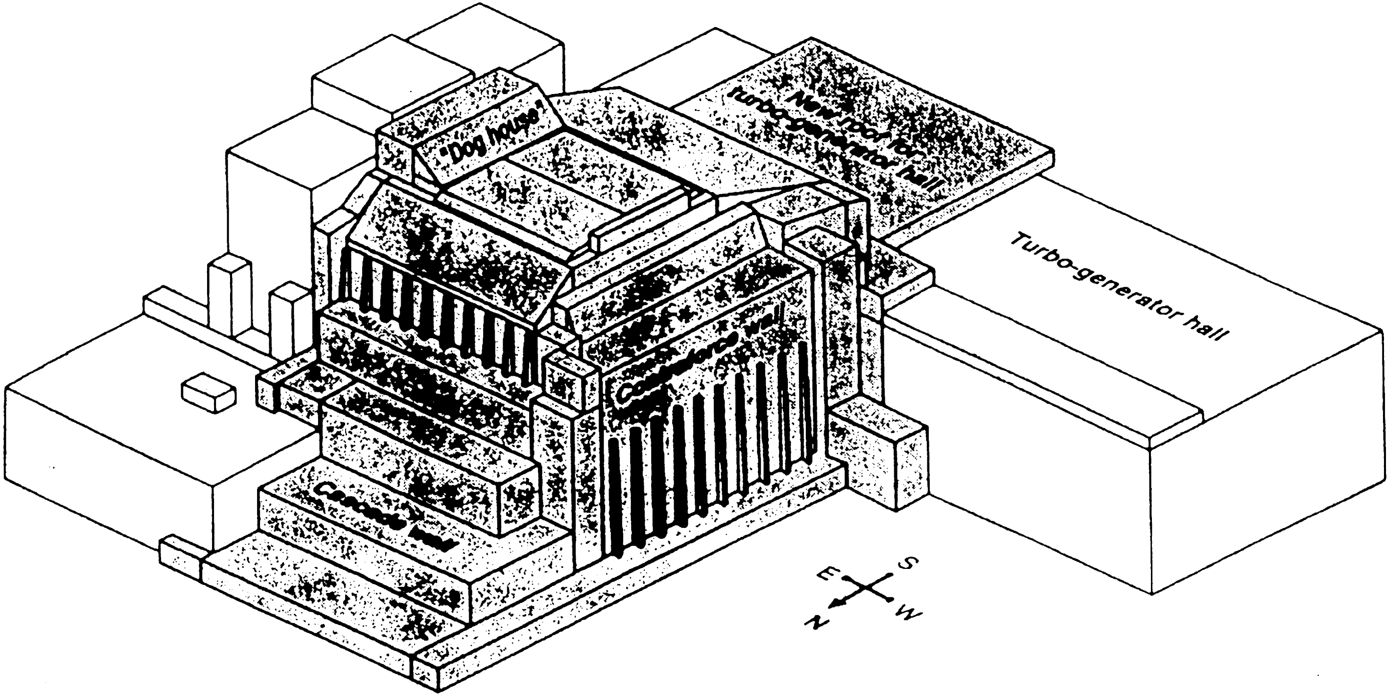
The degradation and corrosion of the melted fuel masses (lava) generates radioactive dust which would be spreaded over the environment in case of a collapse of the Shelter.

4.2 Structural situation

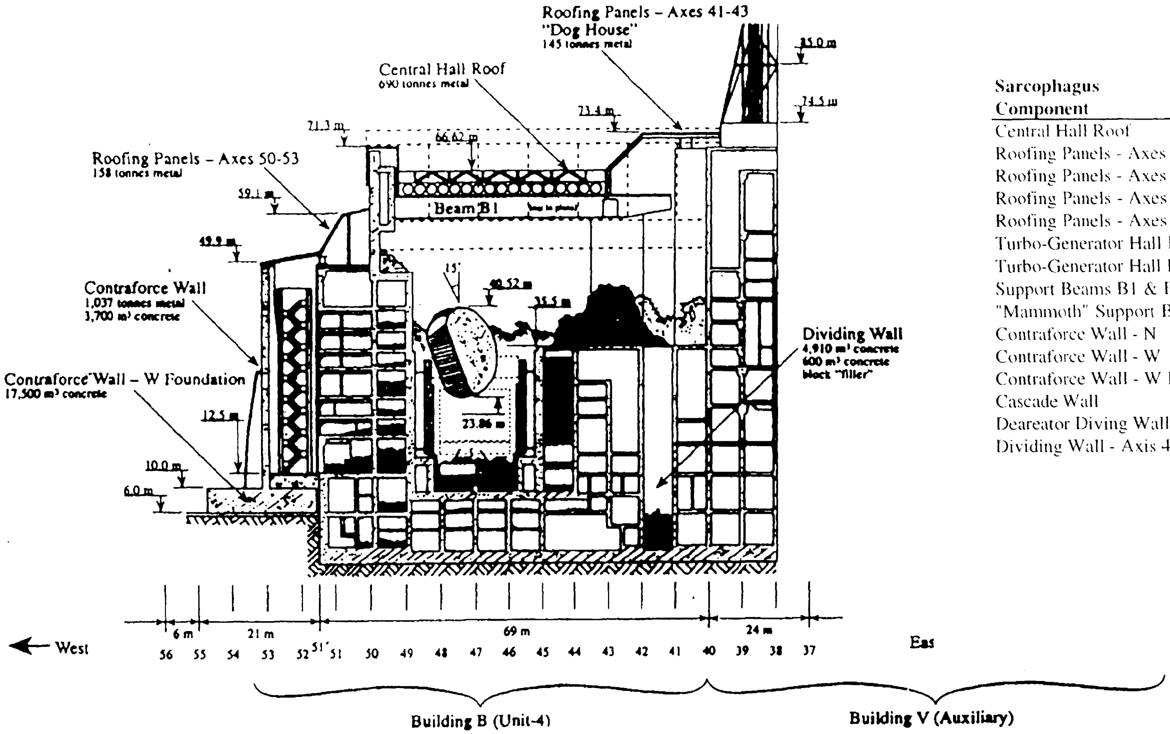
All the main bearing structures of the shelter (girders, pipe ceiling, steel shields) were designed and manufactured in compliance with the building code and can be considered as safe. But their service life is limited and, due to radiation situation, they cannot be inspected and their corrosion resistant coating cannot be restored. Furthermore, since most of the erection work was remote controlled, the support sub assemblies were executed without precise fixing (welding or bolts) and no quality control could be performed.

The shelter is essentially supported by the remaining structures of the reactor, the integrity of which has not been controlled, due to limited accessibility.

Varying humidity and heat as well as the atmosphere moisture inside the shelter accelerates corrosion of metallic pieces and degradation of concrete elements.



General view of the Chernobyl Unit 4 sarcophagus "Shelter"
(Photograph courtesy of Valentin Ivanovich Obodzinski of the Kurchatov Institute, Moscow)



Sarcophagus Component	Metal Mass (t)	Concrete Volume (m³)
Central Hall Roof	690	-
Roofing Panels - Axes P.S	160	-
Roofing Panels - Axes B-Zh	597	-
Roofing Panels - Axes 41-43	145	-
Roofing Panels - Axes 50-53	158	-
Turbo-Generator Hall Roofing Panels	635	-
Turbo-Generator Hall Lateral Wall	85	-
Support Beams B1 & B2	300	-
"Mammoth" Support Beam	140	-
Contraforce Wall - N	253	1.500
Contraforce Wall - W	1.037	3.700
Contraforce Wall - W Foundation	-	17.500
Cascade Wall	800	115.800
Deareator Diving Wall	-	17.000
Dividing Wall - Axis 41	-	5.510
	5.000	161.010

Schematic of the Chernobyl Unit 4 sarcophagus "Shelter"
East-West cross section along axis L

Sarcophagus Component	Metal Mass (t)	Concrete Volume (m³)
Central Hall Roof	690	-
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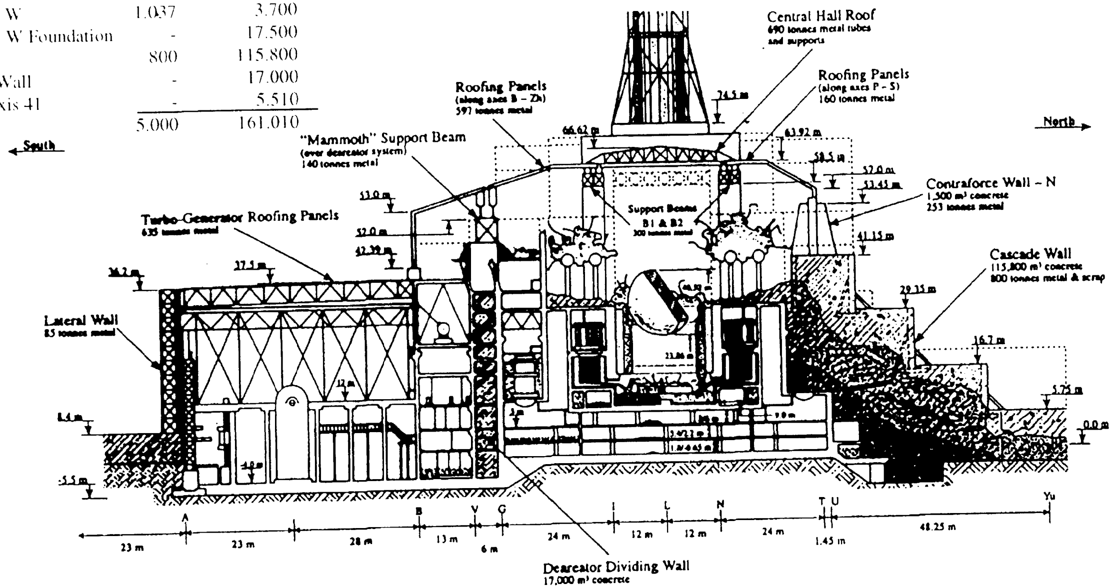

Schematic of the Chernobyl Unit 4 sarcophagus "Shelter"
North-south cross section along axis 47

More than 1000 m^2 of leaks allow the release of radioactive material as well as the entering of water.

Migration of radioactive material down to the watertable cannot be excluded.

In view of this situation, the Shelter cannot be considered as safe and the risk of collapse grows higher as time elapses. Such an accident would probably not result in as important a disaster as in the 1986 accident since in the absence of fire, the contamination would be limited to the site and its immediate vicinity.

5. Actions implemented

In the summer of 1992, the National Academy of Sciences of the Ukraine decided to launch a competition with the intention of soliciting ideas that could be developed into an acceptable solution to transform the existing encasement of Chernobyl unit 4 into an ecologically safe system. This competition attracted some 394 entries and, because no entry was deemed by the judges to meet all of their criteria, no first prize was awarded although the French consortium "Resolution" was declared the best entry. Five other entries from France, Germany, Great Britain, Russia and Ukraine were jointly awarded third place.

On the 12th of August 1993, acknowledging the results of the competition, the Cabinet of Ministers of Ukraine issued a decree (N 604) instructing various organizations to prepare an international tender to carry out a feasibility study to define a concept for an environmentally safe system.

The European Commission accepted to finance this study and allocated for that purpose 3 million ECU under its programme of Technical Assistance to the Commonwealth of Independent States (Tacis).

The Terms of Reference for the tender were endorsed by the Ukrainian Minister for the Protection of the Population from the Consequences of the Chernobyl Accident (MINCHERNOBYL) as well as by the President of the National Academy of Sciences. They were substantially based on the rules adopted for the competition. These terms required, *inter alia*, that any solution for the transformation of Ukritiye into an environmentally safe object be effective for one hundred years and be compatible with the continued operation of the three remaining reactors at Chernobyl NPP. It was inevitable that these conditions, which reflected genuine concerns in the scientific community in Ukraine, would have a major impact on the type of solution and its final cost.

On September 1994, a contract was awarded to "ALLIANCE", a consortium formed by Campenon

Bernard, Bouygues and SGN from France, AEA Technology and Taywwod Engineering of the United Kingdom, and Walter Bau of Germany, for the carrying out of a feasibility study for the project entitled "*The stabilization of the existing shelter and the containment of both the exiting shelter and the damaged remains of Reactor 4 at the Chernobyl Nuclear Power Plant*".

The study was carried out in two phases. The first phase was an analysis of the problem and the definition of final technical orientations. The second phase was to take the design option (or options) recommended in the first phase, forward to an outline design, a budget cost and to produce an implementation schedule.

At the end of each phase, the results were presented to a panel of Ukrainian and international experts for comments and proposals.

It was then agreed between the Ukrainian authorities and the European Commission that the results and conclusions of the study were to be considered as a valuable basis as well as a technical element for a decision of Ukraine about the future of Chernobyl NPP Unit 4.

On the 11th of September 1995, a meeting took place in Brussels between the European Commission and an Ukrainian delegation headed by Mr Kholocha, Minister of Chernobyl and composed of representatives of the Ministry of Environment Protection and Nuclear Safety, the Utility (Goskomatom) and the Academy of Sciences. It appeared very clearly that the solution of the Chernobyl Unit 4 issue was considered by the Ukrainian authorities as a high priority while it was agreed that the assumptions which had formed the basis of the Alliance study could be revised and that alternative solutions should be explored before searching for financial solutions.

As a result of the meeting, the following actions were agreed upon and entered into a protocol signed by both parties:

1. definition of safety objectives and design criteria for the stabilization of the existing shelter,
2. establishment of terms of reference for the stabilization of the existing shelter,
3. definition of safety objectives and design criteria for a new encasement,
4. establishment of terms of reference for the construction of a new encasement.

These four actions are financed by the European Commission within the framework of its Tacis programme.

Two western Technical Safety Organizations, IPSN of France and GRS of Germany have been awarded a contract to provide assistance to the Ukrainian Nuclear Regulatory Administration in the implementation of actions 1 and 3. A grouping of organzations and experts of the European Union shall assist the Ukrainian operator for the implementation of tasks 2 and 4.

These actions aiming at a solution for the Chernobyl Unit 4 issue sould not be considered in isolation. Actually, they are placed within the general framework of the G7 Action Plan for the Ukrainian Energy Sector. This action plan, put forward and proposed to the Ukraine by the European Council in Corfu and the G7 summit in Naples consists of a set of measures aiming at the early closure of the Chernobyl Nuclear Power Plant while ensuring that sufficient electricity is available to meet Ukrainian demand and taking into account the economical, financial and social constraints. It includes in particular proposal for substancial reforms in the energy sector at large.

As a first important step in the implementation of the a.m. action plan, a Memorandum of Understanding on the closure of Chernobyl NPP has been signed on December 20, 1995 in Ottawa by Mrs Sheila Copps Deputy First Minister of Canada on behalf of the G7 leaders, and Mr Yuriy Kostenko, Ukrainian Minister for Environmental Protection and Nuclear Safety. This Memorandum calls for the creation of a comprehensive program to support the decision of the Ukraine to close the Chernobyl NPP by the year 2000. It covers the following aspects:

1. Power sector restructuring,
2. Energy investments program,
3. Nuclear Safety
4. Social impact plan.

This Comprehensive Program shall be based on the critical linkage between energy sector reform and the achievement of Ukraine's economic and social reform, as well as on the complementarity between the closure of Chernobyl NPP and the development of a long term strategy for the energy sector in the Ukraine.

Résumé

A la date du 26 avril 1986 un accident nucléaire majeur s'est produit à la Centrale nucléaire de Tchernobyl en Ukraine, détruisant le réacteur n°4 et relâchant une quantité considérable de matériel radioactif dans l'environnement. Les débris du réacteur et de son confinement furent emballés dans un abri ou "Sarcophage" construit à la hâte et dans des conditions très difficiles. On sait actuellement

qu'une telle structure est instable, qu'elle a plus de 1000 m^2 de vides et ne peut être considérée comme sûre. Des actions sont constamment entreprises afin de remédier à cette situation en stabilisant l'abri actuel et par l'érection d'un nouvel abri. Ces actions se situent maintenant dans le cadre plus large du plan d'action G7 pour le secteur de l'énergie en Ukraine.

Samenvatting

Op 26 april 1986 gebeurde er een zeer zwaar ongeval in de Chernobyl kerncentrale in Oekraine met verwoesting van reactor nr 4 en vrijlating van een grote hoeveelheid radioactief materiaal in de omgeving. De stukken van de reactor en van zijn omheining werden opgesloten in een ruimte ofte "Sarcophaag" in aller heil en extreem moeilijke omstandigheden. Men weet nu dat dergelijke structuren niet stabiel zijn, meer dan 1000 m^2 doorgang laten en kunnen niet meer als veilig beschouwd worden. Er worden acties gevoerd om deze toestand te verbeteren door stabilisatie van de bestaande bunker en het bouwen van een nieuwe omheining.   Deze acties worden nu opgenomen in het brede G7 actieplan voor de Oekraine energie sector.

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THE ATLAS OF CAESIUM-137 CONTAMINATION OF EUROPE AFTER THE CHERNOBYL ACCIDENT

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Abstract.

The Atlas. which was compiled under the Joint Study Project (JSP6) of the CEC/ CIS Collaborative Programme on the Consequences of the Chernobyl Accident. implemented into the European Commission's Radiation Protection Research Action. summarizes the results of numerous investigations undertaken throughout Europe to assess the ground contamination by caesium-137 following the Chernobyl accident. The Atlas incorporates about 100 color maps at a range of scales (1:200k - 1:10M) which characterize the contamination in Europe as a whole. within state boundaries. and for zones where the contamination levels are above 40 kBq/m^2 (≈2.0% of the European territory) and above 1480 kBq/m^2 (≈0.03 % of the European territory). Investigations have shown that around 6 % of the European territory has been contaminated for more than 20 kBq/m^2 after the Chernobyl accident. The total amount of deposited caesium-137 in Europe is 8×10^{16} Bq and distributed in the following manner : Belarus 33.5 %. Russia 24 %. Ukraine 20 %. Sweden 4.4 %. Finland 4.3 %. Bulgaria 2.8 %. Austria 2.7 %. Norway 2.3 %. Romania 2.0 %. Germany 1.1 %.

1. Introduction

The Chernobyl nuclear power plant (CNPP) accident of 26 April 1986 was followed by a partial destruction of reactor IV which resulted in a significant release of radioactive material into the natural environment. The release from the Chernobyl incident was much greater than either the Windscale (United Kingdom) or the Three Mile Island (USA) reactor accidents.

As a result of the complicated meteorological situation which persisted after the accident and the relatively long exposure of the reactor to the atmosphere. radioactive materials were deposited over a wide area. In the vicinity of the CNPP. graphite and particles from the destroyed reactor were deposited while finer particles were found at substantial distances from the site. Depending on the prevailing wind direction and precipitation events during the weeks immediately following the accident. volatile products such as iodine-131 (with a half-life of 8 days). tellurium-132 (3.2 days) and long-lived caesium-137 (about 30 years) were spread over thousands of kilometers. In the days immediately following the accident. contaminated air masses moved west. then north-west then north-east. As a result territories. in the Ukraine. Belarus. the European part of the Russian Federation and. to a lesser extent. Scandinavia were heavily contaminated. Subsequently. the wind direction switched to the south then swung to the south-west. bringing the radioactive cloud over the Balkans and the Alps. Several days after the accident. the air masses carrying the radioactive particles had traversed almost all European countries.

Based on a series of radioactivity measurements carried out after the accident. it was determined that volatile fission products (Te-132 and I-131) deposited in close proximity to the accident (i.e. up to a distance of 40 km) amounted to about 5 % of those in the reactor. Similar studies of refractory products amounted to about 1 % while Cs-137 was approximately 2 %.

The total radioactive release which was deposited over the European territory amounted to 4 % of the total radioactivity accumulated in the reactor. of which Cs-137 was about 15 % or $\approx 7.8\text{x}10^{16}$Bq ($\approx 4\text{x}10^{16}$ Bq of this amount was deposited over the former USSR territory).

During the initial period of the accident the largest doses resulted from I-131. After the initial period. especially for the area outside of the evacuation zone. caesium-134 and caesium-137 were the major contributors to the exposure of the population. The external dose from caesium-137 between one and fifty years on differently directed patterns was 75-90 % of the dose of the total sum of radionuclides deposited over the terrain.

After the Chernobyl accident various compilations have been made of the contamination of particular countries or regions in Europe. These compilations have been made for different purposes and consequently there are significant differences in their resolution and quality. To date no attempt had been made to compile a comprehensive presentation of the contamination over the whole territory of Europe. the continent on which by far the majority of released material was deposited. In many cases improved data have since been. and continue to be. obtained through more refined and extensive monitoring. in particular in those areas where greater contamination occured.

Therefore it is opportune to prepare a comprehensive atlas of the radioactive deposition of the whole of the European territory consequent upon the Chernobyl accident. The publication of such an atlas by the tenth anniversary of the accident would have wide public and scientific interest. In addition to the more obvious interest in and use of the factual content of the atlas. it would provide most useful and needed perspective. especially in the former Soviet Union. for judging the significance of the contamination.

2. The Objectives

Since caesium-137 presents a long-term threat for the population of Europe and given its wide dispersion across the continent. the European Commission accepted a proposal on a joint study to compile "The Atlas of caesium contamination of Europe after the Chernobyl accident". The goals of the Atlas are :

- to provide generalized and detailed information on the distribution of caesium-137 in soil over the whole European territory. and separately by countries.
- to provide an estimate of the total amount of caesium-137 deposited across Europe and separately by country as a result of the Chernobyl NPP accident.
- to assess the external gamma dose from the Chernobyl caesium-137 and compare it with that from natural radionuclides in soils and rocks. as well as that from cosmic radiation.
- to familiarize the general public. governmental and municipal bodies with a comprehensive view of the pattern of caesium-137 across the whole of the European continent.

In the future. based on the data analysis made for the Atlas. the problem of the harmonization of the different sampling and measurement methods between different countries can be analyzed in order to improve the quality of the information that could be exchanged. Also. because the measurements on which the Atlas is based have been made sometimes at identical locations but at different times. it should be possible to investigate the behavior of the caesium-137 in a wide variety of European soils and under different climates. Finally. the spatial analysis of these data should bring us new information about the way to improve the sampling structures and the analysis of these data.

3. The Content and the Structure of the Atlas

The Atlas contains about 100 color maps. mostly of A2 format. with accompanying texts. Although other artificial radionuclides were released. it was decided to present only Cs-137 levels. because of the availability of the many measurements performed throughout the European countries and because it is by far the major contributor to dose other than in the very short term following the accident. Since this radionuclide was already deposited due to the atomic bomb tests. the situation before and after the Chernobyl accident can be compared.

The following chapters describe the five sections of the Atlas.

3.1 The Introductory Section

This section deals with:

- an overview of the phenomena of radioactivity for the layman (natural and artificial radioactivity. scientific units) as an explanation of external dose. Additionally this is illustrated with small scale maps of Europe containing information about natural and artificial radioactivity;
  - natural radionuclides including external gamma doses;
  - dose rate from cosmic radiation;
- a brief description of the history of the Chernobyl accident. the temporal dynamics of radionuclide fallout together with their volumes. as well as an assessment of the scale of the catastrophe.

3.2 The Data Section

This is by far out the largest part of the Atlas. Because the radioactive material was deposited in a highly inhomogeneous way. and because the various European countries adopted different sampling strategies resulting in maps with varying sampling densities. the Atlas presents Cs-137 deposition at various scales. All deposition levels are normalised to 10 May 1986. the day at which the radioactive release from the reactor stopped. The scale with isoline values (see Table 1) is based on scientific and administrative considerations: since deposition is purely a physical phenomena. it is normal practice to present it by a consistent logarithmic scale. On the other hand. political and administrative deposition levels which were adopted in the former USSR. i.e. 185. 555 and 1480 kBq/m^2 (resp. 5. 15 and 40 Ci/km^2) have to be considered.

The values chosen for the Caesium deposition isolines depend on the scale map. A summary is presented in Table 1. In order not to overload the European overview map with information. alternative values on this scale are presented. The levels of the highest contamination are only shown on the local maps with deposition values > 1480 kBq/m^2: these areas are relatively small and require a separate scale to show appropriate details.

Table 1: Isoline values of the Cs-137 contamination density by map type

Contamination levels*		**Map type**			
		European	**Country**	**Local**	
kBq/m^2	**Ci/km^2**			**> 40 kBq/m^2**	**>1480 kBq/m^2**
0.4	0.01	+	+		
1	0.027		+		
2	0.054	+	+		
4	0.1		+		
10	0.27	+	+		
20	0.54		+	+	
40	1.08	+	+	+	
100	2.7		+	+	
185	5	+	+	+	
555	15		+	+	
1480	40	+	+	+	+
4000	100				+
10000	270				+

(*) The values shown are preliminary and may be subject to changes with respect to those presented in the Atlas

3.2.1 The Overview Section

This subsection contains radiological information at a European scale presented in the following maps:

- pre Chernobyl caesium-137 deposition (normalised to 10 May 1986) at scale 1:20M (1:20.000.000);
- post Chernobyl caesium-137 deposition (normalised to 10 May 1986) at scale 1:10M;
- caesium-137 external gamma dose.

Figure 1 shows an initial attempt to map caesium-137 deposition in Europe. It is possible to show from the map in Fig. 1 that levels > 20. > 40 and > 1480 kBq/m² were deposited on respectively ≈6 %. ≈2 % and ≈0.03 % of the European territory.

Table 2 shows the areal extent of contamination by caesium-137. for the various deposition intervals. for Europe as a whole. The total amount of caesium-137 deposited in Europe is about 8×10^{16}Bq.

Table 2 : The areal extent of total caesium-137 (bomb fallout + Chernobyl) deposition in Europe

Cs-137 deposition interval (kBq/m²)	Area (x1000 km²)	% of the European territory
>1480	3.1	0.03
555-1480	7.2	0.03
185-555	19	0.2
40-185	211	1.7
20-40	432	3.6
10-20	871	11.6

The map in Fig. 1 also indicates the direction of caesium-137 deposition patterns. The eastern pattern. passing from the Chernobyl NPP across the Russian territory to the Urals and further to Siberia. is clearly seen. In the Ukraine. several southern patterns. interrupted by the Black Sea. are observed with their onward contamination being recorded in Bulgaria. Turkey and Greece. The south-western patterns leave noticeable spots in the Ukrainian Carpathians. later on appearing in the Balkan mountains. The western patterns. passing across the territory between the Ukraine

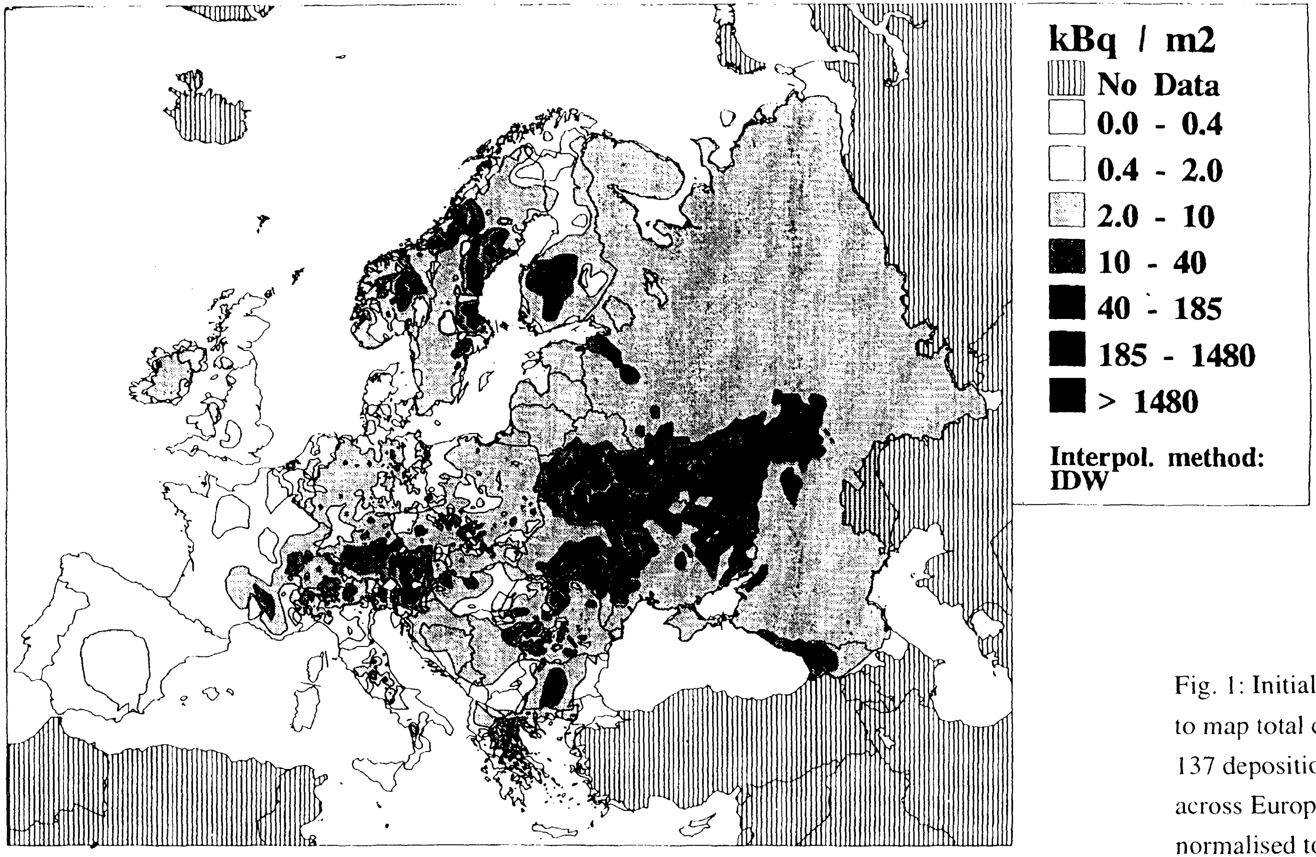

Fig. 1: Initial attempt to map total caesium-137 deposition levels across Europe, normalised to 10 May 1986

and Belarus show a series of northward branches. then turning eastward. This leads to the deposition patterns for Belarus. Poland. Germany. Lithuania. Sweden. Norway. Finland and the Leningrad oblast of Russia. In the Alps. some anomalies with levels above 40 kBq/m^2 are observed.

3.2.2. The Country Map Section

In order to give more geographical and radiological details to reflect the national or regional situation. the country map section includes maps showing the caesium-137 deposition in almost each European country at a medium scale (1:1M - 1:2.5M). together with the sampling/measuring locations.

Table 3 shows the areas of Chernobyl contamination by caesium-137 in European countries as calculated from the map shown in Fig. 1. The results were obtained by multiplying the average deposition value with its corresponding area. These areas were calculated by means of Autocad. Special attention was given to the region around Chernobyl with deposition levels > 1480 kBq/m^2. where the calculation of the corresponding areas was performed on 1:200k maps.

3.2.3 The Section on High Contaminated Zones

This section contains maps that present deposition information for local zones:

- maps with levels above 40 kBq/m^2 : zones of enhanced contamination (i.e. parts of Scandinavia. the Alps. Greece. Rumania. Russia. Belarus and Ukraine) are highlighted by means of large scale maps (1:500k);
- maps with levels above 1480 kBq/m^2 : the highest contaminated zones. i.e. certain areas of Briansk-Mogilev and Chernobyl-Pripiti. are shown on very large scale maps (1:200k). An example for the 60 km zone around Chernobyl can be found in Fig. 2.

The quality of the mapping is determined largely by the density of sampling and measurement points. Hundreds of thousands of measurements were performed in the Ukraine. Belarus. Russia and Sweden by aerogamma surveys conducted at scales of 1:200k and 1:1M at flight altitudes of 50-150 m. About ten thousand soil samples were taken in Central and Western

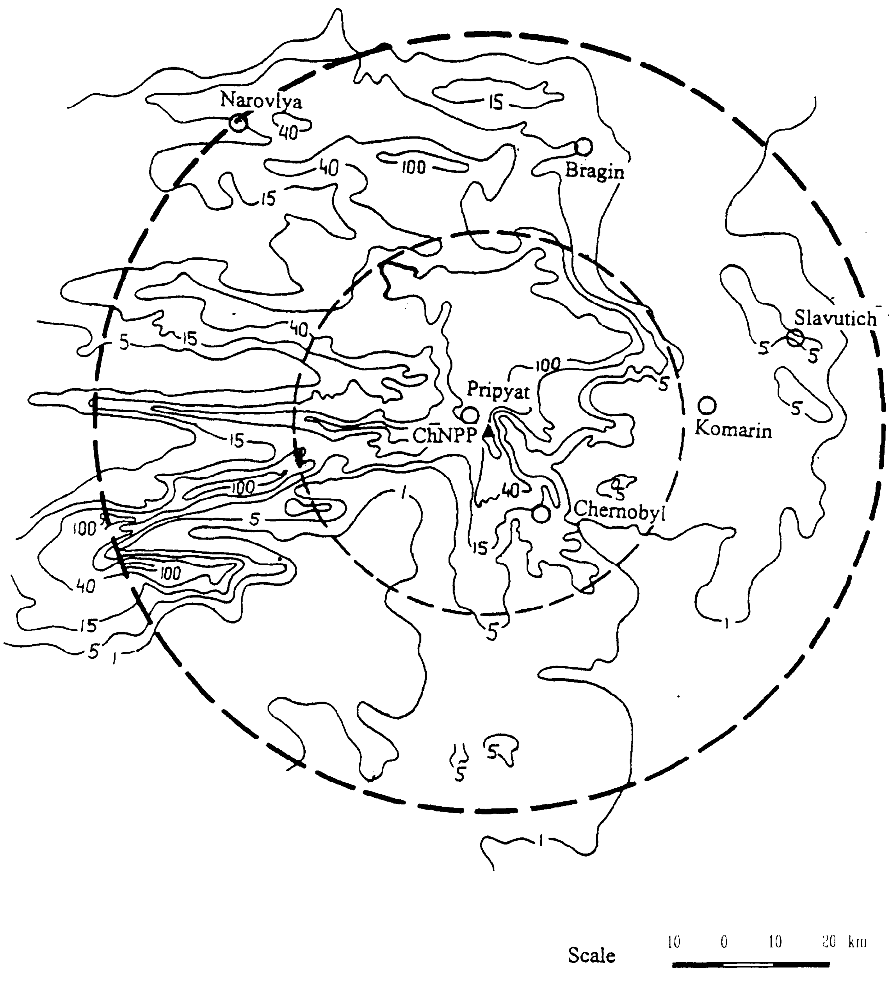

Fig. 2: Sixty km zone map around Chernobyl.
Deposition levels of Caesium-137 (1989) for 185, 555, 1480 and 3700 kBq/m²
(on the map indicated as 5, 15, 40 and 100 Ci/km²)

European countries. The territories of Norway. Finland. UK. Greece. Germany. the Netherlands. Austria. and Switzerland are most completely investigated.

Table 3 : caesium-137 (total) contaminated areas in European countries in thousand km²

Countries	**Area (in 1000 km²) contaminated above specified levels (kBq/m²)**						**% of contamination deposited in Europe**
	10-20	**20-37**	**37-185**	**185-555**	**555-1480**	**> 1480**	**(%)**
Belarus	60	30	29.9	10.2	4.2	2.2	33.5
Russia	300	100	48.8	5.7	2.1	0.3	23.9
Ukraine	150	65	37.2	3.2	0.9	0.6	20
Sweden	37.4	42.6	12.0	-	-	-	4.4
Finland	48.8	37.4	11.5	-	-	-	4.3
Bulgaria	27.5	40.4	4.8	-	-	-	2.8
Austria	27.6	24.7	8.6	-	-	-	2.7
Norway	51.8	13.0	5.2	-	-	-	2.3
Romania	14.2	43.0	-	-	-	-	2.0
Germany	28.2	12.0	-	-	-	-	1.1
Greece	16.6	6.4	1.2	-	-	-	0.8
Slovenia	8.6	8.0	0.3	-	-	-	0.5
Italy	10.9	5.6	0.3	-	-	-	0.5
Moldova	20	0.10	0.06	-	-	-	0.45
Switzerland	5.9	1.9	1.3	-	-	-	0.35
Poland	8.6	1.0	-	-	-	-	0.23
Estonia	4.3	-	-	-	-	-	0.08
Czech Rep.	3.4	0.36	-	-	-	-	0.09
Slovak Rep.	2.1	-	-	-	-	-	0.05
Lithuania	1.2	-	-	-	-	-	0.02

3.3. The reference section

The reference and information section of the Atlas includes supporting maps on population density. soil type. elevation and vegetation for Europe. at scales of 1:15-20M.

3.4. The meteorological section

Deposition patterns depend largely on the wind fields and precipitation patterns. Meteorological data. (daily precipitation and twelve hourly wind fields) during. and for two weeks after. the initial release are presented on 1:40M scale maps.

3.5. Technical appendices

Technical appendices to the Atlas consist of a description of the methods used for soil sampling. remote and laboratory measurements of caesium-137 contamination density together with the procedures used to process the data and compile the maps.

4. The map compilation procedure

One of the important elements of this project is the use of a Geographic Information System (GIS) for the preparation and production of the maps showing the density of caesium-137 deposition across Europe. A GIS is a set of software tools designed to efficiently capture. store. update. manipulate. analyze and display all forms of geographically (or spatially) referenced information. Certain complex spatial operations that would be very difficult. time consuming or impracticable in traditional database or computerized drawing packages are possible only with a GIS (1). Individual datasets can be stored as separate layers which can then be combined with each other as required allowing relationships. trends and patterns to be visualized. The GIS being used in this project is ARC/INFO. version 6.1.. a powerful software developed by ESRI Inc. of California. ARC/INFO includes a relational database interface for integration with commercial database management systems (DBMSs) and a fourth generation macro language for developing customized applications.

The cartographic detail for the European and Country scale maps is provided by information contained in the Digital Chart of the World (DCW). The DCW. produced by the US Defense Mapping Agency (2). is an established dataset of assorted digital cartographic features for the world at a scale of 1:1M. This provided a common base from which all the maps within the Atlas could be produced. Where necessary. the DCW data have been supplemented by additional information from the Lovell Johns 1:5M European Digital Database and the European Commission's Eurostat GISCO-Database. Some digitizing was undertaken in order to add further geographical detail to the larger scale maps (e.g. to add localities in order to improve the visualization of the large scale maps). Substantial editing of the DCW was necessary prior to iets effective use in the Atlas. The information on radioactive deposition from the collaborating laboratories came in the form of point data. geographically located by a latitude and longitude coordinate. This information is stored in the GIS which creates a "point" coverage (or theme) of the sampling locations for the area of interest whereby each point is tagged with a unique identification code. Additional information. such as caesium level and any other attribute information. can then be attached directly to the location through the point's identification code. The deposition sampling points are then transformed to a suitable equal area map projection (in this case the Lambert Azimuth Projection). Once the data have reached this level. cartographic data (e.g. coastline) can be overlaid for checking the locational accuracy of the sampling point coordinates. This primary analysis of the data includes also the analysis of the relation between different layers : e.g. the meteorological parameters and the elevations have been compared to the spatial distribution of the contamination; the display of the cities could explain in certain cases the lower deposition levels in those areas as the heat generated by the cities can be an obstacle to the radioactive deposition.

The next stage in the project requires the generation of maps that display isolines of deposition. This task. depending on the density of the points and the requested degree of resolution of the map. requires a degree of interpolation and generalization of the radiation data. More details on the methods used can be found in the Atlas. In case of densely distributed points. the inverse distance weighted interpolation method has generally been used. In other cases. deeper and more complex investigations were necessary and have required external software like GEOEAS (3). GSLIB (4). VARIOWIN (5) and basic statistical packages. The very general steps of such analysis were finding the populations which were presenting different spatial distribution of the contamination. finding models which would describe these distributions and finally interpolate these data on the base of these models. The result of these interpolations are new point coverages with regular structures and with data generated at the unsampled places. This data can then be contoured and represented with isolines.

5. Conclusions

By collecting more than 500.000 data related to the spatial distribution of caesium-137 in Europe after the Chernobyl NPP accident. the Atlas has clearly shown the importance of such a dataset. For the first time it is possible to provide a comprehensive map of European contamination after the Chernobyl accident. useful for scientific community and also enable layman to better appreciate the extent of the contamination and its relative impact. Since the Atlas was fully electronically prepared the data could be made available on CDROM. useful for further scientific study. Taking into account the radioactive decay for caesium-137. the user of the Atlas can estimate the radioactive levels in the future over all Europe. Further onwards. the data generated by interpolation during the preparation of the Atlas can be used as a reference to which scientists can compare new measurements in order to analyze the contamination in time. and this for different regions and for different conditions. Further to these conclusions. it is hoped that this study can be expanded to other long-lived (e.g. strontium-90. plutonium-238. -239. -240. and americium-241) and short-lived (e.g. I-131) radionuclides.

Acknowledgments

The Atlas was compiled under the Joint Study Project (JSP6) of the CEC/CIS Collaborative Programme on the Consequences of the Chernobyl Accident. implemented into the European Commission's Radiation Protection Research Action.

The authors gratefully acknowledge the invaluable contribution to this project by all the collaborating and participating institutes in terms of the supply of data and in the constructive comments that they have provided. as well as Gregoire Dubois for his important efforts in introducing and applying spatial analysis techniques for the deposition interpolation procedures.

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Résumé

L'atlas résume les résultats des efforts entrepris à travers toute l'Europe dans le but d'établir la contamination superficielle en Césium 137 due à l'accident de Tchernobyl. Il contient quelque cent cartes en couleurs dont les échelles sont comprises entre le deux cent millième et le dix millionième. La contamination y est donnée pour l'ensemble de l'Europe, état par état et pour les zones dont le niveau de contamination dépasse 40 kBq par mètre carré soit environ 2,0% du territoire de Europe d'une part et 1480 kBq/m2, soit environ 0,03%, d'autre part. Quelque 6% du territoire de l'Europe ont subi une contamination de plus de 20kBq/m2. La quantité totale déposée de Césium en Europe est de 8.10^{16} Bq. Elle est distribuée comme suit: Belarus 33,5%, Russie 24%, Ukraine 20%, Suède 4,4%, Finlande 4,3%, Bulgarie 2,8%, Autriche 2,7%, Norvège 2,3%, Roumanie 2,0% et Allemagne 1,1%.

Samenvatting

De atlas geeft een overzicht van diverse onderzoekingen die over heel Europa werden gedaan om het besmettingspeil van de bodem aan Caesium 137 na Tjernobyl te bepalen. Hij omvat een honderdtal kaarten in kleuren met schalen van één tweehonderd duizenste tot één tien miljoenste.Zij geven de besmetting aan voor Europa in zijn geheel binnen de staatsgrenzen en voor de gebieden waarvan de besmetting meer dan 40 kBq/m2 (circa 2% van het Europees grondgebied), en meer dan 1480 kBq/m2 (circa 0,03%).Ongeveer 6% van het Europees grondgebied toonde een besmetting van meer dan 20 kBq/m2. De totale hoeveelheid Cs-137 in Europa is 8.10^{16} Bq als volgt verdeeld : Belarus 33,5%, Rusland 24%, Ukraïne 20%, Zweden 4,4%, Finland 4,3%, Bulgarije 2,8%, Oostenrijk 2,7%, Noorwegen 2,3%, Roemenië 2,0%, Duitsland 1,1%.

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THE NEED FOR STANDARDISATION IN THE ANALYSIS, SAMPLING AND MEASUREMENT OF DEPOSITED RADIONUCLIDES

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Abstract:

Following the Chernobyl accicent in 1986, diverse sampling and measurement methods for radioactivity deposition have been applied by the various European institutes. When compiling these datasets together on the same data platform, in view of preparing the atlas on caesium contamination in Europe, data quality analysis has shown a lack of harmonisation between these various methods. Because of the necessity to dispose of compatible and representative measurements for further analysis, e.g. time series analysis, and the need for better standardisation methods in the event of a future accident with large transboundary release, several suggestions are made of how such harmonisation might be achieved.

Also in view of taking appropriate decisions in case of accidental releases by gaining experience in data standardisation, the variety of the sampling and measurement methods of radioactivity currently used are briefly summarised and the results intercompared.

In order to improve the quality of datasets, GIS, amongst other methods, can be applied as a useful tool to highlight the lack of harmonisation between the various sampling methodologies by indicating the data uncertainty.

1. Introduction

The largest nuclear accident in history took place at the Chernobyl Nuclear Power Plant on the 26th of April 1986 . The radioactive release continued for 10 days and was accompanied by a very complicated, unusual meterological situation. In the initial period of the accident the air masses were transported westward and north-westward. Later onwards, the wind changed direction to the north-east and to the east (throught the north), and from 30 April to the south and south-west. As a result, considerable parts of some republics of the former USSR are highly contaminated, namely Belarus, Ukraine and western regions of the Russian Federation; some lower levels of ground contamination were a characteristic feature for the territories of Moldavia, Latvia, Lithuania and Estonia. The central and western European countries were also contaminated by the Chernobyl fallout. Only Portugal, the western regions of Spain and the northern parts of Scandinavia were characterised by low depostion levels. As one could expect, the highest deposition levels were observed in the highlands of northern, central and southern Europe, i.e. in the Alps, the Carpathians, the Balkans, and certain regions of Scandinavia.

The monitoring of environmental objects on the presence of the Chernobyl radionuclides began in May 1986 over almost all European countries. In this study we consider only soil contamination. The data which are further being discussed were collected from European Institutes in view of the preparation of "the Atlas of Caesium-137 Contamination of Europe after the Chernobyl Accident", which was compiled under the Joint Study Project (JSP6) of the CEC/CIS Collaborative programme on the Consequences of the Chernobyl Accident, implemented into the European Commission's Radiation Protection Research action.

2. Overview of Sampling and Measurement Methods

From 1986 till 1991 all investigations of terrain contamination in the republics of the former USSR which were contaminated resulting the Chernobyl NPP accident were conducted using the same techniques and under the direct methodical leadership of "Goscomhydromet of the former USSR". The central and western European countries followed their own sampling and measuring strategy in case of nuclear accidental situation. As could be expected, there was no common procedure for soil sampling and analysis of the contamination by the long-lived radionuclides. Besides, there was no any agreed way of approach to measuring of the soil contamination by Cs-134 (caesium-134) and Cs-137 (caesium-137) in situ, i.e., using gamma-spectrometers located directly in the field.

Probably initially - and in some countries also at later stages - the aim of the conducted investigations were not to map the results, since less attention was paid to the regularity of the sampling net.

Nevertheless, mainly three methods were used to investigate the terrain contamination:

- Soil sampling where samples of varying area and depth are taken, eventually mixed, treated (removal of stones and dried), followed by semi-conductor gamma-spectrometer measurements in laboratory;
- Field gamma-spectrometry, where a gamma-spectrometer is mounted at a height of 1 m, and the measurements are carried out in-situ;
- Aerial gamma-spectrometry, with a scintillation or semi-conductor gamma-spectrometer mounted under a helicopter (or plane), flying along fixed routes at an altitude of 50-150 m and at a speed of 60 - 150 km per hour.

At the initial stage of the JSP6 Project (The Atlas of caesium-137 contamination of Europe after the Chernobyl accident), it turned out that no common soil sampling and measurement methodology existed for the various institutes. Table 1 shows the above mentioned differences in the ways of approach for thirteen European countries.

The main differences can be summarised as following :

1. In the CIS, soil sampling and analysis was carried out from the first days of the Chernobyl NPP accident, and the initial database has been updated up to now repeated soil sampling, and analysis, and by soil sampling in new regions (previously not covered by the sampling). Two different methods of analysis of the soil contamination by gamma-radiating radionuclides have been used :
    - soil sampling with the following gamma-spectrometry ;
    - air-gamma-spectrum survey.
2. In Western Europe and some countries of central Europe, sampling and analysis are not unified by common procedures, and the techniques used are not intercompared by results of intercalibration. Where aerial gamma surveys were conducted at a high level, no reliable data on comparison of these results with groundbased measurements (soil sampling) were available.
3. At the initial stage of the work at "the Atlas of Caesium-137 Contamination of Europe after the Chernobyl Accident" the differences in the approach to the ways and stages of the maps compilation have already been highlighted. A common methodology has been defined and is here briefly presented : the map compilation of caesium-137 deposition are based on manual and automated plotting of isolines of fixed deposition values (e.g. 1, 5, 15, 40, 100 Ci/km^2)on

the field of values recorded in the dataset. Therefore nearly every single value has been carefully and repeatedly compared with its neighbouring values taking into account :

- orographical conditions of the territory;
- precipitation maps during the initial period;
- wind field information during the radioactive release.

Table 1 . Difference in ways of sampling and measurements methods in some European countries

Country		Number of sampling points	Measured soil depth (cm)	Method of analysis
Albania		1	5	SAL
Bulgaria		35	deposition on plane	SAL
Croatia		4	5 and 10	SAL
Germany	FRG	250	5, 15-20	SAL-FGS
	GDR	500		
Poland		310	10	SAL
Portugal		14	?	SAL
Romania		47	5	SAL
Slovakia		388	3	SAL
Slovenia		44	12	SAL
Sweden		200,000	15-20	AGS
Switzerland		160	15-20	FGS
Turkey		38	1	SAL
United Kingdom		242	5-15	SAL

SAL : Sample analysis in laboratory

FGS : Field gamma-spectrometry (in-situ)

AGS : Aerial gamma-spectrometry

3. On the Standardisation of Sampling and Measurement Methods

As an example of possible ways of standardisation of soil sampling and analysis, as well as of intercomparison of aerial gamma survey data and corresponding ground-based measurements, the way of approach initially used in the former USSR and then in Russia from 1986 up to now, is considered.

3.1. The requirements to the soil sampling (1, 2, 3)

- Samples have must be taken at a depth not less than 5 cm (during the first two years) and further at a depth not less than 10 cm.
- The place of soil sampling must be located not less than 20 m far from roads, trees, buildings and other obstacles in order to obtain representative results.
- The soil sample has to be taken without being disturbed to avoid the mixing of its layers.
- The gamma-dose rate should also be measured in order to estimate the representation of the soil sample. In this case, if we consider D_0 is the gamma-dose rate at the ground level and D_1 is the gamma-dose taken at the height of 1 m, the ratio D_0/D_1 should be equal to 1.5 - 2.0 to obtain accurate measurements.
- Checking the ratio of Cs-134 and Cs-137 is also an efficient way to determine the quality of the Cs-137 measurements. The ratio Cs-134/Cs-137 was equal to 0.56 immediately after Chernobyl accident and decreased with time.
- The measurements of the radioactivity in the soil samples must be carried out using standard gamma-spectrometry methods defined by international calibration exercises.
- These standardised methods should be defined by international calibration exercises.

3.2. The Requirements to the Aerial Gamma Survey

- The aerial gamma survey must be combined with soil sampling - 5 samples on 100 km of aerial survey. Maps on terrain contamination must be compiled based both on data of aerial gamma survey and of soil sampling.
- The requirements for aerial gamma survey for various Cs-137 deposition levels are described in Table 2.

Table 2. The requirements for the scale of survey (4)

Condition of measurement	Scale of survey	Distance between the routes (km)	One measurement on one route (km)
Preliminary territory survey	1:1,000,000	10	2.0
Territory survey for Cs-137 levels from 18.5 till 185 kBq/m²	1:200,000	2	0.4
Territory survey for Cs-137 levels>1480 kBq/m²	1:50,000	0.5	0.1

- Reproducibility of the aerial gamma-spectrometry of Cs-137 by the same way is determined in Table 3.

Table 3. The require to reproducibility of aerial gamma-measurement of Cs-137 at the global level (4 kBq/m²) (4)

Condition of measurement	**Error** (%)
on anchored land	< 10
on arable land	< 10
on forest land	< 10
on arable land with 30 cm of ploughing depth	< 15

- Relative means quare errors (rms) of Cs-137 determined by the comparison with sampling must not exceed 30-40 %. The values of these errors are shown for the real measurements conducted on the territory of Russia in 1992 (See Table 4).

Table 4. The comparison of the aerial gamma-survey and soil sampling data in various regions of Russia (4).

Region	**Deposition interval for Cs-137** (kBq/m²)	**average Cs-137 deposition (kBq/m²)**		**nr. of measure ments**	**systematic error** (kBq/m²)	**mean rms square error (σ)** (kBq/m²)	**errors contents of Cs-137** (%)
		soil sample	**aerial gamma survey**				
Voronesh	3.7-59.2	20	18.9	103	1.1	7.4	37.0
Belgorod	11.1-64.8	28.1	30.0	34	-1.9	8.9	31.6
	14.8-46.2	31.0	24.8	17	6.2	6.7	21.6
Briansk	3.7-273.9	45.5	41.1	72	4.4	10.0	22.0
	370-1116	540.2	570.0	47	-29.8	96.2	17.8
	148-555	227.2	225.0	60	2.2	37.0	16.3
Rostov	3.7-25.5	7.4	6.3	90	1.1	1.8	24.3
Saratov	3.7-55.5	7.8	7.0	159	0.8	0.74	10.5
Tambov	3.7-85.1	17.5	17.4	106	0.1	7.0	40.0
Ulianovsk	9.2-74.0	24.8	32.9	28	-3.2	10.0	40.3

The main requirements to the investigations of the radioactive contamination of the territories by gamma-radiating radionuclides is the necessary to use these methods of soil sampling and aerial gamma-spectral methods in complex. It is aimed to decrease the enormous mount of hand-work. E.g. in some countries of the CIS where aerial gamma survey was not performed 500,000 soil samples had to be analysed during the last ten years.

4. The Use of GIS as a Tool to highlight the Lack of Harmonisation between the various Sampling Methodologies.

4.1. Introduction

In the course of preparing the Caesium contamination atlas, Geographic Information Systems and the semivariogram were found to be a powerful combination for analysing the quality of datasets which come from different sources. This chapter will briefly discuss their combined use. In order to generate maps of contamination, we usually had to estimate the level of the radioactivity at a non-sampled spatial point, when a set of spatial data is available. One approach was to assume the data to be spatially correlated normally it would be assumed that the correlation decreases with distance, so that the closer together two points, the more likely it is that they are similar. Formalising the intuition leads to the specification of a stochastic model for the distribution of the pollutants. To narrow down the possible choice of stochastic models, we apply regionalised variable theory (5), which assumes that the value of any spatial variable can be expressed as the sum of three terms : a deterministic component with a constant mean value (the drift), and two stochastic error components, a spatially correlated random component and a residual term which is spatially uncorrelated (6). Such an approach was adopted by Kanevski (7) in his investigation of data pertaining to the Chernobyl accident.

The semivariogram is used to describe the spatial variability of the data, in order to select a theoretical model to be used for the prediction of the unknown points. It is defined as

$$\hat{\gamma}(\mathbf{h}) = \frac{1}{2N(\mathbf{h})} \sum_{i=1}^{N(\mathbf{h})} \left[z(\mathbf{x}_i) - z(\mathbf{x}_i + \mathbf{h}) \right]^2$$

where z(x) is the value of the radioactivity at point x. The distance and direction between x and x +h, defined by vector h, is termed the lag of the semivariogram. N(h) is the number of pairs of observation separated by the lag.

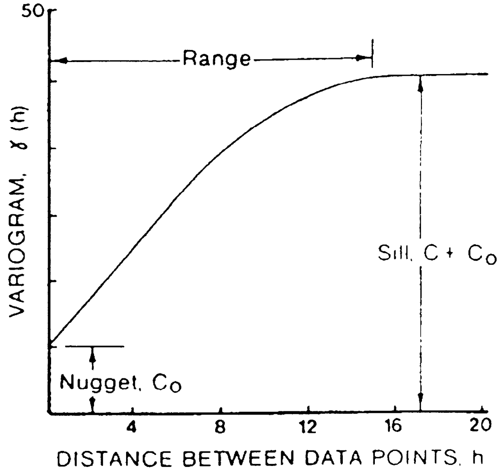

Fig. 1. Example of a spherical semivariogram model (8)

The range is defined as the distance at which the observations become independent. The sill is the maximum value reached at the range and is equal to the variance of independent observations. Comparing the sills between two semivariograms in nearby regions is a good way to indicate the different sample sizes and measurement methods and preferential sampling strategies.

The nugget, which should be zero in theory, represents the stochastic component of the variance at a given scale of observation. It includes the variation due to an irregularity of the studied phenomenon at a very small scale and the variation due to errors in measurements. The ratio of the nugget effect to the sill is often referred to as the realtive nugget effect and reflects in a standardised way the variations from the point of view of the sampling and measurement methods between close or overlapping datasets.

Other statistical tools for examining the spatial correlation structure of a dataset include h-scatterplots, correlograms, madograms, crossvalidation techniques and have been described in (9) and (10).

Prior to define the semivariogram model checking for data quality, clusters, trends and discontinuities is essential (11). The primary analysis has revealed the wide variety between sampling methodologies and measurements methods.

4.2Data Quality Analysis

In view to improve the effectiveness of this primary analysis, a general quality control procedure was defined: the data were sorted depending on their place of origin to obtain data with identical histories. Those with inaccurate positions or with an extravagant Cs-137/Cs-134 relation were deleted. It was expected that this global filtering would result in homogeneous data-sets between which comparisons or relative quality could be made.

4.3. The Variety of Sampling Strategies

Two types of sampling strategies have been encountered during the preparation of the atlas: regular and irregular sampling networks.

Since a regular sampling generally tends not to generate too many problems during primary analysis (if periodicity in the data is not suspected), much more attention has been paid to irregular sampling networks. Random and prederential samplings may lead to spatially clustered data. In general, preferential sampling occured at strategically sites such as cities and power plants; i.e. areas with higher levels of contamination tended to be oversampled. This is easily shown by displaying cartographic information overlaid with indicator maps, by checking duplicated sample locations in data sets and, by displaying Voronoi polygons (12). Therefore, in order to obtain representative distributions of data for further analysis, the different weights of these data had to be taken in consideration.

Discontinuities in these irregular sampling scheme could be explained most of the time with the help of additional information provided by cartographic information : the display of the political borders and geographical barriers (seas, lakes, mountains) often explain the lack of data at certain places. Therefore, depending on the required map resolution of the investigated area, interpolating data including these discontinuities had to be done with extreme care.

Another type of discontinuity we have encountered was due to the different sampling and/or measurement methods. Two neighboured datasets can show at their borders a "jump" in the values of the measured variable.

In previous papers, Burgess, Webster, and McBratney (13) have shown how to make better use of data or sampling resources for isarithmic mapping. Reconnaissance samplings should be made in view to obtain the semivariogram and so to define the appropriate sampling strategy. If the semivariogram is not known, the best strategy would be to sample on a regular grid with an interval determined by the number of observations that can be afforded. Irregular sampling strategies appeared in our analysis to have been generally preferred to regular networks, especially in the western countries.

Another important difference between the sampling strategies we have encountered was the density of samples.

4.4. Sampling Density :

As underlined by Burrough (14), it should always be possible for a given aim "to devise a local optimum for sampling that will give the most precise and the most accurate results for a given expenditure". The different sampling densities show that the objectives were slightly different between the countries. Apparently, a common scenario that followed the Chernobyl accident was for every country to perform global monitoring to obtain a first estimate of the radioactive fallout. Based on these measurements new samplings were organised to define zones of higher contamination. Also, because of the very complex spatial structures of the radioactive trails, higher density samplings were often necessary to describe these zones in order to reduce the probability that some regions of higher contamination would be omitted (15).

In consequence, the quality of the estimated radioactivity at unsampled locations is directly related to the amount of data surrounding these locations. Therefore this lack of harmonisation in the sampling density leads to a loss of data quality in zones of low level contamination when estimations are made.

5. Conclusion

When "The European Atlas of Caesium-137 after the Chernobyl accident" project was carried out, analysis of spatial data made clear the need for further collaboration between the countries. The variety of sampling and measurement methods has been shown, due to the lack of harmonisation between the countries. Common requirements to the application of soil sampling by aerial gamma spectrometry and ground-based gamma spectrometry were stated to define future monitoring of the radioactivity. Also, in order to compile maps on caesium-137 deposition, there is a need for deeper analysis of the very local parameters affecting radioactive fallout if complex interpolation methods are required. Finally, after sharing experiences between the members of the CEC and the CIS involved in the JSP6 project, considerable progress has been achieved in developing common methodologies in the fields of radioecology and spatial data analysis. In the future, an optimal monitoring network based on this experience should certainly improve decision making by indicating general contamination patterns based on harmonised measurements, by reducing sampling cost and by conducting further investigations for the contamination assessment at very local scales.

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Résumé

Après l'accident de Tchernobyl en 1986 les laboratoires européens ont utilisé des méthodes différentes de prélèvement et d'analyse pour déterminer la contamination. La compilation des données pour une même plateforme en vue de préparer l'atlas et leur analyse a montré un manque d'harmonisation. Cette harmonisation est nécessaire dans le cas d'un accident à venir dépassant les frontières des états,comme pour l'étude des données étalées dans le temps.Plusieurs suggestions sont faites sur la façon de procéder à cette harmonisation. Pour pouvoir prendre les décisions appropriées en cas d'accident en accumulant de l'expérience en matière de standardisation, il est procédé à une courte revue des méthodes de mesure et de prélèvement de la radioactivité et à leur intercomparaison.L'amélioration des banques de données peut être réalisée, parmi d'autre méthodes par l'utilisation des systèmes d'information géographique(GIS) qui soulignent le manque d'harmonisation des méthodologies d'échantillonnage à travers l'incertitude liée aux données.

Samenvatting

Na Tjernobyl werden in de europese laboratoria een aantal bemonsterings- en meetmethoden gebruikt om de afgezette radioactiviteit te bepalen.De compilatie, op eenzelfde platform, van de gegevens om de atlas van de Caesium 137 besmetting klaar te maken heeft aangetoond dat er een gebrek aan harmonisatie van de methoden bestond. De behoefte aan verbetering blijft bestaan in het geval van ongelukken met grensoverschrijdende gevolgen en om de evaluatie van datasets die lange perioden bestrijken mogelijk te maken. Om de harmonisatie tot stand te brengen worden een aantal voorstellen gedaan. De gebruikte methoden worden kort samengevat en vergeleken met het oog op het nemen van geschikte maatregelen bij het accidenteel ontwijken van radioactiviteit die voortvloeien uit de ervaring met het standardizeren van gegevens.

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Impact of the Chernobyl accident on the environment and management of contaminated areas

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Abstract

The Chernobyl accident affected the environment in different ways and to a different extent, depending on the levels of radiation exposure and radioactivity deposition. Deterministic radiological effects were only observable in areas of high contamination close to the nuclear power plant (NPP). Lethal effects were observed in the first year on pine trees and forest soil microfauna in the immediate vicinity of the NPP. Other non-lethal effects were observed at greater distance, including morphological, physiological and biochemical changes in organs, tissues and at the cellular level. Genetic effects were also identified in plants and animals living in the 30 km zone and other highly contaminated areas. Depending on the intensity of the deposit, populations were evacuated, restrictions were established on the use of environmental materials (e.g. firewood) and the consumption of a number of foodstuffs, and countermeasures were applied to reduce radionuclide concentrations in food products. Indirect consequences of the accident on plant and animal communities, resulting from the evacuation of certain regions, abandoning of farming or application of countermeasures, are already observed or can be expected in the future.

INTRODUCTION

On April 26, 1986, the Chernobyl reactor n° 4 suffered a major accident which destroyed the reactor core, blew of the roof of the reactor building and scattered around fragments of the core. The initial explosion injected radioactive debris and aerosols into the atmosphere up to a height of 1 km [Margoulis, 1988; BNIF, 1995]. The emission which took place on the first day of the accident contributed, however, only some 25% of the total radioactivity release; the major part occurred as a protracted process over a nine-day period [Belyayev *et al.*, 1991]. After the explosion, the emission rate of radionuclides in gaseous and aerosol forms, caused by the graphite combustion and the high temperatures developed in the fuel, was first decreased as a result of the 5,000 tons of neutron-absorbing, heat-removing and filtration materials (i.e. boron carbide, dolomite, sand, clay and lead) dropped from helicopters into the reactor well. From

May 2, however, the emission rate started to increase again and kept on rising steadily until May 5 before it suddenly dropped by 2 to 3 orders of magnitude on May 6 [Belyayev *et al.*, 1991; Devell *et al.*, 1995]. It is now understood that the cause of this rapid decline in temperature was due to molten fuel flowing out of the base of the reactor (which had been pushed down by the force of the explosion) and mixing with sand (which formed part of the reactor shield) to form a glass-like substance in chambers below the reactor.

At the time of the accident, the surface winds at Chernobyl were weak and variable in direction, but at 700 to 1500 m altitude, 5 to 10 $m.s^{-1}$ winds which were blowing to the North-Northwest, transported the radioactive plume generated by the explosion towards Scandinavia, which was the first affected among the European countries. There, a weak frontal system led to some areas of high wet deposition. Subsequently the plume moved South, across Poland and central Europe, in a wedge shaped formation to the South of a ridge of high pressure which intruded from the Atlantic. Another plume went East across Russia before its trajectory turned Westward again across Europe. As a centre of high pressure moved across the North coast of Europe, this plume was deviated Northwards, over the East of France, Benelux and United Kingdom [ApSimon *et al.*, 1991]. This cloud reached Belgium on May 2 [Deworm, 1987]. During the early days of May, the plume trajectories from Chernobyl oriented Southwards and passed over Greece before turning Northwards to give further enhanced deposition over Scandinavian countries [ApSimon *et al.*, 1991].

The Chernobyl accident resulted in an uneven pattern of contamination in the former Soviet Union and all over Europe. Since the atmospheric release of radioactivity from the damaged reactor occurred over 9 days, the pattern of the contamination -in terms of deposition levels and radionuclide composition- in the affected territories is rather complex, reflecting simultaneous variations in emission height and rates, and wind characteristics. Local meteorological conditions (especially rainfall) during the passage of the radioactive cloud had a major effect on contamination intensity along the plume trajectories, defining heavily contaminated areas (hot spots). Another important, and unique, aspect of the Chernobyl accident was the release and deposition (mainly in regions close to the reactor) of “hot particles” of which the fate, according to their nature, deeply influenced the medium term impact of the accident in the areas submitted to this type of deposit.

IMPACT IN THE FORMER SOVIET UNION

The Chernobyl region:

The Chernobyl nuclear power plant (NPP) is located in the North of the Republic of Ukraine, at a short distance (some 10 km) from the border with the Republic of Belarus. It is situated at a distance of about 120 km North from Kiev (Fig. 1). The region of concern is a flat plain with minor slopes not exceeding 200 m above sea level. It is characterised by a moderate continental climate with hot summers and rather mild winters; annual precipitation ranges from 500 to 650 mm, of which about 2/3 is deposited during the warm seasons.

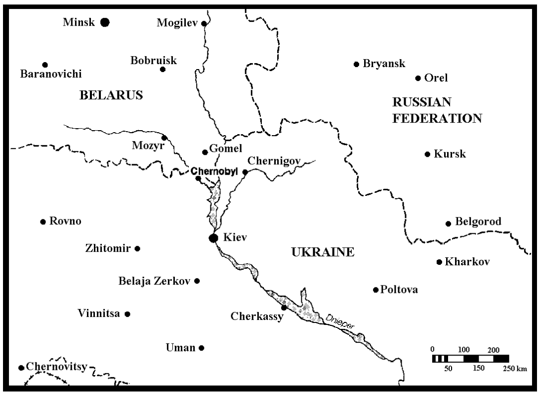

Fig. 1: Map of the regions of Belarus, Russia and Ukraine most affected by the Chernobyl accident.

The topsoil in the South part of Belarus consists mainly of soddy-podzols and swampy peat soils; in the Southeast, they consist of soddy-podzol, clay and sandy-clay soils. The “Polesse” or woody area (South of the Gomel Oblast and North from the Kiev and Zhitomir Oblasts) is principally characterised by swampy sandy and clayey-sandy soddy-podzols and peat-bogs. Light textured soils occupy 58% of the total area. All soddy-podzol soils exhibit a low natural fertility, low pH’s (between 4 and 5.5) and are characterised by low nutrient content (namely potassium, phosphorus and magnesium) and a low sorption capacity. Seventy percent of the territory is occupied by forests. Conifers (pine trees) represent the most common species (63%), the remainder being deciduous trees (oak, white beech, birch and alder). Owing to the characteristics of the environment, agricultural activities are mainly represented by dairy farming and meat production. About one fourth of the total land area is devoted to agriculture, half of it being used for the production of natural fodder (natural meadows). Cultivated lands are principally used for cereals (about 50%), fodder crops (35 to 40%), potatoes (8%) and long-staple flax (5%).

In the Ukrainian Polesse, affected by the Southern “trace”, there begins an area of forest steppe of which the top soil consists primarily of podzolised black earth (chernozem) and grey/light grey soils on forest litter. The main tree species in the Ukrainian Polesse are pines, with some birch and oaks; the forest steppe is characterised by oaks, white beeches and lime-trees.

According to Alexakhin [1993], the total area of the former USSR territory contaminated above 37 kBq ^{137}Cs.m^{-2} amount to 13,107,000 ha, of which 1,026,000 ha exhibit contamination levels above 555 kBq ^{137}Cs.m^{-2} and 310,000 ha were above 1.48 MBq ^{137}Cs.m^{-2} (Table I).

Region	^{137}Cs deposition level (kBq.m^{-2})				
	37-185	185-555	555-1,480	> 1,480	> 37
Russia	39,280	5,450	2,130	310	47,170
Belarus	29,920	10,170	4,210	2,150	46,450
Ukraine	34,000	1,990	820	640	37,450
Total former USSR	103,200	17,610	7,160	3,100	131,070

Table I: Areas of land (km^2) contaminated by ^{137}Cs due to the Chernobyl accident (1991 data). [From Alexakhin, 1993].

An exclusion zone of 10 km around the Chernobyl nuclear plant was created on 27 April, and was extended on 2 May to a radius of 30 km. The exclusion zone was based on specific criteria involving either the total level of contamination with ^{137}Cs, or ^{90}Sr, or ^{239,240}Pu. It therefore has a rather complex shape reflecting different patterns of deposition at different times after the accident. The town of Pripyat (about 49,000 inhabitants) was completely evacuated in three hours on 27 April. On 5 and 6 May, 73 villages in the 30 km exclusion zone were evacuated, raising the number of relocated people to about 135,000. Most domestic animals and poultry were abandoned, but farmers brought their cattle (86,000 head were moved in May 1986), pigs, sheep and horses with them. Unfortunately this proved to be a serious mistake since the subsequent lack of fodder for evacuated animals meant that they had to be slaughtered. This, in turn, lead to a stockpile of meat with significant radiocaesium contamination. When, in June, it became evident that hot spots existed outside the 30 km exclusion zone (in the Gomel, Briansk and Mogilev regions), 113 more settlements (100,000 to 150,000 ha of agricultural land) located in Belarus and Ukraine were also abandoned [Medvedev, 1990]. Sixty percent of the territories with contamination above 555 kBq ^{137}Cs.m^{-2} is located outside of the exclusion zone.

In the following years, evacuations of population at risk were carried on. A USSR law adopted in May 1991 stated the contamination limits for the territories to be evacuated and the compensation to be paid to relocated people:

- in zones where ^{137}Cs level exceeds over 1,480 kBq.m^{-2} (33,000 inhabitants), evacuation was compulsory; the land was completely restricted from any agricultural use; instead, it was made over to GOSLESFOND (Governmental Forest Fund) to constitute an ecological and radioecological natural reservation.
- in zones where the ^{137}Cs contamination level comprised between 555 and 1,480 kBq.m^{-2} (210,000 inhabitants), evacuation was mandatory if the annual dose equivalent was expected to exceed 5 mSv and on a voluntary base otherwise; all inhabitants living in these zones had the right to compensation. In these areas of “strict control”, restrictions on consumption of locally produced foodstuffs were set up and are still in application: the inhabitants, which were forced to give up their dairy cattle, were recommended to exclude from their diet all foodstuffs grown on personal plots as well as products collected in forests

(such as mushrooms and wild berries). Clean food supplies from less contaminated areas were organised.

- in regions where the ^{137}Cs contamination level was less than 555 kBq.m^{-2} but higher than 185 kBq.m^{-2} (550,000 inhabitants), the right of inhabitants to evacuation and to compensation was acknowledged as far as the annual dose equivalent was expected to exceed 1 mSv.

Impact on the vegetation

In the first weeks after the accident, lethal doses were reached for some radiosensitive organisms, namely coniferous trees, representatives of the soil fauna and some small mammals, within the 10 km zone around the reactor. By autumn 1986, dose rates had decreased by a factor of 100 due to the physical decay of short-lived radionuclides, allowing the ecosystems to progressively recover.

One of the direct effects of radiation on plants, which appeared in areas close to the nuclear plant affected by high radioactive deposition, was the serious damage caused to pine plantations and the destruction of 580 ha of coniferous forests exposed to the plume formed by the initial explosion (estimated absorbed dose: 80-100 Gy). The lethal effects of irradiation on pine trees became visible towards the end of the summer 1986, whereas broad-leaved species (mainly birches, aspens, alders and oaks) were less affected and showed only partial lesion of their crowns. This is the consequence of a) a higher radio-sensitivity of coniferous trees (ten times higher compared to that of deciduous trees), b) the fact that the deposition occurred in the early spring, when buds were opening, and c) higher interception on evergreen trees compared to that on deciduous trees (reduced leaf biomass at the time of the accident). There were no immediate visible changes in the herbaceous vegetation in this zone.

From 1986 to 1987, in an area of 3,000 ha where trees were exposed to sub-lethal doses (exceeding 8-10 Gy), 25 to 40% of pine trees (mainly aged between 10 and 12 y) died while 90 to 95% of the young individuals showed necroses in buds and young sprouts, a partial drying-out of their crown and a near complete interruption of their growth and reproductive functions. Morphological changes, such as twisted and thickened needles and bare branches with partially preserved needles, were observed at sites with medium exposure (3-4 Gy). In most cases, when the young branches died, lateral replacement buds appeared on the second-year branches. Considering the reproductive organs of pine trees, the observations showed that male organs are more radio-sensitive than are female organs. Radiation effects were also observed at the cellular level in needles growing on abnormal branches: damage to the organelle membrane system (e.g. the lamellar system in chloroplasts) was noted, leading to the destruction of the chlorophyll-protein-lipid complex. In 1986-1987, meristems, flowers and seeds from trees and natural grassland vegetation were collected to investigate the increase in mutation frequency. The results showed a statistically-significant effect (obvious mutations with an increased frequency of chromosome abnormalities) in areas where the dose rates exceeded 10 mR.h^{-1} in May 1986 [Kirchmann, 1990].

In both the zone of total destruction of the forest and that of sub-lethal dose, indirect modifications of the ecosystem were observed. These were associated with factors such as an increase in light intensity at the ground level and an increase in the height of the water table and the associated soil moisture content. The decomposition of contaminated needles together with increased soil moisture creates conditions favourable to the leaching of radionuclides and nutrients in the soil. In affected forests, fallen trees have not been replaced by the growth of young trees, and there has been an accumulation of dead wood resulting in an increased fire risk and vermin. Production of timber remains prohibited in the most affected areas. The total loss of wood from fire, storms and degrading soil conditions (increased soil humidity) substantially exceeds that from the direct effect of radiation.

In most of the exclusion zone however (out of the hot spots), no effects directly attributable to radiation were observed.

In the severely affected zones, trees are presently recovering. But morphological and physiological modifications can be recognised (recovering from the top of the tree with plumes of needles at the top of bare trunks, growth inhibition, alterations of leaf or needle morphology, pollen sterility). Remote genetic aberrations are also observed in pine saplings issued from seeds collected in 1986-87 [Arkhipov *et al*., 1996] as well as in cereals (e.g. winter wheat, rye, barley) growing in the exclusion zone.

Impact on animals

As is the case for vegetation, a number of alterations have been registered in the fauna at the molecular and cellular levels, as well as disruptions in physiological and biochemical processes. However, profound pathological modifications and lethality were only observed among particularly radio-sensitive species and in animal groups whose habitat was exposed to very elevated radiation doses.

The radioactive fallout had a marked effect on the populations of soil-dwelling fauna in a zone of 3 km around the nuclear plant (Fig. 2). Fauna living in the soil, on account of the shielding by the soil, was less affected than litter fauna. The intensity of these effects decreased with the distance from the NPP. In addition to the high radioactive contamination of litter and surface soil in forests, the fact that the accident occurred in the middle of the breeding and moulting season tended to maximise the radiological consequences on the soil fauna. 30 Gy dose produced no direct effect on adult invertebrate populations living in the soil and litter, but badly affected eggs and juvenile forms, leading to a decrease in population size. Populations of numerous microfauna groups declined almost 30 times in 1986 upon exposure to 5-7 $mR.h^{-1}$. The fauna in farmland soils and in deep layers of forest soils was less affected and declined only 2-3 times. Re-colonisation of contaminated forest soils started after the period of ^{131}I decay and took 2-3 years to restore population sizes and dynamics similar to those in control areas. However, the species diversity (number of species represented) remained two times lower than that of control zones [Krivolutsky & Tourchaninova, 1994].

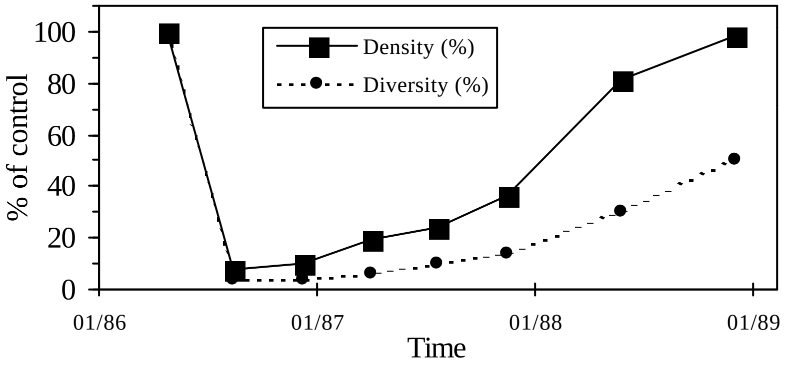

Fig. 2: Dynamic of soil fauna populations in terms of density and diversity at plots situated at 3 km from Chernobyl NPP [from Krivolutsky & Tourchaninova, 1994].

Vertebrates, and especially mammals, are the most sensitive animals to radiation. However, there is no proof of a mass death of vertebrates in the area surrounding the NPP during the weeks following the accident.

Rodent populations on the same plots did not seem to be affected in terms of population size and dynamics. However, alteration of female fertility, higher embryonic mortality, and somatic and genetic mutation were recorded [Taskaev *et al.* cited by Krivolutsky & Tourchaninova, 1994].

To a large extent, livestock evacuation from the contaminated areas paralleled the displacement measures taken to safeguard man and was also staggered over several months. The absorbed dose for the total body and specific tissues was assessed for different groups of cattle moved to radiologically “cleaner” areas at different times after the accident (Fig. 3). Clinical observations carried out in November 1986 and April 1987 on cattle evacuated soon after the accident (within the first 9 days) or animals from farms located next to, but outside, the exclusion zone showed no pathological damage typical of that caused by radiation. Animals evacuated later, and having grazed freely for 90 days on grassland where the contamination level in forage on 1 May 1986 was estimated to range from 40 to 60 MBq $^{137}Cs.kg^{-1}$, exhibited symptoms such as myxoedemas, lengthened hair (especially at the base of the neck), skin thickening at the nape and, in some cases, signs of exophtalmia, snoring respiration and a drop in body temperature to 34-35°C. In this group, several animals with hypothyroidism, atrophy or near total necrosis of the thyroid gland and signs of radiation-induced myxoedemas died.

No essential morphological changes were observed in the blood of cattle which were outside the 30 km zone and among those evacuated in the early phase. However, among those which spent three months on pastures near the Chernobyl site, clinical signs of myxoedemas were accompanied by changes in blood cell morphology (increased number of bi- and tri-nucleated cells, nuclear pycnosis, rhexis and amitoses) [Kirchmann, 1990].

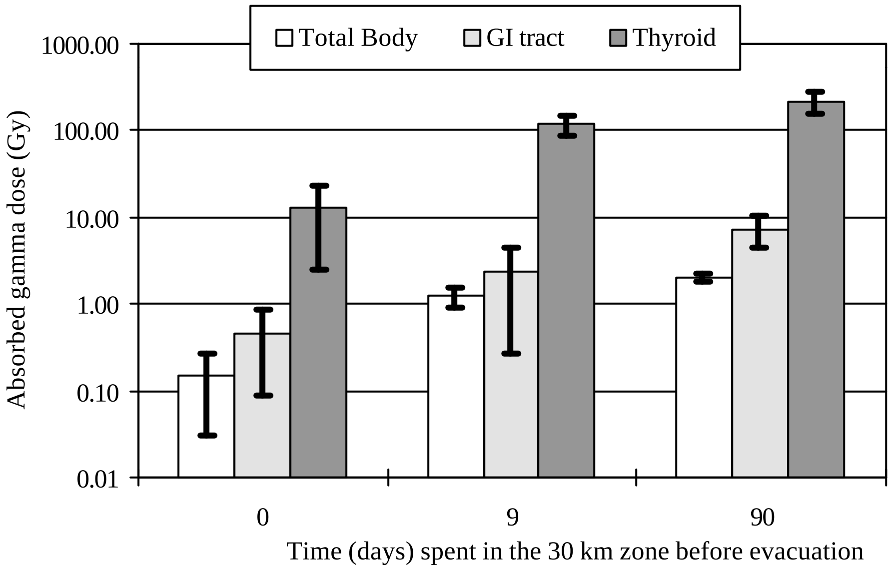

Fig. 3: Absorbed gamma dose (Gy) in 90 days estimated for three cattle groups depending on the time they spent in the 30 km zone.

In cattle from farms located next to the zone and among animals evacuated to these areas, there was a factor 1.5 to 2.5 increase in blood cholesterol concentration during the first three months following the accident. This increase was also observed in sheep, horses and cows which had grazed in the contaminated zone over a long period. A high stimulation of adenyl cyclase in the platelets and lymphocytes of sheep, horses and horned animals was noted, together with a significant drop (about 30%) in the nucleic acid content of the leukocytes of sheep which had spent 8 months in areas of high radiation. The activity of glycolysis enzymes in these animals was about half that of clinically healthy animals. A general tendency in examined animals was to return to normal biochemical levels after complete cessation of radionuclide ingestion; it is therefore possible that the changes mentioned above are adaptive reactions of the body to chronic exposure to ionising radiation [Kirchmann, 1990]. Pathological changes, including effects on the reproductive function, were also reported by Arkhipov *et al.* [1996] in animals kept for a long time in the 10 km zone.

Occasionally, mutations in animals born after the accident were reported: an increased frequency of abnormalities in new-born piglets and calves has been reported in districts with high deposition levels (up to 3 $MBq.m^{-2}$) [Medvedev, 1990]. However, systematic studies do not support the assertion of a higher frequency of abnormalities as a direct consequence of radioactivity released from Chernobyl.

Changes in economic activity within the 30 km exclusion zone sharply affected the anthropic influence upon the ecosystem. The compulsory depopulation of the zone and the end, or sharp reduction, of human activities like hunting, poaching and farming created favourable conditions for game animals, especially since unharvested agricultural crops provided an abundant forage supply for herbivorous animals. Extermination of deserted dogs and cats minimised their possible pressure on rodents population. Hence, a new ecological equilibrium tended to be reached with the re-development of populations of previously endangered wild species. Populations of game animals significantly increased: moderately for elk and roe deer but sharply for the very prolific wild boar (8-10 times). The roe deer population growth is also limited by wolves whose population in the zone sharply increased (it has now reached 5-7 packs). As a consequence of the increased pressure put on their habitats by such an exploding multiplication of wild ruminants, a deterioration of the forest can be expected because of the grazing of saplings and the barking of trees, especially in winter. Also the intensive turning over of the soil by wild pigs can influence soil stability and, hence, its erosion susceptibility.

The fox population density increased until 1989 and than reduced, probably due to the stabilisation of rodent populations. Since 1993, the growth of elk and wild boar populations has tended to diminish (decrease in fertility but higher mortality due to epizooty can be expected) [Gaichenko *et al.*, 1994].

Impact on aquatic systems

Several aquatic systems are located in the 30 km exclusion zone: the Northern part of the Kiev reservoir, the Pripyat river and the 22 km^2 cooling pond of the NPP, connected to, but at a higher level than, the Pripyat river. Cooling ponds of RBMK reactors provide cooling waters but also act as a decontamination reservoir under normal operation since most radionuclides accumulate in the bottom sediments. The Chernobyl cooling pond was heavily contaminated by the accident, not only from fallout, but also by water poured onto the reactor by the emergency cooling systems (during some 12 h at a rate of 200-300 t.h^{-1}) and by the fire brigade. About 80 km of protective dams and underground walls were built to prevent discharges into open waters of the Pripyat river and Kiev reservoir. In May 1986, contamination of the bottom sediments amounted to 37 MBq.kg^{-1}, five orders of magnitude higher than the contamination of water. The daily radiation dose to fish species living and breeding in the undergrowth of aquatic vegetation was estimated to be 100-200 rad [USSR, 1986]. In October 1988, the ^{137}Cs concentration in the 0-5 cm top layer of the bottom sediment still amounted to 0.2 to 0.35 MBq.kg^{-1}. In the Kiev reservoir, the contamination level of the sediments was much lower and amounted in 1987 to 2,200 and 600 kBq.kg^{-1} for ^{137}Cs and ^{90}Sr respectively.

In the segment of the Pripyat river and lakes located in the 30 km zone, the maximum ^{137}Cs content in fish in 1986 was found in perch and amounted to 31.5 kBq.kg^{-1}. Radiocaesium concentrations reported in 1993 in perch of the Smerzhov lake were 11 kBq.kg^{-1}, one order of magnitude higher than for the same species in the Pripyat river. Compared with perch from the Pripyat river, those from the Smerzhov lake had a lower fecundity due to disturbances in the development of sexual cells (namely oocytes); the overall growth rate in weight and size of these fish from both ecosystems were similar [Pikulik & Plenin, 1996].

Radioactivity levels in food products and the effects of countermeasures

During the first days and weeks after the accident, iodine radioisotopes (through inhalation and ingestion of contaminated foodstuffs, primarily milk) were the principal source of internal exposure of the population in the contaminated territories. Progressively, food products contamination by radiocaesium, and to a lesser extent radiostrontium, became the predominant contributors to the internal exposure.

In the first year, the contamination level in plant products was essentially caused by direct deposition on plant foliage when present, subsequent foliar absorption and translocation to organs developed later, such as cereal grains. In the following years, root uptake became the major route for transfer of radionuclides into food chains. The availability of radionuclides for plant uptake depended strongly on the soil type and the physico-chemical properties of the fallout radionuclides (deposited as condensed forms or associated with fuel particles), and also changed with time as a result of natural processes in soil (ageing, weathering of fuel particles).

The highest transfers of radiocaesium were observed on organic soils (peat, forest and meadow soils); in these soils, poor in mineral (namely clay) fractions, radiocaesium availability is not much affected by ageing processes and tends to remain high. In mineral soils (podzols, chernozem), the presence of clay minerals immobilises radiocaesium on specific, hardly-reversible binding sites, and decreases its solubility in the soil solution and its availability for plant roots. The fraction of radiocaesium bound to the mineral phase increases with time (ageing) until a quasi-equilibrium is reached. From 1987 to 1990, neglecting 1986 which was mainly influenced by direct deposition and/or a potentially high contribution of resuspension, the availability of ^{137}Cs in mineral soils of the Gomel area decreased on average by a factor 5, ranging from 3 to 9 (Fig. 4).

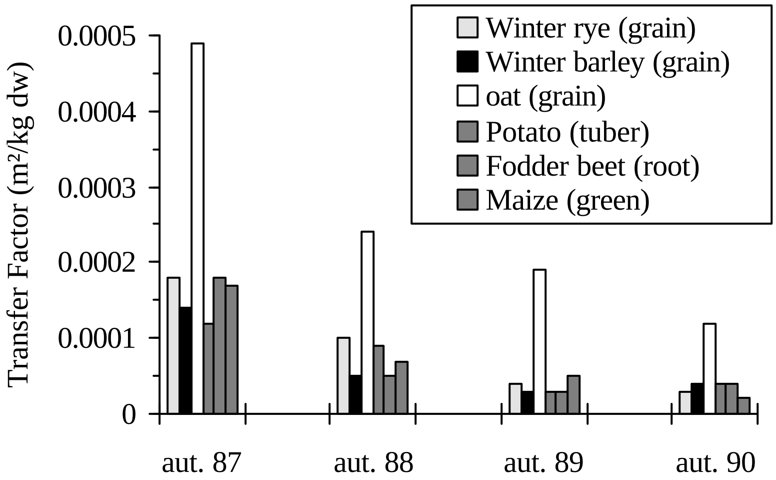

Fig. 4: Changes with time of the transfer of ^{137}Cs to various agricultural products grown on mineral soils in the Gomel area between 1987 and 1990 [from Rauret & Firsakova, 1996].

In contrast with radiocaesium, the bio-availability of radiostrontium can be approximated from the soil cation exchange capacity; therefore it is better taken up by plants on mineral soils then on organic ones. On the other hand, due to its refractory character, radiostrontium was primarily associated with fuel fragments and its initial availability was rather poor compared to what could be expected for ionic forms deposited on the same soil types. Weathering processes release ^{90}Sr from its fuel matrix and progressively increase its bio-availability (Fig. 5); therefore ^{90}Sr is of greater concern with time in areas affected by high radiostrontium contamination.

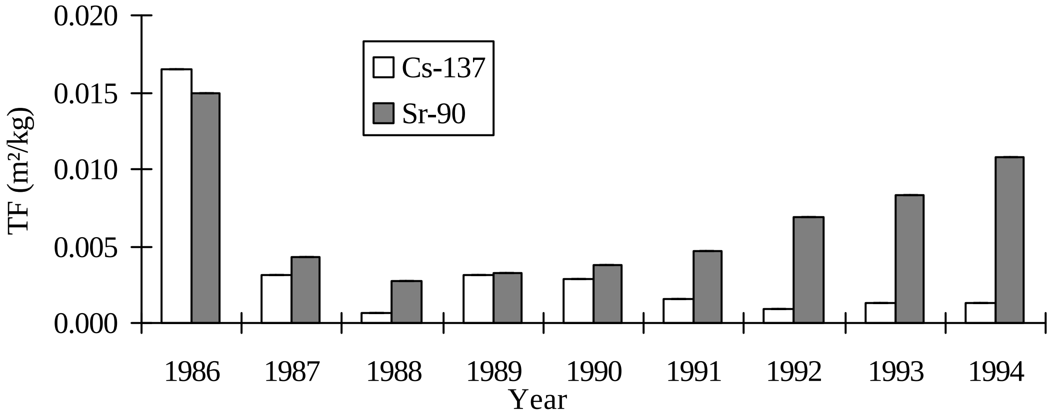

Fig. 5: Changes with time of the transfer of ^{90}Sr and ^{137}Cs to grass from meadows on podzol soils in the 30 km zone between 1986 and 1994 [from Rauret & Firsakova, 1996].

In order to limit as much as possible the quantities of agricultural products contaminated with radionuclides above defined reference levels, various countermeasures were introduced into the farming practice. The principal remedial actions for decreasing radionuclide content in foodstuffs were [Alexakhin, 1993]:

- ploughing, to dilute the highly contaminated surface layer in the plough layer
- liming acidic soils
- application of organic and mineral fertilisers (especially potash and phosphates)
- application of alumino-silicates (clay, zeolites, micas) on soils poor in clay minerals to increase the soil sorption capacity
- selection of crops with lower accumulation potential (primarily for ^{137}Cs)
- radical amelioration of natural meadows (ploughing, re-seeding and fertilising)
- organisation of a rational feeding of farm animals (dilution of contaminated forage with non-contaminated ones and concentrates, providing uncontaminated feeds in the period before slaughter to allow biological decorporation)
- use of feed additives (Prussian blue compounds, alumino-silicates) to reduce the gastro-intestinal absorption of radionuclides, especially radiocaesium)
- processing agricultural products into less contaminated derivates (milk into cheese and butter)

In Russia, Belarus, Ukraine and in parts of Scandinavia, the use of caesium binders such as alumino-silicates or Prussian blue compounds as feed additives has greatly contributed to ensuring that radiocaesium concentrations in milk and meat produced from cattle in semi-natural and agricultural systems comply with the intervention levels [Strand *et al.*, 1990; Firsakova, 1993; Prister *et al.*, 1993].

As a result of the application of countermeasures, combined with natural ageing effects, the quantities of agricultural products above ^{137}Cs reference levels has been constantly decreased since 1986 (fig. 6).

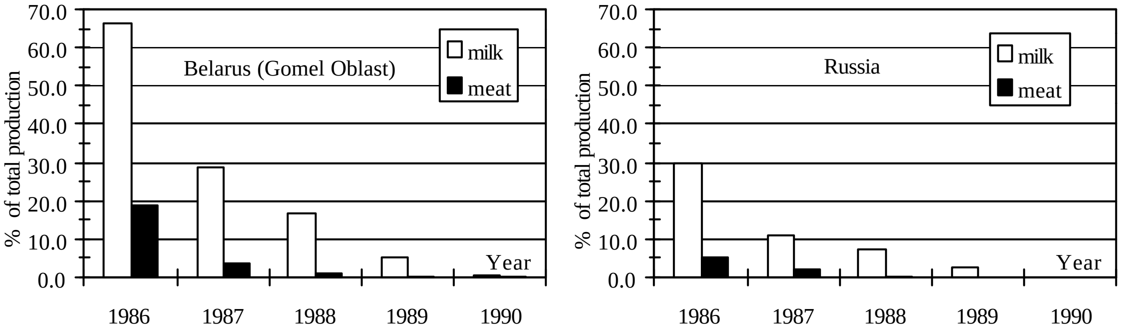

Fig. 6: Fraction of the total milk and meat production above reference levels in Belarus (Gomel Oblast) [Grebenchikova *et al.*, 1992] and Russia [Alexakhin, 1993].

Unfortunately, the present decline in economic condition in the "New Independent States" (NIS) prevents continued funding for the purchase of mineral fertilisers and other reclamation measures on contaminated lands. This has led to an increase in radionuclide concentrations in agricultural products in the Novozybkov District (Briansk Oblast) where cuts in the countermeasures budget have contributed to a 50% increase in the contamination levels in hay and root crops between 1992 and 1994.

Restrictions on local food consumption were imposed in areas of "strict control" (contamination exceeding 555 kBq.m^{-2}) and clean food supply from outside was foreseen. However, the quality of the products provided (namely milk) was sometimes markedly lower than that of the local products and, moreover, some foodstuffs could not be provided to the requirement of the populations living in these zones (mushrooms, fresh fruits and vegetables). Moreover, products from outside the "strict control" zone are more expensive than are local ones and not affordable by poor rural families. This situation incited people to produce their own supply (by rearing private cows grazing in meadows and forests, breeding pigs, sheep, goats and poultry, cultivating private gardens and fields, and collecting mushrooms and berries from forests). At these private farms, the application of countermeasures is more limited and less efficient than in collective farms and the foodstuffs produced therefore exhibit higher contamination levels than do products from collective farms. In Belarus in subsidiary small-holdings, 10% of the milk still exceeds the control limits level for radiocaesium.

Moreover, a significant problem exists, in Ukraine and other Republics, for private farms established on organic (peat) soils which produce milk at concentrations higher than 1,000 Bq ^{137}Cs.l^{-1} even in regions where the deposit amounts to 37 kBq.m^{-2}.

Consumption of wild mushrooms and other products from the forest represents an important contribution to diet in rural populations. Owing to the characteristics of forests, and other natural ecosystems (soils rich in organic matter and poor in nutrient content, namely potassium), radiocaesium remains highly available; it accumulates to a large extent in mushrooms, berries and other plants. A clear relation has been established between the ^{137}Cs body burden of members of the rural population and their mushroom consumption (Fig. 7).

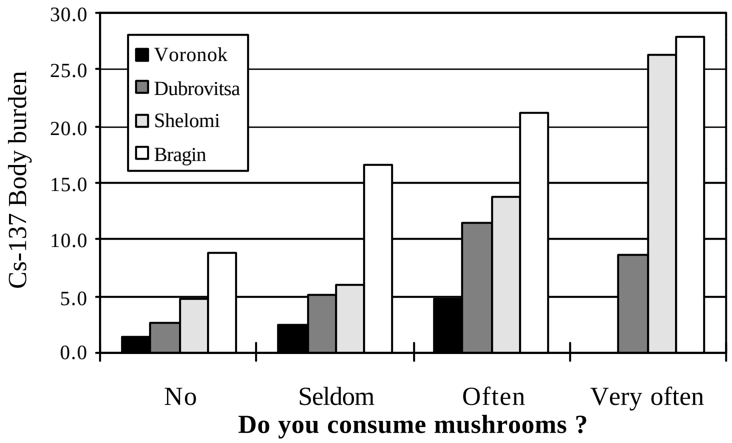

Fig. 7: Radiocaesium body burdens in population groups of mushroom consumers [from Strand *et al.*, 1996].

In game, wild boars exhibit the highest ^{137}Cs contamination level. In the evacuated zone of Belarus, the maximum ^{137}Cs levels in wild boar muscle dropped from 413 kBq.kg^{-1} in 1987-88 to 7.7 kBq.kg^{-1} in 1993-94; in areas with deposit lower than 37 kBq.m^{-2}, it decreased over the same period from 800 to 100 Bq.kg^{-1} [Pikulik & Plenin, 1996]. The contamination level in individuals is however highly variable, depending on the areas frequented by the animals, their diet and seasonal variations in availability of dietary components (e.g. mushrooms).

Contamination levels in fish from oligotrophic lakes can reach several 10 kBq.kg^{-1}. Predatory fish like pike and perch, exhibit higher contamination levels than herbivorous species (roach) and bottom feeders (golden carp) [Ryabov *et al.*, 1996]. A ban was applied on the consumption of lake fish and some restrictions on fishing in the Kiev reservoir were still in application in 1995 [Sikorenko-Gusar, personal communication].

As an indirect consequence of the radiocontamination problems faced by agriculture and forestry, industries in the contaminated territories suffer from an incomplete utilisation of their production capacities because of the withdrawal from economic exploitation of contaminated agricultural lands, forests and water resources. Sales are also limited by official restrictions on food consumption and free trade and by public reluctance in purchasing products originating from contaminated areas. This situation is worsened by the general economical situation in the NIS and the subsequent lack of guaranteed State orders and delays in wages payment [IAEA, 1996].

IMPACT OUTSIDE THE FORMER SOVIET UNION

In Western Europe, the main sources of contamination were from radioiodine and radiocaesium. Neither plutonium nor strontium were of real significance compared to radioiodine and radiocaesium since they are refractory, generally associated with fuel particles, and were not generally dispersed far from the accident site (although traces of plutonium were detected in Sweden).

Terrestrial ecosystems

Restrictions on cattle grazing and on milk consumption were introduced in many countries. Large quantities of milk contaminated by radioiodine and radiocaesium were destroyed in Poland, Hungary, Austria and Sweden. At the end of April 1986, vast amounts of leafy vegetables were destroyed in Austria, Greece, Italy, France and The Netherlands. About 60,000 tons of tea leaves in Turkey were contaminated above the maximum permissible concentration and disposed in 1989 in several selected ground repositories [Ertürk *et al*., 1996].

The main lasting effect concerned restrictions on the consumption of reindeer meat in the Scandinavian countries, and consumption of contaminated lamb in United Kingdom, Sweden, Germany and Eastern Europe. In the UK the consumption of lamb containing more than 1,000 $Bq.kg^{-1}$ radiocaesium was banned in Cumbria, Wales, part of Scotland and North-Ireland. As of January 1995, 66 farms in Cumbria and 70,000 sheep were still under restriction. However, radiocaesium concentrations in sheep removed to less contaminated pastures fall rapidly. Radiocaesium concentrations in game from heavily contaminated regions where radiocaesium remains available are still of concern.

Aquatic ecosystems

The behaviour of radiocaesium in freshwater systems is ruled by the particularities of the aquatic system considered. Restrictions on the consumption of wild fish had to be imposed in regions of high deposition for oligotrophic lakes. In these ecosystems, poor in nutrients and suspended minerals capable to bind it, radiocaesium remains available in the long-term and contamination levels in excess of acceptable concentrations still occur in some Scandinavian countries. Farmed fish, fed uncontaminated artificial food, have been much less affected than have wild fish.

IMPACT ON THE BELGIAN TERRITORY

The Chernobyl plume entered Belgium from the South during the night of 1 to 2 May 1986. The concentration of radionuclides in air (air dust collected on filters) reached a maximum in the end of the morning at Mol. The highest deposit was associated with rainfall in the two next days (3 and 4 May). Variation in rainfall intensities over the territory explain the observed deposition pattern (Fig. 8).

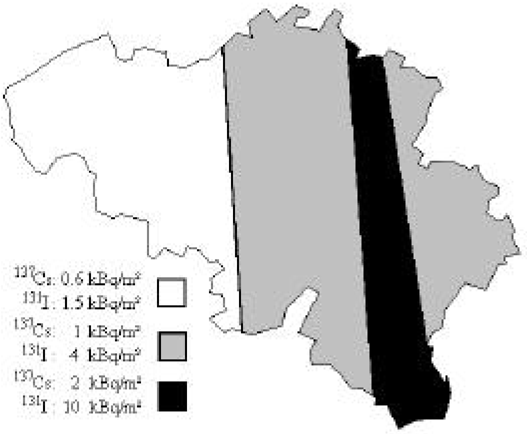

Fig. 8: Contamination map for Belgium

Leafy vegetables contaminated by direct deposition from the atmosphere showed maximal activities of 400 Bq.kg^{-1} for cornsalad, 300 Bq.kg^{-1} for lettuce and 100 to 200 Bq.kg^{-1} for other vegetables including spinach, watercress, endive, leek and celery [Cottens, 1986]. Radiocaesium concentration in spinach decreased rapidly from a maximal value of 200 Bq.kg^{-1} immediately after the deposit to 30 Bq.kg^{-1} in the second half of May 1986.

The transfer of radioiodine and radiocaesium from grass to cow's milk is very rapid and milk is a good biological indicator of the intensity of the deposit. Therefore, and also because of the important contribution of milk to the internal dose to population, milk from dairies and individual farms and cows was intensively monitored. Nearly the whole country was covered by this sampling campaign as all important dairies were included. The maximum ^{131}I concentration values for dairies amounted to 225 Bq.l^{-1} on 5 May 1986. Of course, milk from individual farms and cows could have higher values (ranges from 100 to 660 Bq.l^{-1} were reported [Cottens, 1986]). Figures 8 and 9 represent the changes with time (since 1963) of the concentrations of ^{137}Cs and ^{90}Sr, respectively, in milk from a dairy located in Gierle (Antwerp Province, about 20 km NW from Mol). The influence of the Chernobyl accident is clear for ^{137}Cs, with a first peak immediately after the accident and another one in Autumn 1986 when the cows were stalled and fed contaminated hay collected at the end of May or in June. ^{90}Sr was not present to an appreciable extent in the deposit (the Chernobyl deposit in the most contaminated zones in Belgium contributed only 2% of the ^{90}Sr still present in soil from weapons testing fallout), and therefore did not contribute to the contamination of milk to any practical extent.

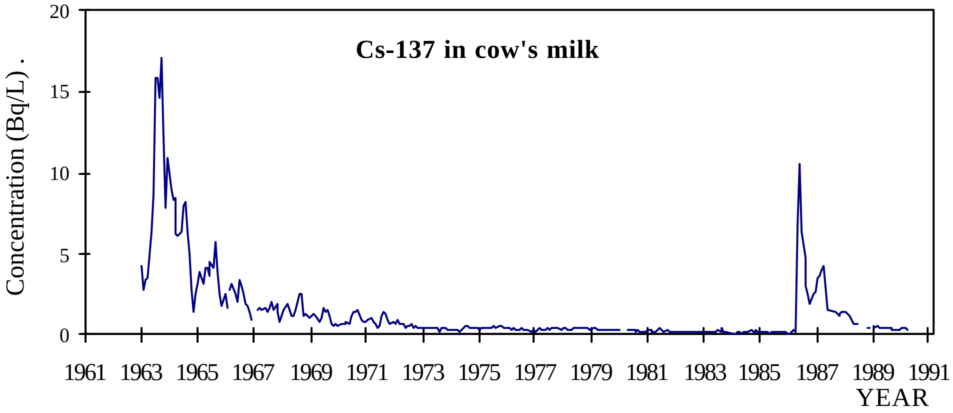

Fig. 9: Changes with time of the ^{137}Cs concentration in milk collected at a dairy at Gierle (Antwerp Province) between 1963 and 1990

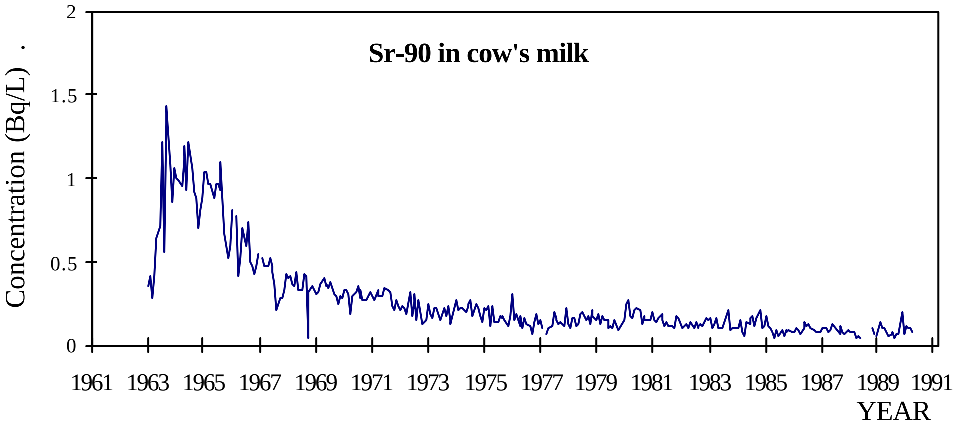

Fig. 10: Changes with time of the ^{90}Sr concentration in milk collected at a dairy at Gierle (Antwerp Province) between 1963 and 1990

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Résumé.

Suite à l'accident de Tchernobyl, l'environnement fut affecté à des degrés divers en relation avec l'intensité du dépôt et le niveau de radiation. Des effets déterministes ne furent mis en évidence que dans les régions où les dépôts furent particulièrement élevés, c'est-à-dire au voisinage immédiat de la centrale nucléaire. Des effets létaux s'exprimèrent durant la première année chez les pins et la microfaune édaphique des forêts proches de la centrale. A plus grande distance, seuls des effets sub-létaux furent enregistrés, parmi lesquels des altérations morphologiques, physiologiques et biochimiques au niveau des cellules, tissus et organes végétaux ou animaux. Des modifications génétiques furent également observées chez les plantes et les animaux de la zone des 30 km et d'autres régions à contamination élevée. Selon l'intensité du dépôt, les populations civiles furent évacuées et des restrictions furent instaurées quant à l'utilisation de certains produits naturels (bois de chauffage) et à la consommation d'un certain nombre d'aliments d'origine agricole ou forestière. Une série de contre-mesures furent mises en application afin de réduire les niveaux de radiocontamination des denrées alimentaires. L'accident de Tchernobyl eut également des répercutions indirectes sur les communautés végétales et animales, conséquences de l'évacuation des populations, de la cessation des activités agricoles et de l'application de contre-mesures. On peut s'attendre à ce que ces effets se prolongent dans le futur.

Samenvatting.

Het Tsjernobylongeval leidde tot verschillende effekten op het milieu, afhankelijk van de radiologische dosis en van de radioactieve neerslag. Deterministische radiologische effecten waren te zien in zones met hoge stralingsniveau's, dichtbij de kerncentrale. Dodelijke effekten kwamen voor gedurende het eerste jaar bij dennen en bij de mikrofauna van de grond in bossen in de nabijheid van de centrale. Op grotere afstand werden niet-dodelijke effekten waargenomen zoals morfologische, fysiologische en biochemische veranderingen in organen, weefsels en cellen van planten en dieren. Genetische effekten waren ook geïdentificeerd in planten en dieren uit de 30 km zone en andere hoog besmette streken. Afhankelijk van de

intensiteit van de neerslag werd de bevolking geëvacueerd en werden beperkingen voor het gebruik van produkten uit de natuur (bv. brandhout) en de consumptie van bepaalde voedingsstoffen vastgelegd. Tegenmaatregelen om het radioactiviteitsniveau in het voedsel te beperken werden toegepast. Als gevolg van de evacuatie van bepaalde regio’s, het stoppen van landbouwactiviteiten en de toepassing van tegenmaatregelen werden reeds indirecte gevolgen waargenomen op planten en dieren. In de toekomst worden nog dergelijke effekten verwacht.

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THE CHERNOBYL ACCIDENT

HEALTH EFFECTS : CLINICAL AND ONCOLOGICAL CONSIDERATIONS

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Abstract

The Chernobyl accident provided us with following important biomedical information:

A- From the point of view of emergency nuclear medicine and the control of a nuclear disaster:
- how to try to control the acute phase of a large scale nuclear accident
- how to face, planify or not impose - without panic- the evacuation of the inhabitants in function of the distance from the epicentre of the disaster, the measures of the collective doses, the direction of winds and in function of the mass of the concerned population
- the importance on short and long term of the pathology of burns
- the advantage without discussion of the immediate dispensing of potassium iodide tablets.

B- From the few trustworthy results, verifiable and looking statistically valuable some well established notions of radiopathology (and maybe or radiobiology) should be revised in the expected delay (2 to 5 years after exposure). The same concerns the concept according to which the apparition of solid radioinduced tumours may be expected after decennias (20 years or more).
The large and still increasing number since 1989 of differentiated thyroid cancers in children living in contaminated areas is a consequence with unpredictable delay.
There is no significant increase of any other disease which might be linked to the consequences of the explosion. For the time being it does not appear as if the number of congenital malformations would have increased significantly.

C- From a methodological point of view it is extremely difficult if not impossible to organise the registry of the whole population being touched and contaminated by different ways and for variable reasons (liquidators, population directly exposed to radioactive fallout, victims of the contaminated food chain) and the rigorous follow up on a national scale or continental i.e. the size of former Soviet Union, and the variable origin of the liquidators. Furthermore major obstacles remain in the

interpretation of the different pathological phenomena registered in the concerned populations when comparative values concerning the same population during years preceding the accident are often missing and will never be recuperated.
Substantial biasses interfere in a number of medical findings.

D- It will remain to evaluate the real impact of the contamination of the soil, waters (lakes, streams, ground waters) and of the food chain by radioactive isotopes with long half life on the concerned population.

E- One should note the importance of a psychological guidance, on short and long term of the immediate victims of the accident, members of first aid and the whole concerned population not to forget the evacuated families.

The Chernobyl accident which occurred already 10 years ago, had had a main political, ecological-environmental, mediatic and medical (nuclear emergency medicine, epidemiological and radiobiological contributions) impact on the history of the humanity during the 2 last decades of the XX-th century. This event presents at least two symbolical consequences : it was (later on) the first clinical sign of the future explosion of the soviet empire, and on the other hand it constitutes, still ongoing, the biggest in vivo radiobiological (involuntary) experience of the humanity since Hiroshima and Nagasaki.

This accident was more than reasonably mediatized and an extremely high number of articles and books has been published on this topic, without any correlation between the extend of the publications and their scientific importance. The bibliography of the present article gives to the reader a realistic selection of valuable contributive books and articles, which, retained in the present work, can give a true source of - often detailed - references about technical and biomedical aspects of the Chernobyl accident. A special attention should be paid to the 3 recent (often identical) publications, issues from the meetings held in Geneva (WHO), in Minsk (UE) and in Vienna (IAEA) which summarized relatively correctly,with some other general references (15, 16, 17), what we can consider as the "state of art of our post-Chernobyl knowledge". The present short paper should again highlight, in first line from the clinical point of view, the main biomedical considerations issues from the Chernobyl accident.

I. General considerations.

A. The exact release of the various radioactive elements is relatively exactly established (11), based on the analysis of the core material and of the internal contamination of the reactor on the one side and on the measurements of the environmental samples on the other side. The main contamining isotopes have been identified and taking into account their chemical nature, physiological (in vivo) involvement in vegetal and animal tissues, their physical and biological half-life as well, 131-I, 134-Cs, 137-Cs and 90-Sr play the most important role in the post-Chernobyl pathology (15, 16, 17) whereas the importance of early contaminants (132-Te, 95-Zr, 103-Ru, 106-Ru, 140-Ba, 141-Ce, 144-Ce and 89-Sr) is still not enough analyzed, the role of transuranian elements (Np, Pu) as well. From the point of view of iodium contamination, the 131-I isotope seems to concentrate the whole interest of the scientists involved, but we should not forget, that there are exactly 25 radioactive I-isotopes, among them 5 pure beta and 18 combined beta/gamma emitters and 13 exhibit a physical half-life between 1.5 sec and 52.3 min, and their possible role from the point of view of radiopathology was still not evaluated.

B. The direction of the winds and the meteorological conditions just after the accident have already been extensively studied (11, l5). As result the main routes of contamination were established. Thus, it is evident that the main contaminated regions are those nearest to Chernobyl Aunder the wind", located in the republics of Belarus, Ukraine and Russia, whereas in the Central and Western European countries the general exposure of the population to radiations remained only slightly elevated: 20-30 % more in 1986 than the normal average exposure of the countries concerned (9, 15).

As far as the Cs- and Sr- deposits on the soil are concerned, extensive analytic work was done and the collected results give useful data in order to evaluate, for instance, the potential radioactive charge of the nutritive chain. The exact and detailed influence of these contamination is still not identified on the human clinical level.

C. For the interpretation of all biomedical effects there is an another conceptual problem: whereas there are useful statistics in the formerly soviet republics as far as cancerous diseases are concerned, for other health problems (epidemiologic studies on non-neoplasic thyroid diseases, etc) where is no possibility for comparaison with pre-Chernobyl data, health problems having been rather neglected in the formerly soviet system. By the same way the disappearance of the structures of the Soviet-Union prevented the comparaison of epidemiological results registered in the contamined area with those which could be obtained in "matched" populations, located in the untouched regions of the past Empire (1,6).

II. Direct effects on the public health.

A. As far as the <u>acute phase</u> is concerned, the numerous reports (3, 7, 10, 15, 16) give a true description of the manner, how ukrainian and soviet responsibles were able to control the situation, and taking into account the real problems (the responsibles on place, the workers, the rescue-teams and the population, for political reasons, never considered the possibility of a severe accident as a reality which can occur) it can be stated that a relatively good global work was done.

In proportion to the extent of the accident the number of the cases with acute radiation disease (and of the deceased people) was not excessive. The classical principles (3, 7, 13, 15) of the nuclear emergency medicine have been respected according to the generally recommended algorithms.

- saving of people in critical situations;
- selection of the cases
- decontamination;
- dosimetry; evaluation of the (radiation) exposure;
- surgical and medical intervention in case of clinical necessity;
- evacuation in the direction of specialized institutions.

The heroism and the spirit of sacrifice of the first medical and other rescue trams must be here against underlined.

B. The necessity of evacuation of the population concerned has been relatively good evaluated and on a realistic base taking into account the radioactivity released (so far evaluable), the dosimetric data, the direction of winds and the danger of panic, especially when a huge population should be concerned. (See the correct decision, avoiding the evacuation of Kiev with 3.5 million inhabitants).

C. The prophylactic distribution of "cold" iodium tablets has only been done with delay and incompletely thus the contamination by short-period-I-isotopes and by 131-I could not be avoided (12, 15).

D. At medium term a large number of people were mobilized in order to keep under control the accident or to eliminate the consequences. These people (military personnel, emergency volunteers, operators of the plants, medical auxiliary troups, often non-professional helpers) constitute the population of the so-called "liquidators". Their amount is roughly evaluated to 600.000 - 800.000, among them at least 200.000 worked in the Chernobyl region during the 1986/87 phase. The theoretical philosophy in order to use this large population was to "dilute" the radiation exposure, limiting the time spent by each individual in the contaminated area. This population constitutes one of the largest problem of the post-Chernobyl period from the point of view of health public because of their incomplete registration, dispersion (in other actually independent states) and of absence of valuable dosimetric data.

E. Radiopathological considerations

1. According to our collective knowledge, as result of the radiation exposure, blood malignancies (leucemia, lymphomes) should be appear as first pathological consequences 2 to 5 years after the accident, whereas the emergence of solid tumors was foreseen from the twentieth year after the accident. The facts reported seems to be quite different (16, 17). The statistics of blood malignancies remained stable in the 3 republics concerned until 1994 included. Only in the last months (17) were some individual (and to few) cases reported, which could be considered as a slight modification of the incidence of these diseases.
   Still more cases and a strong epidemiological evaluation are needed in order to be able to identify them as a statistically significative consequence of the Chernobyl accident.

2. On the other hand there is now no more doubt, that the incidence of thyroid cancer in children living in the most contaminated regions about 100 km around Chernobyl (mainly in Belarus) increased significantly since 1989 (2, 6, 8, 14, 15, 16, 17). Moreover even, when these cases are histologically well differentiated papillary carcinomas, their behaviour is particularly aggressive, with early invasion of lymphatic vessels and blood capillaries, involving rapidely the locoregional lymph nodes. The geographic localization of the cases identified shows a clear coincidence with the highest contaminated regions by the radioactive fall-out during the initial phase after the accident, when the concentration of the different iodium isotopes was still particulary high.

   This increase concerns quite-exclusively the children born before or during the first 3-4 months after the accident, corresponding to the physiologically high incorporation rate of radioactive iodium into the child-thyroid and to the physical half life of these I-isotopes. Differentiated thyroid cancer being actually a significative health problem in several regions, extensive screening work is recommended, based on clinical examination, echographic control, thyreoglobulin determination and if possible, on scintigraphic examination as well. In case of relatively not too late diagnostic and using well established therapeutic policy and assuming a correct follow-up (4, 5, 12) differentiated thyroid cancer can be cured in more than 85-90 % according to the initial stage. Thus, all technical and epidemiological conditions must be assumed by the international community that this clinical work should be done in the best conditions. More than 350 000 new cancer cases should be appear each year, independently from the Chernobyl accident in the approximatively 70 000 000 people , who are concerned by the consequences of the accident in the former Soviet-Union. Even if the cumulative number of thyroid-cancer in children (800 until now) is low in comparaison to the new cancers registered yearly, each individual case is 1 too much for the family concerned and is for this reason inadmissible.

F. As possible consequences of the genetic damage, malformation in humans and occasionally mutations in some animal species born after the accident have been reported. Nevertheless, any systematic study can not support until now the assertion of higher frequency of malformations in humans or animals which would be induced by the consequences of the Chernobyl accident.

G. The investigations of the people concerned by the different aspects of the accident (health problems, evacuation, economical changes, environmental considerations, familial consequences, their future and that of the next generation) underline the rising importance of psychological problems in strong connection with the ongoing deep transformation of the ex-soviet society and of the economic structures both exerting actually a rather destabilizing effect on the inhabitants of the most ex-socialist countries.

As conclusion, the main direct and indirect biomedical lessons of the Chernobyl accident can be summarized as follows :

1. During the initial phase : how to control the acute phase of a nuclear plant accident when the number of expected victims is high.
2. The problem of evacuation of the population as function of the radiation doses, of the distance and of the direction of the winds.
3. The constitution and coordination of the medical rescue teams in the beginning of the acute phase of catastrophe.
4. The importance of burn-scars.
5. The advantage of Iodium-prophylaxe, which was not done on enough large population basis in the formerly Soviet-Union.
6. The influence of the Chernobyl-accident on the new national emergency plans, established since ago in several countries.
7. The importance of the soil and water contamination by isotopes with medium and long T 1/2 : how to control the alimentary chain. (water, fish, meal, vegetables, etc).
8. How to organize largest scale follow-up of huge population (liquidators and simple "standard" inhabitants in well determined zones) in a country without traditional and for western countries "normal" medical culture .
9. How to interprete epidemiological results without valuable comparison with non-existing former data or with population- based similar concomitant results in non-contaminated ex-soviet regions.
10. The relatively fast appearance of differenciated thyroid-carcinomas in children presenting a particulary aggressive histological aspect.
11. The absence of the expected increase of blood and lymphatic malignancies.

12. The actually registered lack of malformations and other significative signs of genetic damage.
13. The importance of long-time psychologic care of the victims, of the people involved in the rescue teams and of the general population.
14. The importance of pure psychological aspects as far as the political, economic, energetic and ecologic aspects of the accident are concerned worldwide, even on highest international level and in the media.
15. The demonstration of the total absence of coordination (fortunately after the acute phase of the accident) as far as the evaluation of the consequences, organization of research programs and long time medical aid are concerned, on the level of major international organizations (WHO-IAEA-UE), in the medically well developed western countries (each working for his own glory) and even among the concerned former Soviet Republics (Russia-Ukraine-Belarus).
16. The necessity that the international community should help by a disinterested manner the concerned countries and regions in order to face in the best conditions the socioeconomic, and biomedical challenge, constituted by the consequences of the Chernobyl accident. This help must involve all scientific, pedagogic, methodologic, technic and psychologic aspects needed, avoiding the multiple errors which occurred during the first decade since the accident.

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Résumé

L'accident de Tchernobyl a permis de tirer les leçons biomédicales majeures suivantes :

A . Du point de vue de la "médecine nucléaire d'urgence" et de la maîtrise de la catastrophe nucléaire :
  - Comment essayer de maîtriser la phase aiguë d'un accident nucléaire à grande échelle;
  - Comment constituer et employer les équipes médicales de secours immédiatement et à moyen terme;

- Comment envisager, planifier, réaliser ou ne pas imposer - sans panique - l'évacuation des habitants en fonction de la distance par rapport à l'épicentre de la catastrophe, des doses collectives mesurées et extrapolées, de la direction des vents et en fonction de la masse de la population concernée;
- l'importance à court et à long terme de la pathologie due aux brûlures;
- L'avantage indiscutable de l'administration immédiate, dès l'alerte, des comprimésd'iodure de potassium.

B. D'après le peu de résultats fiables, contrôlables et paraissant statistiquement valables, certaines notions bien établies de radio-pathologie (et peut-être de radiobiologie) doivent être revues; ainsi que des hématosarcomes (leucémies et lymphomes) ne sont pas apparus dans le délai prévu (2 à 5 ans après l'exposition). Il en est de même pour la conception selon laquelle l'apparition de tumeurs solides radioinduites ne peut être attendue qu'après des décennies (20 ans et plus tard); le nombre relativement élevé et en augmentation constante depuis 1986 des cancers thyroïdiens différenciés chez les enfants vivant dans les régions contaminées est une conséquence à cadence imprévue. Il n'y a pas d'accroissement significatif d'aucune autre maladie qui pourrait être liée aux conséquences de l'explosion. Pour le moment il ne semble pas que le nombre de malformations congénitales aurait augmenté de façon prouvée.

C. Du point de vue méthodologie il est extrêmement difficile, si pas impossible, d'organiser l'enregistrement de toute la population ayant été atteinte et contaminée à divers titres et pour des raisons variables (liquidateurs, population exposée directement aux retombées radioactives, "victimes" de la chaîne alimentaire contaminée) et leur suivi rigoureux à l'échelle nationale voire continentale vu l'étendue géographique de l'ancienne Union soviétique et l'origine diversifiée des liquidateurs. De plus, il reste des obstacles majeurs afin d'interpréter les divers phénomènes pathologiques enregistrés au niveau des populations concernées lorsque les données comparatives concernant la même population pendant les années précédant l'accident manquent souvent et ne seront jamais récupérables. Des biais substantiels pèsent ainsi sur une série de constatations médicales.

D. Il restera à évaluer l'impact réel de cette contamination du sol, des eaux (lacs, fleuves, nappes phréatiques) et de la chaîne alimentaire par les isotopes radioactifs à demi-vie longue sur la population concernée.

E. L'on notera l'importance d'une prise en charge psychologique, à court et à long terme, des victimes immédiates de l'accident, des membres des équipes de secours et de toute la population concernée, notamment des familles évacuées.

Samenvatting

Het ongeval van Tsjernobyl heeft ons de volgende belangrijke biomedische lessen geleerd :

A. Vanuit het oogpunt van de "dringende nucleaire medische hulp" en de beheersing van een kernramp:

- Hoe trachten de acute fase van een nucleair ongeval op grote schaal te beheersen;
- Hoe de medische hulpteams onmiddellijk en op middellange termijn samenstellen en gebruiken;
- Hoe de evacuatie van de omwonenden overwegen, plannen, uitvoeren, - zonder paniek - verplichten of niet, in functie van de afstand t.o.v. het epicentrum van de ramp, van de gemeten en geëxtrapoleerde collectieve doses, van de windrichting en van de omvang van de betrokken bevolking;
- Het belang op korte en op lange termijn van de pathologie te wijten aan brandwonden;
- Het onbetwistbaar voordeel van de onmiddellijke toediening - na het alarm - van kaliumjodide.

B. Op basis van de weinige betrouwbare, controleerbare gegevens die statistisch geldig lijken, moeten sommige stevig ingeburgerde noties van radiopathologie (en misschien van radiobiologie) worden herzien; zo hebben hematosarcomen (leukemie en lymfonen) zich niet voorgedaan in de voorziene termijn (2 tot 5 jaar na de blootstelling). Hetzelfde geldt voor de opvatting volgens welke door straling veroorzaakte vaste tumoren pas na tientallen jaren (20 jaar en meer) te verwachten zijn. Het vrij hoge - en sedert 1986 constant stijgende - aantal gedifferentieerde schildklierkankers bij kinderen die in de besmette gebieden wonen is een gevolg met onvoorzien tempo. Geen enkele andere ziekte die men met de explosie in verband zou kunnen brengen neemt opvallend toe. Momenteel lijkt het niet bewezen dat de aangeboren afwijkingen in aantal zouden toenemen.

C. Vanuit het oogpunt van de methodologie, is het uiterst moeilijk - zoniet onmogelijk - om de registratie van de volledige bevolking die op verschillende wijzen en om verschillende redenen is getroffen en besmet (opruimers, rechtstreeks aan de fall-out blootgestelde bevolking, "slachtoffers" van de besmette voedselketen) evenals de strikte opvolging op nationale of zelfs continentale schaal te organiseren, gezien de geografische omvang van de oude Sowjet-Unie en de verschillende oorsprong van de opruimers. Bovendien blijven er belangrijke obstakels om de diverse pathologische fenomenen die zijn vastgesteld bij de betrokken bevolkingsgroepen te interpreteren wanneer vergelijkende gegevens betreffende diezelfde bevolking tijdens de jaren vr het ongeval vaak ontbreken en nooit teruggevonden zullen kunnen worden. Er blijven grote vraagtekens bij een reeks van medische vaststellingen.

D. De reële impact van de besmetting van de bodem, het water (meren, rivieren, grondwater) en de voedselketen door radioactieve isotopen met lange halveringstijd op de betrokken bevolking zal nog geëvalueerd moeten worden.

E. Er moet worden gewezen op het belang van de psychologische begeleiding, op korte en middellange termijn, van de rechtstreekse slachtoffers van het ongeval, van de leden van de hulpteams en van de hele betrokken bevolking, met name van de geëvacueerde families.

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EFFETS SANITAIRES DE L'ACCIDENT DE CHERNOBYL : EFFETS STOCHASTIQUES ET CONSÉQUENCES DES IRRADIATIONS IN UTER0.

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Résumé

Dix ans après l'accident de Chernobyl, l'effet le plus marquant et le moins contestable est l'augmentation importante de l'incidence du cancer de la thyroïde parmi les enfants des régions les plus affectées par les retombées initiales du nuage radioactif. Ces cancers affectent particulièrement les tout jeunes enfants, ont un temps de latence remarquablement court et sont de nature très agressive. Si les tendances actuelles persistent et d'après l'expérience du passé, il faut s'attendre à un nombre très élevé de cancers de la thyroïde radioinduits lorsque ces populations auront atteint l'âge adulte.

Une augmentation des autres cancers solides n'était pas attendue durant ces dix premières années, vu les temps de latence, et elle ne semble en effet pas s'être produite, les augmentations relevées dans les zones affectées paraissant être déjà initiées dans les années précédant l'accident. Si les coefficients de risque de cancers radioinduits retenus actuellement sont corrects, il sera de toute façon difficile, pour des raisons statistiques, de déceler dans le futur une augmentation de ces cancers solides, et cela même si les milliers de cas radioinduits pronostiqués surviennent réellement. II en sera probablement de même pour les affections héréditaires radioinduites. Ceci n'enlève rien au drame humain que représenteront ces maladies pour les familles concernées.

Enfin, en ce qui concerne les effets de l'irradiation in utero (difficiles dans ce cas à distinguer d'éventuels effets de l'irradiation des gamètes parentaux), il est et restera très difficile de trancher la question de savoir si l'augmentation des anomalies congénitales observée dans certaines des régions affectées a un rapport causal avec les radiations ionisantes ou si d'autres facteurs sont en cause, en tout ou en partie. La coïncidence géographique et temporelle n'en est pas moins troublante. Les études actuellement en cours sur des cohortes d'enfants ayant subi une irradiation in utero pendant la période de radiosensibilité maximale du système nerveux central, semblent montrer actuellement un certain nombre de perturbations au niveau des tests d'intelligence réalisés mais elles doivent être poursuivies et affinées avant de pouvoir tirer des conclusions fermes.

Remarques préliminaires

En cette année anniversaire de l'accident de Chernobyl, diverses organisations nationales et internationales ont tenté de rassembler les informations disponibles sur l'état de santé des populations affectées par l'accident, particulièrement dans les zones de l'ancienne U.R.S.S. les plus touchées par les retombées.

Le présent article tente de faire la synthèse de ces informations, en recourant autant que possible aux "sources", pour éviter le classique effet de recopiage et d'élagage subséquent de l'information.

L'attention sera focalisée sur les effets stochastiques classiquement attribués à !'exposition aux radiations ionisantes (cancers, affections héréditaires) et dans une moindre mesure sur les effets des irradiations in utero.

II importe dès à présent de signaler que l'accident est beaucoup trop récent pour que l'on puisse tirer des conclusions définitives. Rappelons que les études sur les populations survivantes des explosions atomiques au Japon n'en finissent pas, aujourd'hui encore, de nous livrer des informations. Autour de Chernobyl, beaucoup d'études épidémiologiques, coordonnées au niveau international, viennent à peine de débuter...

Remarquons enfin qu'un grand nombre de publications ont paru et paraissent à propos d'effets classiquement non liés aux radiations ionisantes et attribués, à tort ou à raison, à l'accident de Chernobyl. Le présent article n'a pas l'ambition d'explorer ce domaine mais, face à la tendance actuelle à tout ramener à des effets psychosomatiques, je ne résiste pas à l'envie de souligner qu'il est dangereux, d'un point de vue scientifique, de s'enfermer dans son paradigme et ses présupposés et de refuser a priori toute hypothèse surprenante.

1. Cancers de la thyroïde.

1.1. Introduction

La sensibilité de la glande thyroïde à l'induction de cancers par les radiations ionisantes, spécialement en cas d'irradiation externe, est connue de longue date et elle est particulièrement élevée chez les enfants. Rappelons les cas radioinduits chez des enfants traités par radiothérapie pour des thymus élargis ou pour des affections fongiques.

Les cancers radioinduits sont généralement de type papillaire et dans une moindre mesure de type folliculaire.

Les études épidémiologiques réalisées sur des cohortes exposées pour des raisons médicales (hyperthyroïdie, diagnostic médecine nucléaire) à une irradiation interne par l'iode 131 n'ont pas révélé de façon probante jusqu'ici de radioinduction de cancer de la thyroïde chez les patients traités : la durée d'observation de ces études est cependant parfois réduite et la population suivie est composée essentiellement d'adultes présentant une affection thyroïdienne et non d'enfants en bonne santé. Par ailleurs, l'iode 131 est capable d'induire des cancers de la thyroïde chez l'animal.

Des cancers de la thyroïde ont été observés chez les personnes exposées aux retombées des tests thermonucléaires Bravo sur les îles Marshall : la contribution de l'irradiation externe et des radioisotopes à vie courte de l'iode a vraisemblablement été prédominante par rapport à celle de l'iode 131. Par contre, parmi les enfants de l'Utah et du Nevada exposés aux retombées de tests d'armes nucléaires, Kerber et al ont rapporté une association entre les cancers de la thyroïde et l'exposition à l'iode 131 (dose moyenne estimée : 0,17 Gy).

Au bilan, on admet généralement (CIPR, UNSCEAR 1994, NCRP 1985) que la capacité d'induction de cancers thyroïdiens par l'iode 131 est trois à quatre fois plus faible que celle liée à l'irradiation externe par des rayons X ou gamma, mais il y a peu d'observations concernant spécifiquement des enfants et certaines études animales contredisent cette hypothèse (3).

Le coefficient de risque pour l'induction de cancers de la thyroïde par des rayonnements ionisants à transfert linéique d'énergie (TEL) faible est évalué par la CIPR (publication 60) à $0{,}8.10^{-2}$ Gy^{-1} : ceci représente le risque "vie entière" pour une population de tous âges et signifie que, par millier de personnes dont la thyroïde a été exposée à la dose de 1 Gy, on verra apparaître 8 cancers supplémentaires de la thyroïde. La courbe dose-réponse observée chez l'homme est de type linéaire (Dose and Dose Rate Effectiveness Factor = 1) et le risque est observé même dans la gamme des faibles doses (quelques cGy).

Notons que la période de latence est de l'ordre de 5 à 10 ans (parfois moins) et que le risque de cancer après irradiation persiste pendant des dizaines d'années.

1.2. Incidence dans les zones autour de Chernobyl

Avant l'accident, l'incidence annuelle du cancer thyroïdien chez l'enfant était d'environ un par million en Biélorussie. Il est intéressant de noter à ce propos que la Biélorussie dispose d'un registre du cancer informatisé qui fonctionne depuis les années 1970.

Un tel registre centralisé n'existait pas en Russie et en Ukraine.

D'après le rapport OMS de 1995 (1), l'incidence annuelle préaccidentelle en Ukraine était d'environ 0,4 à 0,5 par million d'enfants (1981-1985) et, dans les oblasts russes de Bryansk et Kaluga, d'environ 0,5 par million.

A titre de comparaison, les taux observés dans les pays nordiques sont du même ordre de grandeur (3).

A partir de 1990, soit 4 ans à peine après l'accident, le nombre de cas annuels de cancers thyroïdiens chez l'enfant * a commencé à augmenter drastiquement en Biélorussie et en Ukraine.

Le même phénomène est observé dans les oblasts russes de Bryansk et Kaluga, mais plus tardivement (1994) et de façon moins prononcée. Fin 1994, 659 cas avaient été recensés (1); le chiffre de 800 cas était atteint fin 1995 (2)

La rapidité d'apparition des cancers a été surprenante.

L'incidence post-accidentelle des cancers thyroïdiens, qui était, nous l'avons vu, de l'ordre de 1 par million au plus, a atteint des valeurs importantes : 36.10^{-6} en 1994 en Biélorussie, 22.10^{-6} la même année dans les oblasts russes précités et $3{,}1.10^{-6}$ en Ukraine.

En Ukraine, la plupart des cancers (plus de 60%) ont cependant été enregistrés dans les régions du nord les plus contaminées : les incidences sont plus élevées à ce niveau et on trouve pour les années 1992-1994, des valeurs (par million d'enfants et par an) situées entre 20 et 24,5 dans l'oblast de Kiev, entre 15,4 et 35 dans celui de Chernigov et entre 10 et 16 dans celui de Zhitomir.

En Biélorussie, c'est l'oblast de Gomel qui a été le plus touché : il comptabilise plus de la moitié des cancers thyroïdiens infantiles, dont l'incidence annuelle a atteint 48 par million en 1995 (plus de 50 fois supérieure à l'incidence préaccidentelle) (2). Gomel est situé au nord de Chernobyl dans l'axe initial du nuage radioactif.

* Par convention et pour tous les chiffres cités, il s'agit des cancers enregistrés chez des enfants âgés de moins de 15 ans au moment où ils ont été opérés. Certains enfants exposés par exemple à l'âge de 10 ans et développant un cancer 8 ans après (en 1994) ne sont donc pas comptabilisés.
Les chiffres présentés pourraient donc être sous-estimés.

1.3. Rôle de l'âge.

Si l'on compare les cas de cancers thyroïdiens de l'enfance observés entre 1990 et 1994 dans les zones autour de Chernobyl avec ceux survenus dans des régions non contaminées (Grande- Bretagne), on constate de nettes différences dans la structure d'âge des cas au moment de l'opération. A une augmentation continue du pourcentage de cas en fonction de l'âge, telle qu'observée chez les britanniques, s'oppose un pic de fréquence pour les âges de 8-9 ans chez les cas biélorusses et ukrainiens, pic se déplaçant au fil des années d'observation.

L'analyse de ces structures d'âge suggère l'existence d'un effet de cohorte et d'une radio- sensibilité fortement accrue pour la catégorie des enfants les plus jeunes : si on regarde en effet séparément les cohortes d'enfants cancéreux âgés de 1 , 2, 3, . . ans au moment de l'accident, on constate d'une part une augmentation du nombre de cancers en fonction de l'âge atteint et d'autre part, un plus grand nombre de cancers chez les enfants les plus jeunes au moment de l'accident.

Le risque relatif atteint 300:1 pour les enfants de moins de 1 an (au moment de l'accident) pour descendre aux alentours de 30:1 chez les enfants âgés de 7 ans au moment de l'exposition (4).

Cette grande radio-sensibilité des tout jeunes enfants a des implications importantes au niveau des plans de secours et de la prophylaxie iodée et est un élément de mauvais pronostic pour l'évolution de la situation dans le futur dans les zones affectées par l'accident de Chernobyl.

1.4. Type histopathologique et caractères cliniques des cancers de la thyroïde observés autour de Chernobyl.

De nombreux cas de cancers de la thyroïde survenus en Biélorussie et en Ukraine ont été vérifiés par des experts internationaux indépendants. Ainsi, 134 cas de cancers thyroïdiens provenant de Biélorussie ont été étudiés conjointement par un Institut biélorusse et le département d'histopathologie de Cambridge : les diagnostics concordaient dans 98 % des cas. Un même taux de concordance a été trouvé pour les cas ukrainiens (presque tous les cancers survenus entre 1990 et 1994 ont été contrôlés). Quelques cas russes seulement ont été vérifiés (2).

Sur le plan histopathologique, plus de 94 % des cancers thyroïdiens étaient des carcinomes papillaires, les autres se partagent en carcinomes vésiculaires (follicular carcinomas) et médullaires. Parmi les cancers papillaires observés autour de Chernobyl, plus de 70 % étaient du sous-type "solid follicular". Ce sont les mêmes types de cancers que ceux que l'on observe chez l'enfant dans des régions non contaminées mais les proportions de cancers papillaires et surtout du sous-type "solid follicular", sont beaucoup plus élevées dans les régions contaminées par l'accident de Chernobyl (2).
Rappelons que la grande majorité des tumeurs de la thyroïde survenant naturellement ont leur origine dans les cellules folliculaires (ce sont notamment les carcinomes papillaires et vésiculaires) et que ce sont les seuls cancers de la thyroïde pour lesquels une radioinduction a pu être montrée ; les cancers médullaires au contraire trouvent leur origine dans les cellules C, ne sont pas directement concernés par le métabolisme de l'iode et surviennent fréquemment en rapport avec une prédisposition héréditaire.

Sur le plan clinique, les cancers de la thyroïde observés dans les régions proches de Chernobyl présentent un caractère agressif, avec, dans une proportion considérable des cas, invasion vasculaire et infiltration des tissus mous avoisinants et fréquemment des ganglions lymphatiques.
De telles infiltrations ont même été observées pour des tumeurs de très petite taille (moins de 1,5 cm de diamètre). Des métastases à distance (pulmonaires) ont été observées dans environ 15 % des cas (11), entraînant parfois la mort.

Des travaux ont été menés dans le but de déterminer si les cancers thyroïdiens des enfants exposés aux rayonnements ionisants présentent des caractéristiques spécifiques sur le plan génétique (signature), quand on les compare avec les cas observés en Grande-Bretagne. Les études réalisées ont confirmé l'association déjà connue entre des réarrangements d'un type particulier d'oncogène (ret) et un type tumoral (le carcinome papillaire). Aucune association avec un sous-type particulier n'a pu être mise en évidence et il n'y avait pas d'association avec l'activation d'autres oncogènes connus pour leur rapport avec les cancers de la thyroïde (TSH receptor gene, p53, les 3 gènes ras) (4).

1.5. Corrélation avec la dose à la thyroïde

En dépit des nombreuses campagnes de mesure et des diverses estimations de dose à la thyroïde qui ont été publiées, il persiste une considérable incertitude sur les doses reçues dans les zones avoisinant Chernobyl, tant au niveau des doses moyennes reçues par la population qu'à celui des fourchettes de dose individuelle.

Les causes en sont multiples. Ainsi, le terme source en iode 131 a été revu encore récemment, avec une augmentation d'un facteur 3 par rapport aux premières estimations. L'activité du ^{132}Te relâché - lequel décroît en quelques jours en iode 132, un radioisotope à vie courte de l'iode - a également été revue à la hausse : or, le rôle de ces isotopes à vie courte de l'iode sur la cancérogenèse thyroïdienne pourrait être important, comme suggéré par les études effectuées dans les îles Marshall, et il y a très peu de mesures directes de l'exposition de la population dans les tout premiers jours. Des mesures réalisées dans certains pays d'Europe Occidentale peu après l'accident suggèrent que le premier nuage radioactif contenait une proportion élevée de ces isotopes à vie courte de l'iode (3).

Par ailleurs, les dépositions ont été très variables en fonction du vent et de la pluie, et la composition du nuage radioactif a varié dans le temps.

De très nombreuses mesures de l'activité de l'iode dans la glande thyroïde ont été réalisées en mai/juin 1986 en Ukraine, en Biélorussie et en Fédération de Russie : une partie de ces mesures a cependant été exécutée au moyen d'une instrumentation et dans des conditions de mesure non appropriées (5).

Remarquons qu'une bonne partie de la dose à la thyroïde provient de la consommation de lait, et parfois de légumes frais, contaminés : l'évaluation des doses encourues par cette voie repose sur des questionnaires soumis a posteriori à la population visée, avec ici aussi des sources d'erreur possibles.

D'après les estimations rapportées par l'AEN, ce sont les enfants de 0 à 7 ans de la région de Gomel en Biélorussie qui ont reçu les plus fortes doses à la thyroïde (5) : 300 ont reçu plus de 10 Sv, 3100 entre 2 et 10 Sv, 13900 entre 0,3 et 2 Sv et 15100 moins de 0,3 Sv.

Remarquons que, notamment pour des raisons de volume de la thyroïde, une même activité incorporée d'iode radioactif donnera une dose beaucoup plus élevée chez l'enfant que chez l'adulte (5 à 10 fois plus).

En Ukraine, les plus fortes doses à la thyroïde ont été détectées dans la population vivant dans les oblasts de Chernigov, Kiev et Zhitomir proches du site du réacteur. Des mesures directes de l'activité de l'iode 131 dans la thyroïde ont montré que les enfants de Chernigov ont reçu des doses moyennes de 3,3 Gy à la thyroïde (2).

Les doses thyroïdiennes les plus élevées rencontrées en Russie ont été mesurées chez des enfants âgés de 1 à 3 ans dans les oblasts de Bryansk et Kaluga (doses moyennes à la thyroïde allant de 10 mGy à 2,2 Gy selon les groupes) (1).

Selon l'OMS, parmi les enfants présentant un cancer thyroïdien, 66 % ont reçu des doses à la thyroïde inférieures à 0,3 Gy, 22 % ont eu 0,3-1 Gy et 12 % ont reçu 1 Gy ou plus (1).

Sur le plan individuel nous avons vu qu'il est très difficile de reconstruire avec précision la dose reçue et donc de réaliser de véritables courbes dose-effet, comme cela a été réalisé à Hiroshima-Nagasaki. Néanmoins, il apparaît clairement que ce sont les zones connues pour être les plus contaminées qui voient également le plus de cancers thyroïdiens chez les enfants : l'oblast de Gomel en Biélorussie, les oblasts du nord de l'Ukraine et la partie S.O. de l'oblast de Bryansk en Russie.

On notera également la bonne correspondance de la carte des cancers de la thyroïde avec la carte des retombées <u>initiales</u> du nuage radioactif (Abelin, 7).

Par ailleurs, le fait que l'incidence du cancer de la thyroïde chute drastiquement chez les enfants nés plus de 6 mois après l'accident, indique clairement une relation entre les cancers de la thyroïde observés et l'exposition aux iodes radioactifs produits par l'accident de Chernobyl (2).

1.6. Rôle éventuel de l'effet screening et d'autres facteurs.

La question a été soulevée de savoir si le nombre de cancers thyroïdiens observés autour de Chernobyl n'a pas été gonflé artificiellement par un effet dit de screening, en ce sens qu'un dépistage accru des affections thyroïdiennes aurait permis de détecter un grand nombre de cas cliniquement muets.

II semble clair à l'heure actuelle que le screening n'a pas contribué de façon significative au nombre de cas observés chez les enfants : ainsi, 12% seulement des cancers ont été dépistés par le seul moyen d'examens aux ultra-sons. Mais surtout il convient de rappeler que ces cancers sont particulièrement agressifs, même lorsqu'ils sont de petite taille, ce qui les différencie nettement des micro-carcinomes papillaires qui sont d'observation courante dans des populations adultes.

Comme autres facteurs, des polluants chimiques ont été incriminés mais cette hypothèse est difficilement recevable car aucun carcinogène n'est connu pour être spécifique non seulement de la glande thyroïde mais aussi d'un type de cancer particulier à ce niveau.

Quel rôle a éventuellement pu jouer une carence alimentaire en iode ? II est certain qu'une telle carence, là où elle existe, a pu contribuer à augmenter l'incorporation d'iode radioactif et, partant, la dose à la thyroïde. Il ne semble cependant pas que la carence en iode soit associée à une augmentation des taux de cancers thyroïdiens de type papillaire (2).

L'hypothèse d'un facteur racial (radio-sensibilité accrue de la thyroïde chez les sujets de race juive) a également été soulevée et doit être investiguée vu les caractéristiques démographiques des populations touchées.

1.7. Pronostic

Les études sur les cancers thyroïdiens radioinduits montrent que les cas de cancer en excès persistent pendant des dizaines d'années après l'exposition, même si l'excès de risque peut décroître après 20 ou 30 ans (8). Ces études suggèrent un risque de type multiplicatif, c'est-à-dire un excès de risque qui obéit à un modèle de type relatif, dans lequel la fréquence des cas radioinduits est proportionnelle à celle des cancers survenant spontanément dans la population témoin. Comme la fréquence des cancers augmente avec l'âge, une telle relation implique que, plus la population exposée vieillit, plus le nombre (absolu) de cancers radioinduits augmente (on parle d'excès de risque relatif).

La radio-sensibilité des enfants en bas âge est par ailleurs connue et a été observée notamment parmi les survivants des explosions atomiques au Japon.

Nous avons vu que les premières analyses de cohortes exposées autour de Chernobyl confirment cette grande radio-sensibilité des tout jeunes enfants : elles semblent par ailleurs compatibles avec un modèle de risque de type relatif (2), quoique une plus longue observation soit nécessaire pour permettre de confirmer cette tendance.

Vu notre ignorance des doses réellement encourues par la population et du nombre d'enfants touchés, et vu par ailleurs l'insuffisance des données épidémiologiques relatives à l'irradiation à doses élevées de très jeunes enfants, il est difficile de faire un pronostic.

Si on utilise les coefficients de risque proposés par la CIPR (6) et si l'on suppose qu'un million d'enfants ont reçu en moyenne 0,5 Gy, on doit s'attendre à environ 4.000 cas de cancers thyroïdiens radioinduits dans la population d'enfants irradiés (risque vie entière).

Les taux observés à Gomel font cependant craindre que ce coefficient de risque ne soit trop optimiste pour une population de jeunes enfants : il pourrait être de 10 à 50 fois plus élevé (2).

Si l'on applique aux excès de risque actuellement observés un modèle de projection de type relatif, on obtient, rien que pour les enfants de Gomel (au nombre de 400000) un taux prévisible de 1.000 cas de cancers thyroïdiens par an pour l'époque où ces enfants auront atteint l'âge adulte (2).

Remarques : Autres effets thyroïdiens.

Une incidence accrue d'hypothyroïdie et de nodules thyroïdiens a été observée dans les régions contaminées, particulièrement à Gomel. Comme les habitants de cette région ne semblent pas par ailleurs souffrir de carence en iode, il est probable que ces deux effets soient radioinduits.

Des taux augmentés d'anticorps antithyroïdien ont également été observés dans certaines zones autour de Chernobyl, notamment à Zhitomir (recherches de la fondation Sasakawa). La relation de ce phénomène avec l'exposition aux radiations ionisantes a été montrée dans des études sur des patients traités à l'aide d'iode 131 . Des hypothyroïdies d'origine autoimmunitaire ont été observées parmi les survivants des explosions nucléaires au Japon, particulièrement chez les personnes exposées à des doses de moins de 1 Sv à la thyroïde (Nagataki, 7).

2. Autres effets stochastiques à long terme.

2.1. Faisabilité des études épidémiologiques.

Parmi les autres effets stochastiques auxquels on peut s'attendre suite à des expositions aux radiations ionisantes, on peut citer les leucémies, les autres cancers solides, ainsi que les effets héréditaires observables dans la descendance de parents irradiés.
La faisabilité d'études épidémiologiques informatives dépend de 3 facteurs : une population de taille suffisante, un follow-up complet et non sélectif et des estimations de dose individuelle précises et fiables (2).
De grands efforts sont entrepris en vue de reconstruire les doses individuelles liées à l'accident de Chernobyl, mais il est clair que les incertitudes dosimétriques seront difficiles à surmonter et pèseront sur la qualité des informations livrées par les études post-Chernobyl.

Les quatre groupes de population les plus intéressants à suivre sont (2) :

- les liquidateurs, c'est-à-dire tous ceux qui sont intervenus pour les travaux de remise en état, décontamination, nettoyage etc... après l'accident : ce groupe comprend environ 700.000 personnes; au niveau épidémiologique, on suivra surtout ceux qui ont reçu les doses les plus élevées, à savoir les 200.000 personnes qui ont travaillé pendant la période 1986-1987 (la dose moyenne estimée est de 100 mSv mais l'information dosimétrique est insuffisante; 10% ont reçu des doses de l'ordre de 250 mSv et quelques % des doses supérieures à 500 mSv);
- les 135.000 personnes évacuées du périmètre autour de Chernobyl (doses moyennes estimées par reconstruction : environ 15 mSv ; grandes variations individuelles avec des valeurs maximales pouvant atteindre près de 400 mSv) ;
- les résidents des zones les plus contaminées (SCZ : Strict Control Zone : plus de 555 kBq/m^2 ^{137}Cs) : 270.000 personnes avec une dose moyenne estimée à 50 mSv pour la période 1986 - 1995 ;
- la population des zones contaminées (plus de 37 kBq/m^2 ^{137}Cs) : près de 4 millions de personnes avec une dose moyenne estimée entre 5 et 20 mSv (1986-1995).

Les trois premiers groupes cités, ainsi que leurs enfants, font l'objet d'un suivi actif, avec examen médical annuel, initié par l'U.R.S.S. et poursuivi par les états indépendants.
Comme nous l'avons déjà dit plus haut, la Biélorussie dispose d'un registre du cancer depuis les années 70 ce qui permet la réalisation d'un follow-up passif de la population.
Enfin, diverses études épidémiologiques ciblées (études de cohortes, études cas-témoins) ont été et sont

entreprises, souvent dans le cadre de collaborations internationales.

Compte tenu des limitations rappelées ci-dessus, quelle est la faisabilité de la mise en évidence de façon statistiquement significative d'effets stochastiques radioinduits suite à l'accident de Chernobyl ?

E. Cardis, de l'International Agency for Research of Cancer (IARC) à Lyon, a développé ce thème dernièrement à Vienne (2). En partant des coefficients de risque classiques proposés par les organisations internationales et dérivés des observations épidémiologiques actuellement disponibles et en comparant les taux de cas radioinduits potentiels avec les taux de base appropriés, elle a évalué la faisabilité statistique de mettre en évidence des effets radioinduits.

D'emblée, il faut signaler qu'il y a lieu d'éviter la confusion classique entre des effets non détectables et des effets inexistants : le caractère détectable d'un effet dépend des conditions de l'étude et, si celles-ci ne sont pas bonnes, des effets pourtant bien réels, voire massifs, peuvent se révéler indétectables : il ne faudrait pas en conclure qu'ils sont inexistants.

Cela dit, sur la base de coefficients de risque de cancers radioinduits dérivés des études sur les survivants des explosions atomiques du Japon et en utilisant les méthodes de calcul du risque life-time proposée par l'UNSCEAR (8), et sur la base des estimations dosimétriques actuelles, on peut s'attendre à (2) :

- 2000 cancers solides mortels radioinduits et 200 leucémies radioinduites parmi les 200000 liquidateurs du début;
- 1500 cancers solides mortels radioinduits et 100 leucémies radioinduites parmi les 270000 résidents des SCZ;
- 2500 cancers solides mortels radioinduits et 200 leucémies radioinduites parmi les 3700000 résidents des autres zones contaminées;
- 150 cancers solides mortels radioinduits et 10 leucémies radioinduites parmi les 135000 évacués de la zone de 30 km.

Pour les effets héréditaires (première génération) radioinduits, les chiffres sont respectivement de 80, 40, 80 et 5 cas parmi les naissances attendues.

Ces chiffres dépendent bien sûr fortement de la validité des évaluations dosimétriques.

Sur le plan humain, l'induction probable de quelques milliers de cancers mortels et de quelques dizaines de maladies héréditaires (quel que soit le chiffre précis) ne peut moralement pas être négligée ou minimisée, même si ces affections sont difficiles à mettre en évidence sur le plan épidémiologique.

Et précisément, E.Cardis estime qu'il sera très difficile dans l'avenir, vu les conditions de l'étude et les limitations statistiques, de mettre en évidence l'excès de cancers solides attendu. Par contre l'excès de leucémies attendu dans le groupe des liquidateurs devrait pouvoir être observable.

En ce qui concerne les effets héréditaires, vu les limitations statistiques et l'absence de registres adéquats dans la plupart des zones concernées, il devrait être impossible de mettre l'excès en évidence.

2.2. Les observations actuelles

2.2.1. Leucémies.

Chez les liquidateurs biélorusses, une augmentation d'un facteur 2 (statistiquement non significative) du nombre de leucémies a été rapportée (Okeanov, 7; Okeanov, Cardis, 9).
Une augmentation significative du nombre de leucémies a également été signalée chez les liquidateurs ukrainiens (Buzunov, 9).
Bien qu'il faille attendre la confirmation de ces tendances, nous avons vu qu'une augmentation de l'incidence des leucémies chez les liquidateurs n'est pas inattendue. Une augmentation plus forte était même prévisible au départ des observations japonaises mais il convient de se rappeler ici que la courbe dose-effet observée au Japon pour les leucémies était de type linéaire quadratique avec un facteur de réduction du coefficient de risque quand on passe des doses fortes et des débits de dose élevés vers les doses et débits de dose faibles (DDREF), qui est au moins de 2 et pourrait être plus élevé encore.

2.2.2. Cancers de la thyroïde chez l'adulte.

Toujours chez les liquidateurs, une augmentation d'un facteur 2 à 3 de l'incidence des cancers de la thyroïde a été signalée dans les 3 régions affectées (2). Une augmentation d'un facteur 1,5 à 2 a également été observée dans les populations adultes des 3 régions (2).
Ces observations sont actuellement soumises à une vérification critique, notamment pour écarter un éventuel effet de screening.

2.2.3. Autres cancers solides.

On a rapporté une augmentation de 10 à 20 % du nombre total de cancers parmi les liquidateurs de Russie (Ivanov, 9) et d'Ukraine et une augmentation de 3 % parmi les populations résidant dans les zones contaminées de Biélorussie et de Russie (2).
Les études sur les liquidateurs russes montrent une relation linéaire statistiquement significative entre les valeurs du risque relatif et la dose (Souchkevitch, WHO, 9).
Par contre la tendance à l'augmentation de cancers dans la population semble être préexistante à l'accident de Chernobyl (Prisyazhnink, 9).

3. Effets de l'irradiation in utero

Les effets d'une irradiation in utero comprennent schématiquement (10), selon le stade de la grossesse:

- en phase de pré-implantation : risque de létalité embryonnaire (à partir de doses de l'ordre de 0,1 et peut-être même 0,05 Gy);
- en phase d'organogenèse : risque d'avortement ou de malformations congénitales (à partir de doses de l'ordre de 0,05 Gy en début de période et de 0,1 à 0,25 Gy en fin de période);
- de la 8ème à la 25ème semaine : risque d'atteinte cérébrale morphologique et fonctionnelle allant jusqu'au retard mental sévère (seuil probable en fin de période; existence d'un seuil incertaine en début de période);

Se rajoutent à cela les risques de radioinduction de cancers et d'effets génétiques, comme c'est le cas pour l'être humain après la naissance.

Vu les circonstances de l'accident et les caractéristiques du suivi médical des populations avant et après celui-ci, la mise en évidence d'effets radioinduits sur l'embryon est très difficile. Ainsi les effets létaux au stade de pré-implantation et les malformations induites au tout début de la phase d'organogenèse (période d'induction) aboutissent à des avortements spontanés précoces qui peuvent passer inaperçus s'il ne sont pas l'objet d'un dépistage organisé. Les malformations induites en fin de période d'organogenèse présentent chez l'homme un seuil assez élevé et elles sont en compétition avec la tendance aux avortements spontanés; tout dépend de ce que l'on appelle la sélection intra-utérine et celle-ci est variable selon les populations. Se rajoute à cela le fait que suite à l'accident de Chernobyl les expositions aux radiations ionisantes ont été étalées dans le temps et très variables selon les individus: il en résulte que si des anomalies congénitales apparaissent elles peuvent être attribuables à des effets directs sur l'embryon ou à des mutations au niveau des gamètes du père ou de la mère. La situation se complique encore si comme ce fut le cas autour de Chernobyl d'autres facteurs susceptibles d'influencer l'incidence des anomalies congénitales sont présents en plus des rayonnements ionisants (pollution, environnement, alimentation, hygiène de vie ...). L'interprétation des données est dès lors difficile.

A titre d'exemple, citons une importante étude réalisée en Biélorussie par l'Institut biélorusse des maladies héréditaires et portant sur la fréquence des anomalies congénitales avant et après l'accident de Chernobyl. Signalons que la Biélorussie dispose d'un système d'enregistrement obligatoire de certaines maladies congénitales et de divers systèmes de surveillance des maladies héréditaires. L'étude a porté sur plus de 22000 embryons provenant d'avortements médicaux légaux (donc non spontanés) et sur plus de 4000 nouveaux-nés porteurs d'anomalies congénitales à enregistrement obligatoire (soit environ 50% des anomalies). Elle a montré une augmentation considérable des anomalies congénitales depuis 1987. Cette augmentation est corrélée avec le niveau de contamination en ^{137}Cs mais pas avec la dose préconceptuelle à la mère. L'analyse nosologique des anomalies a montré que l'augmentation portait sur l'ensemble de celles-ci et plus particulièrement sur celles d'origine multi-factorielle et sur celles généralement associées à des mutations dominantes (par exemple polydactylie). L'incidence du mongolisme n'était pas augmentée et une augmentation des effets tératologiques indiscutables n'a pas été identifiée. Les auteurs en concluent qu'il y a une réelle augmentation des anomalies congénitales dans les zones contaminées mais qu'elle est probablement liée à plusieurs facteurs, dont peut-être les

radiations ionisantes.
L'interprétation que l'on peut donner à ce type de résultats prête cependant à discussion et il me parait audacieux de disculper d'emblée les radiations ionisantes comme facteur causal essentiel : n'oublions pas que les données humaines en la matière font cruellement défaut. Il ne faudrait pas tomber dans un piège comparable à celui qui a consisté dans le passé, sur base d'observations insuffisantes, à minimiser les effets potentiels d'une exposition des enfants à l'iode radioactif.

En ce qui concerne les effets de l'irradiation sur le système nerveux central en développement une étude de cohorte effectuée sur des enfants irradiés entre la 8ème et la 25ème semaine de grossesse et destinée à détecter d'éventuels dommages cérébraux (performance scolaire, quotient intellectuel, ...) est la plus susceptible, si elle est bien conduite, d'être informative.
Une telle étude est en cours et a été présentée à la conférence OMS de Genève (Kozlova, 7). Elle porte sur plus de 2000 enfants irradiés in-utero (étude dosimétrique non encore réalisée) dont environ 400 entre la 8ème et la 15ème semaine de grossesse (moment le plus critique correspondant à la division et à la migration des neurones corticaux). Divers tests ont été réalisés et on note une incidence accrue d'indicateurs de retard mental chez les enfants irradiés par rapport au taux observé dans le groupe contrôle, et ceci pour les 3 régions (Biélorussie, Ukraine, Russie) .
L'investigation doit bien sûr être poursuivie et affinée et les résultats contrôlés quant à la présence de biais éventuels avant de pouvoir tirer des conclusions fermes.

Mot de la fin.

En guise de conclusion, plutôt que de résumer une fois encore les informations épidémiologiques disponibles ou de discourir sur la question de savoir si l'accident de Chernobyl a été catastrophique, grave ou pas si grave que çà sur le plan de la santé publique, je voudrais, comme le Docteur Mettler l'a demandé lors de la conférence de Vienne, que nous nous rappelions que tous ces enfants malades ne sont pas des chiffres dans un tableau statistique mais qu'ils ont un visage et qu'ils pourraient être les nôtres.

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Abstract

Ten years after the Chernobyl accident the most striking and the least questionable effect is the important increase of the number of thyroid cancers in the children from the regions most affected by the initial fall out of the radioactive cloud.

These cancers affect the most young children, have a very short latency and are very aggressive. If the present trends do persist and from the past experience one should expect a great number of radioinduced thyroid cancers once these populations have reached the adult age. An increase of the number of other solid cancers was not expected in these ten years because of the latency and was not observed. The increases found in the affected zones were initiated in the years before the accident. If the risk coefficients of radioinduced cancers are correct it shall be difficult for statistical reasons to detect in the future an increase of these solid cancers, even if thousands radioinduced prognosticated do really appear. The same shall probably count for the radioinduced hereditary sicknesses, this does not interfere with the human drama represented by these sicknesses for the concerned families.

After all for what concerns the effects of irradiation in utero (difficult to distinguish from possible effects of radiation of the parent gametes) it is and will be very difficult to answer the question whether the increase of congenital anomalies observed in some affected regions has a causal connection with ionising radiations or with other temporal and geographical factors.

The present studies on cohorts of children who have been irradiated in utero in the period of maximal

radiosensitivity of the central nervous system show presently a certain number of alterations, but these studies should be pursued and refined before definite conclusions could be drawn.

Samenvatting

Tien jaar na het Chernobyl ongeval is het meest kenmerkend en minst betwistbaar effect een belangrijke stijging van het aantal shildklierkankers onder de kinderen van de gebieden die het meest getroffen waren door de initiële neerslag van de radioactieve wolk. Deze kankers treffen meestal zeer jonge kinderen, hebben een opvallende korte latentie en zijn zeer agressief. Indien de huidige tendens zich handhaaft, en volgens ondeervinding mag men schildklierkankers verwachten wanneer deze bevolking de volwassen leeftijd zal bereikt hebben.

Een stijging van het aantal andere vaste kankers werd niet verwacht gedurende deze tien eerste jaren omwille van de latentie en heeft zich inderdaad niet getoond. De stijging waargenomen in de getroffen gebieden waren blijkbaar geïnitieerd in de jaren vooraf het ongeval.

Indien de risicocoëfficiënten voor stralengeïnduceerde kankers, als op heden weerhouden, korrect zijn, zal er alleszins om statistische redenen in de toekomst een stijging van deze vaste kankers ontstaan, zelfs indien de duizenden stralengeinduceerde kankers als geprognosticeerd werkelijk ontstaan. Ditzelfde zal waarschijnlijk het geval zijn voor de stralengeinduceerde erfelijke aandoeningen. Dit komt niet in mindering van het drama veroorzaakt door deze aandoeningen voor de betrokken families.

Tenslotte, voor wat betreft de effecten van bestraling in utero (moeilijk te onderscheiden van eventuele effecten van de bestraling van de ouderlijke gameten) zal het moeilijk zijn het vraagstuk op te lossen of de stijging van de congenitale afwijkingen waargenomen in de getroffen gebieden een causale verhouding vertoont met de ioniserende stralen ofwel dat ander factoren zowel geheel of gedeeltelijk verantwoordelijk zijn. De geografische en temporele kunnen samen storen. De op heden in cohorten kinderen uitgevoerde studies in de periode van maximale stralengevoeligheid van het centraal zenuwstelsel, tonen tegenwoordig, een zeker aantal alteraties maar deze studies moeten voortgezet en verfijnd worden vooraleer vaste besluiten kunnen getrokken worden.

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THE PSYCHOLOGICAL AND SOCIAL CONSEQUENCES OF THE CHERNOBYL ACCIDENT *

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Abstract.

This paper presents the main features, from the psychological and social points of view, of the post-accident situation in the contaminated areas around Chernobyl. This is based on a series of surveys performed in the concerned territories of the CIS Republics. The high level of stress affecting a large segment of the population is related to the perception of the situation by those living in a durable contaminated environment but also to the side-effects of some of the countermeasures adopted to mitigate the radiological consequences or to compensate the affected population. Although the size of the catastrophe as well as the economical and political conditions that were prevailing at the time and after the accident have resulted in a maximal intensity of the reactions of the population, there are many lessons that can be drawn for the management of potential post-accident situations more limited in terms of spatial and temporal impacts. These lessons go beyond the historical, cultural, political, sociological, economical and technical context in which it occurred. The paper shows that the objective of returning to normality, seen as a return to the ante-accident situation, is a strong obstacle to the resolution of the post-accident situation. The loss of social trust is another key factor in the subsequent unfavorable development, largely linked with the direct confrontation of the population to the long lasting contamination inducing anxiety and stress. It is also linked with the loss of credibility of the experts resulting from the scientific uncertainty associated with the potential effects of low dose exposures. These different factors led to a complex, unmanageable political and social long term situation. The paper outlines the first elements of a new conceptual approach for the

management of post-accident situations. This basically implies restoring the individual commitment of those directly affected at the local level, which can only be reached through decentralized management of the post-accidental situation. One of the key Chernobyl lessons is that everywhere, if possible, mandatory administrative measures and restrictions must be rejected in favor of voluntary ones, consciously accepted by the population or individuals.

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[*] This paper is based on already published material presented by the author first at the International Conference of the European Commission, Belarus, Russian Federation and Ukraine on the Radiological Consequences of the Chernobyl Accident, 18-22 March 1996, Minsk, Belarus [1] and, secondly, at the International Congress on Radiation Protection-Irpa9, 14-19 April 1996, Vienna, Austria [2].

1. INTRODUCTION

Knowledge of the psychological and social impacts of severe accidents involving radioactivity as well as the comprehension of the mechanisms driving the acceptability of post-accident situations characterized by large contaminated areas were rather limited before the Chernobyl accident. The first attempts in the late eighties to explain the reaction of the population in the affected territories after the accident were superficial. They were founded on the observation that the general public was generally ignorant about the potential effect of radiation, rather suspicious with regard to any official information, largely influenced by media having a strong propensity to spread alarmist news or perturbed by the on-going controversy between experts on the nature and the scope of the measures to be adopted to improve the situation. Although these various aspects have certainly played a role, they were not sufficient to explain how a high level of stress was dominant in a large fraction of the population living in the contaminated territories in the three affected Republics and leading to a profound social crisis many years after the accident.

The paper is first presenting the psychological situation as well as some of the factors that have been identified at the origin of the chronic and acute stress which is still characterizing the situation and preventing a return to normal living conditions from the psychological and social points of view. It is based on the results of a series of studies carried out from 1990 to 1995 in the contaminated areas in Belarus, Russia and Ukraine first in the framework of the International Chernobyl Project initiated by the International Atomic Energy Agency [3,4] then within the Evaluation Programme of the Consequences of the Chernobyl Nuclear Accident (Joint Study Project n°2) from the European Commission [5, 6, 7]. The second part of the paper is an attempt to demonstrate that social trust is the key factor in understanding the post-accidental dynamics. Through an analysis of favorable and unfavorable post-accidental processes, it is shown how most of the difficulties that emerged from the Chernobyl situation were related to the impossibility of establishing a climate of social trust between the population, the experts and the authorities. Finally some considerations for improving post accident management and restoring social trust in the affected population in case of future accidents are presented in conclusion.

2. THE PSYCHOLOGICAL SITUATION

Ten years after the Chernobyl accident, any well informed observer can notice that a large anxiety is still existing among the population living in the contaminated territories around Chernobyl. Quantitative studies on the psychological and social effects carried out in 1992 and 1993 [5,6] highlight an acute feeling of lack of control over individual living conditions clearly linked to a high level of psychological distress in the affected population. This anxiety is essentially related to the potential effect of radioactivity on health and particularly the one of children. Without being able to verify the accuracy of their allegations, interviewed persons are mentioning an abnormal number of somatic effects which are all attributed to the ambient contamination. This last one is a permanent concern for the population who seems in the impossibility to forget the accident and its real or supposed consequences.

As early as 1987, a few Soviet experts have put forward the rather confusing notion of radiophobia to try to explain the psychological reaction of the population. This notion was a convenient explanation for the fears noticed by many individuals inside the population, fears being considered groundless by the experts taking into account the prevailing radiological conditions. The investigations carried out in the contaminated areas have demonstrated that questioned people were expressing fears always supported by rational speeches on the basis of their observations related to the situation [7]. It is difficult to conceive how the concept of phobia, which in psychiatric terms means an unfounded and irrational fear concerning objects and situations that are not in themselves hazardous, could apply to a situation where on the contrary, there were objective reasons to be anxious. It is also interesting to note that this hypothesis of radiophobia, which is now definitively abandoned, received initially a large echo at the international level among experts dealing with the consequences of the Chernobyl accident to explain the attitude of the population in the contaminated areas.

Over the recent years, the concept of chronic and acute stress has progressively emerged to explain some of the symptoms to be observed in the affected population. This stress, which meaning is different from the one given in media and everyday language, can be described as a «continuing inability to adapt at the biological, psychological and social levels. The body, the nervous system and the psychology of those affected enter a state of alert or excitation involving a permanent expenditure of energy. The result is bodily dysfunction and pathological effects manifesting themselves both organically and psychologically (extreme fatigue, insomnia and depression)... A characteristic of the stress situation is that habitual, regular and familiar responses are dislocated, and that the subject is unable to find satisfactory solutions to the problems with which he or she is confronted» [8]. In the post-accident context of Chernobyl, this stress is observable in all groups affected i.e. the re-settled population, the one living in the contaminated areas and of course the liquidators. The anxiety mainly focuses on health, and particularly on the health of children, with a constant reference to somatic disorders. There is also a great concern of the population about its future with the conviction by many people that the situation is not going to improve with time but on the contrary can only get worse thus reinforcing their fatalist and passive attitude.

Many stress factors have been identified which are closely linked with the management of the accident and post-accident phase of the Chernobyl accident. To better understand some of these factors it is useful to distinguish between the Soviet period of the accident management from 1986 to 1990 and the national period with the takeover, from 1991, of the post-accident management directly by Belarus, Russia and Ukraine.

The first period is characterized by the relative failure of the protective measures adopted. Evacuations and iodine distributions were often organized too late and the population affected by the radioactive releases received in some circumstances very high doses. This is in part explaining the growing number of health effects over years that have been observed reinforcing the fear of the population. The context of secrecy and censure which prevailed during this period also largely contributed to the development of distrust toward the authorities. Globally the accompanying symbolization process which normally follows an accident did not take place and the population has attributed all the negative consequences of the accident to the remaining contamination. The occultation of the importance of the accident and of its potential delayed effects by the authorities associated to the fact that the population was permanently confronted to lasting countermeasures led to over-amplify the risk of the post-accident phase. Furthermore, the presence of about 800,000 liquidators disseminated among the general population was a supplementary factor of disturbance. Their greater vulnerability from the health point of view reinforced the distorted perception of the situation as regard to the potential effects of the residual contamination and contributed to maintain or even increase the level of stress in the general population.

The second period has been fundamentally characterized by the willingness of the national authorities to differentiate their management from the previous centralized one by adopting a more realistic and democratic perspective. However, the emphasize put on the defense of the victims of Chernobyl has mainly focused the attention of the new authorities on the post-accident situation. The various national laws adopted by the Republics in the early nineties have established rather generous compensation systems which were supposed to be financed by the Russian Federation. Besides the fact these systems have never been properly financed, they have established a close link between the level of contamination of the environment and the level of compensation thus reinforcing the idea that the risk is first associated to living in contaminated territories. As a consequence, the population many years after the accident tend to attribute all the problems it is facing to the residual contamination and the general feeling is that difficulties will even grow with time. It is evident that such a perception of the situation is a powerful factor for reinforcing the general stress of the population as well as a mental trap to which it is difficult to escape. One can also understand the devastating impact of a lack of objective information on the potential consequences of a large nuclear accident in the early phase and even before.

Another important stress factor is the loss of trust of the population in the scientific, medical and political authorities. Beyond the negative impact of the lack of transparency of the authorities at the time of the accident, the on-going debates on the criteria for establishing countermeasures as well as on the potential health effects associated to the remaining contamination have slowly turned the situation into a very complex one where individuals did not trust anymore experts and felt totally insecure and unable to contribute to resolve the problems themselves. A general feeling of loss of control is thus reinforcing the climate of social distrust.

Observations in the contaminated areas have also shown the paradoxical effects, from a psychological point of view, of many of the countermeasures adopted. The zoning of the contaminated areas has induced a ghetto effect leading to a loss of identity of the population and some forms of exclusion. The definitive resettlement was a strong factor of stress because in most cases the area of relocation was imposed without taking into account the social and cultural affinities of the relocated persons, the conditions of relocation into blocks of flats in urban areas was also creating a ghetto effect installing the relocated population into a social status of «Chernobylites». Finally the compensation system also contributes to develop jealousy in the non compensated population and a reinforcement of the segregation with those affected who are feeling more and more isolated.

It is worthwhile, to complete this rapid overview of the psychological situation, to mention the situation of the few hundreds of persons called the «samossiols» who were initially evacuated at the time of the accident and despite administrative interdictions, came back in the thirty kilometer zone to stay again in their own houses. These generally old persons who are living in an hostile environment and in poor material conditions seems to be in a better psychological situation than the population living in the other contaminated areas. Their willingness to live as before without the financial support of the state can be interpreted as a positive factor to restore their autonomy and thus could explain a lower level of distress than the one observed in the territories affected by the accident.

3. SOCIAL TRUST AND POST-ACCIDENT MANAGEMENT

Why, almost ten years after the accident, is the post-accident situation in Chernobyl still unresolved, despite the successive introduction of several public countermeasure programs? The hypothesis proposed here is that this accident essentially altered peoples' relationship with risk. It marks the introduction of a precarious and vulnerable aspect into their lives. Safety seems to have disappeared. By creating a situation where the means and aims of collective action become uncertain, the post-accident situation took away the authorities' and experts' legitimacy to establish the criteria of public interest. The conventional processes of technical and scientific mediation which facilitated social interaction before the accident, have been rendered inefficient by this transformation. As a result, the profound changes felt with insistence by the population have called the traditional political processes into question. In this respect, the successive post-accident public policies implemented during the years following the accident have been unable to cope with the complexity of the situation and satisfy individual and collective expectations and are still powerless to establish a context of social trust in the contaminated areas.

3.1 "Favorable" post-accident dynamics is based on the implicit perspective of returning to a normal situation

Any individual or collective action involves risk. To allow an activity undertaken on behalf of the common good to be carried out, a society has social conventions of mediation and regulation at its disposal which enable it to organize the risk taking collectively to limit the dangers involved. The borderline between risk and danger is not clear cut, but rather the result of social communication which operates through these regulations and mediations [9]. Establishing the acceptability of a risk is a social convention and can always be disputed and re-negotiated. It depends on the historical, cultural and social context, and on the degree of knowledge. This organization of risk taking always relies on social trust which enables responsibilities and specialist activities to be delegated.

In conventional accident situations, the post-accident social process is similar, at least to a certain extent, to a collective clean-up action which enables the tangible signs of the accident to be progressively erased. On the symbolic level, post-accident management aims to restore, to return to the pre-accident state. In this perspective, people talk about returning to a normal situation. The accident aspect is experienced as something external, as a deviation from the norm and countermeasures are introduced to fight the consequences of the accident. Social trust is preserved thanks to the existence of legitimate mediation between the risk and the individuals and safety systems are strengthened to restore a level of safety that people can again adhere to. The role of the experts in confirming the safety of the renewed system is essential in this process. Social mediation operates effectively thanks to the trust people have in the experts. The acceptability (frequency and consequences) of potential accident situations in the future allow the residual level of risk to be forgotten and suppressed and individuals no longer needs to worry about it. In this sense, each person is safe and can therefore focus on and look after its own affairs. Indeed, in it's deeper meaning, safety is the absence of worry (*sine cura*), that is to say the absence of risk-related stress.

From the individual point of view, it is however important to keep in mind that whatever the final issue of the post-accident period, it is impossible for the victims to return to the pre-accident state. Just like a cure, the resolution of a post-accident situation is not a return to a hypothetical normal state, nor even an adaptation to the new post-accident environment. The French philosopher G. Canguilhem describes this point in his "Essay on the normal and the pathological" [10]: "Man only feels healthy when he feels not just normal (that is to say adapted to the environment and its demands) but normative, i.e. capable of following new ways of life". In this same essay, he also notes that the morbid worry about avoiding situations that may possibly generate catastrophic reactions is an expression of the survival instinct. This instinct is not, according to the latter, the general law of life, but the law of a threatened life. A healthy organism tries less to maintain itself in its state and its environment than to express its nature. However, this means that the organism, when taking risks, must accept the possibility of their consequences.

The reference to normality in a post-accident situation remains, in a certain way, a trick of the post-accident process which facilitates post-accident resolution without significantly disturbing the social equilibrium. In one sense, post-accident social transaction operates without calling into question the actual social regulatory framework (experts' credibility, authorities' legitimacy and social trust). The perennial nature of the regulatory structures can be justified by the socially acceptable character of the accident situation. In certain cases, despite the unacceptable character of the accident consequences for certain categories of people (victims), the regulatory structures do not need to be adapted or to be replaced just because the victims are unable to constitute a social force and to press the authorities to reconsider the social regulatory framework. A new transaction about the risk is therefore avoided by maintaining an appearance of control, by a pseudo-return to the pre-accident state, by preserving power and the experts' positions of authority.

3.2 The "unfavorable" post-accident process at Chernobyl led to the loss of social trust

In the post-accident situation at Chernobyl, the population's appreciation of the acceptability of radiological risk was influenced by the mediation of experts because this risk was not part of traditional knowledge, as are natural disasters, for example. Generally speaking, such mediation is only possible if the population trusts the experts who propose to carry it out. It is this trust which provides the basis for their credibility, which is not only based on their technical skills [11]. Confronted with a choice concerning their health, people trust the person who is the expert, as a human being, not only as a technician.

In the post-accident situation at Chernobyl, the persistence of contamination, and the risk potentially associated with it, is a strong factor to prevent the return to a feeling of safety. The continuing confrontation of the population with contamination, as with the various countermeasures implemented, demands permanently attention. This cohabitation with an invisible and worrying host is a constant source of anxiety. The conventional mechanism of turning to the expert cannot release the tension created by direct confrontation with contamination. Faced with scientific uncertainty regarding the risks associated with low doses and the persistent disagreement among the experts about the best way to proceed, individuals are facing an abyss of complexity which is extremely difficult to manage.

In this context, any position of authority which is meant to confirm the acceptable nature of the risk, is discredited, even branded as dishonest, if it is seen to have anything but an objective scientific foundation. Confronted with uncertainty, the expert expresses a personal and pragmatic opinion dictated by an ethic of responsibility (he feels obliged to do something). In this way, he is moving away from his area of legitimacy, which is to deal with the situation from an objective scientific view point. Unable to express evidence of public interest, he loses his credibility.

The analysis provided here aims to explain the aspects of nuclear accidents which are not specific to the Chernobyl context. Beyond the generic problem posed by the social subject's confrontation with contamination and uncertainty during the post-accident phase, it must also be noted that the attitude of experts and authorities during and after the Chernobyl accident was a significant contributing factor in the loss of credibility and trust in the affected territories. Without going into details, the impact of censorship, secrecy and dissimulation, the anonymity of experts, the systematic denial of the risk, the incoherence of many statements and decisions at the time of the accident, the absence of clear information on the potential effects on health as well as the authorities' strategy of being euphemistic as regards the importance of these consequences during the post-accident situation contributed to the great confusion of the population and the loss of trust in the authorities. Regarding this, the close interdependency of the different phases of the accident (pre, during, post) must be emphasized : each phase creating the conditions for the beginning of the next.

3.3Scientific uncertainty and the experts' loss of credibility

The experts' loss of credibility has led to an ever-increasing demand for protection levels which, due to a lack of an objective limit, do not appear to be able to be clearly set. The proposed radiological protection standards no longer seem dictated by an objective knowledge of risk, but rather by the economic feasibility of the programs they involve. As the social demand is focused on the setting of an objective safety level, this situation leads to a disillusionment and an excess of worry of the population and finally the political authority is discredited. This situation leads to the collapse of social trust and cohesion. Everyone is left alone in the face of danger and unarmed in the face of complexity. Worry, stress, anxiety and depression are the signs of this insecurity, of the forgetting that does not happen [8].

In the post-accident social transaction at Chernobyl, a perverse chain reaction led to the inflation of the social resources assigned to post-accident management, without however, instilling a feeling of safety in the population. Without expressing an objective level of safety, the protection standards and criteria introduced by the different national legislation are structuring a framework for the compensation of the victims of the past and future consequences of the Chernobyl accident. The norm is no longer ensuring safety but compensating for a risk that has been experienced or is still there, that is to say for being put in danger. Significantly, the population talks about "coffin bonuses" when referring to the compensations introduced by the legislation.

The historical analysis [12] of the development of radiological protection concepts for the population after the accident clearly shows the post-accident dynamics which progressively swept away all the attempts made to impose a limit under which it would no longer be necessary to take the risk into account socially. It seems in particular that the concept of intervention level is no longer socially acceptable once the accident period is over. The post-accident phase calls for a return to universal protection standards, that is to say non-accident situations. In post-accident situations, the idea of specific dose limit does not seem to be a tool for social communication. The attempt to implement a life time dose in the late eighties is a good illustration. Initially set at 350 mSv the dose was, after difficult discussions among experts and politicians, reduced to 70 mSv. However, in practice, the post-accident management system takes into account the possibility of a risk well below this value as confirmed by the implementation of countermeasures for contamination levels between 1 and 5 Ci/km^2 (37 and 185 kBq/m^2) that is to say within the annual dose of 1mSv.

3.4Public action is powerless to release the social tension originated by the confrontation with risk

In a context of social mistrust, technical and scientific mediation cannot operate. In the Chernobyl post-accident situation, the lack of social trust, the experts' loss of credibility and as a consequence, the political authorities' loss of legitimacy, revealed a situation where the post-accident management aims and methods could not be established.

Generally speaking, the inability of public policy to release the social tension induced by the post-accident situation has been a constant over many years. A sign of this social tension is given by the stress measurements taken in the contaminated areas. The various psychometric surveys carried out on wide-ranging samples, have shown that the level of stress in the populations most affected by the accident (populations of contaminated areas and re-located populations) was significantly higher than that of populations unaffected by the accident [5,6]. Furthermore, they show that in the contaminated areas, the stress level has risen constantly since 1992.

This situation was particularly acute in the context of the post-soviet political culture, characterized by difficulty in taking public action without technical or scientific specifications. The Stalinist watch-word: "Technology decides everything" reveals the nature of the legitimacy of public action in the Soviet administrative culture. However extreme it may be in this context, this expression of power and knowledge remains a characteristic of Western technological and scientific societies. Therefore, this difficulty in dealing with non-scientifically explained and complex risk situations, is not only specific to the Chernobyl context, but would be observable elsewhere in the event of potential future accidents.

The individual's direct and long-lasting confrontation with environmental contamination make it difficult to attempt to set a generic acceptable risk level. In particular, over and above the exposure limits prevailing for normal conditions (either for the public or the workers) it does not appear possible to establish simply and objectively criteria of acceptability because each individual situation has its own particularity with regard to the risk and its management.

3.5 Complexity and the personal dimension of risk taking

The level of exposure in a post-accident context, finally depends on the behavior of each individual (living conditions and context, ability to adopt a risk reduction attitude...) but also according to the age of the person, his history (accidental exposures or medical history), as well as his physical and psychological state of health. However, the level of risk accepted by each individual is an autonomous choice in which numerous other criteria as those related to the health status and the objective level of risk must be taken into consideration. On the individual level, a person is free to take risks, and this cannot be reduced to a matter of technical options. This choice deeply commits the person.

As shown by a survey [13] carried out in Belarus in 1994, people residing voluntarily in contaminated areas generally clearly expressed their decision to live in this area despite the level of contamination of which they were perfectly aware. The decision to stay in or to move from the district seems to have been carefully considered. The reasoning behind this decision is the result of all the considerations and constraints around which it has gradually developed. These constraints are economic situation, emotional attachment to the land, to the language, to family, to the world they were brought up in, fear of unemployment, fear of not being able to cope elsewhere, and the attitude of others when faced with risk. In this way, the post-accident problem would appear to be deeply complex and difficult to look at objectively. In the Chernobyl context, the implementation of very prescriptive public policies (post-accident legislation of 1991, governmental programs) were unable to resolve the complexity of the post-accident situation in the perspective of the individual dimension.

Numerous indicators demonstrate the difficulties experienced by the system set up by the authorities to effectively taking charge of local and individual problems in their diversity and complexity. In reality, the national measures are most often unsuitable in their design as well as in the way they are put into practice. Developed on a national level, they are often governed by considerations that are only indirectly associated with radiological protection considerations. Set up on a local level, they are not adapted to the specific situation and are most often diverted from their initial aim by the different people involved. Studies have shown that the various groups at the local level use the ambiguities of the system to their advantage. The available funds are appropriated for individual or collective uses that have nothing to do with radiological protection considerations. This leads to deviation, great disorder and low productivity, or even counter-productivity in the systems set up to meet initial objectives.

On a psychological and social level, the centralized nature of the management of the post-accident situation in the Chernobyl context also appears to contribute to increasing the level of stress induced by the confrontation of the population with the contamination. The studies quoted above also show a feeling of powerlessness in the populations of contaminated areas in the face of the risk of contamination. Generally speaking, these people do not believe they are in any way able to contribute personally to protecting their health [6].

4. PERSPECTIVES

Although still limited, the analysis of the post-accident situation at Chernobyl allows to delineate some elements first for designing better communication with the public in case of an accident and, secondly, for establishing criteria and strategies for setting up protection objectives and selecting countermeasures which should be compatible with the progressive restoration of social trust among the affected population.

The Chernobyl experience has demonstrated that beyond a certain level of contamination of the environment the situation is not manageable and it is necessary to relocate the population and to abandon the concerned territories. This is of course true when the level of exposure of the population may lead to the appearance of deterministic effects but also when it is impossible to maintain the integrity of the basic social functions. At the opposite of these unacceptable situations, it is possible to define a level of residual contamination below which the risk can be considered as negligible. This situation must be characterized by the total absence of restrictions on the day to day life to allow the population to slowly forget the accident and its consequences after the process of mourning and symbolization leading to a certain form of return to normality.

Between these two situations (unacceptable and negligible), the population is facing a large spectrum of situations that can be qualified as tolerable. They are characterized by the existence of more or less severe restrictions on normal living conditions affecting the production, the distribution and the consumption of goods as well as the social organization related to education, the health care system or the collective leisure activities. Some of these constraints (countermeasures) which are implemented to last on rather long periods need to be adjusted with time and must be accompanied with an effective and independent structure of surveillance and control of the contamination to insure the transparency of the measurements of the residual contamination. This is a very important element to objectivate the level of risk as well as to decide about the actions to be adopted. Transparency must also prevail as far as the effectiveness and the cost of countermeasures are concerned.

The main difficulty with the management of post-accident situations concerns the establishment of criteria expressed as numerical values that could serve as reference to define the negligible, the tolerable and unacceptable levels. Various considerations have to be taken into account to elaborate these criteria. The Chernobyl experience is clearly demonstrating that it is impossible to set up reference values for structuring decision making processes related to the post-accident management without referring to those which are universally adopted for the protection of the public and workers in normal situations. Furthermore, the control of exposure in the contaminated areas necessarily involve to take into account the diversity of sources and in this perspective it is extremely difficult to envisage centralized and generic measures that could be applied to large areas. The implementation of a decentralized approach relying on the commitment of those directly affected by the accident seem to be the most effective way of attacking the problem.

The Chernobyl experience has also revealed the complexity of managing post-accident situations with the need to reconcile the radiological protection imperative with the various psychological and social dimensions. Taking only into account the radiological considerations may lead to a difficult situation because of the perverse effects of many countermeasures which are reinforcing the feeling of exclusion of the affected population and maintaining the doubt on the risk really at stake. At the opposite, giving priority to the psychological factors may involve serious consequences from the radiation protection point of view if the population is not fully aware about the exposure pathways and the mechanisms through which it is possible to control exposures. Observations have been made over the recent years confirming that the doses received by some part of the population living in the contaminated areas were increasing because of a lack of precaution or even in some cases of a denial of the potential impact of the contamination..

The main difficulty for restoring normal living conditions in contaminated territories is to build collective modalities to cope with the radiological residual risk in order to lead progressively to an acceptable situation from the psychological and social points of view. The success of this approach largely depends on the capability to set up individual and collective management of residual risk, in spite of the implementation of long lasting countermeasures. Anticipating a benefit, the involved persons must be in a position to actively and voluntarily manage the level of their exposure taking into account the specific situation they are facing. From a collective point of view, adequate means to control the risk must be available : concepts, assessment tools, equipment, budget...Such an approach is at the opposite of the one which inspired the various systems implemented so far in the affected Republics where the persons exposed to the residual contamination are compensated for the risk they take and not for the risk they contribute to avoid for themselves and the others. Furthermore, these compensation schemes reinforce the existing risk by objectifying it in financial terms and perquisites.

In practice, the adoption of a pro-active approach involving the commitment of the concerned population should result in the implementation of an ALARA type process close to the day-to-day activities of the population (at schools, in the plants, within families, at the farm level...). This decentralized approach should be implemented in the framework of a more global system ensuring the coherence and the rationale use of the material and financial support indispensable to restore satisfactory living conditions. An independent system for controlling the situation, particularly the contamination of food products and the close environment of the population, should also allow to facilitate the restoration of a climate of social trust within the population with regard to the experts and the authorities. Such mechanisms must rely on solid ethical basis clearly displayed in view to establish the transparency of the decision making processes and the responsabilization of to all concerned actors and primarily the affected population. To respond to the question : Is it possible to live here? it is inevitable to begin with a true characterization of the situation in term of risk which is the first element to develop a commitment to the situation with a protection culture based on the responsibility of each individual to the risk he or she is going to take freely and voluntarily.

5. CONCLUSION

Experience feedback from the post-accident situation in Chernobyl has thrown light on an emerging set of new problems. The question arises of how to reconstruct satisfactory living conditions within an environment which is subject to long term contamination and in a context of loss of trust and social cohesion. The Chernobyl accident has largely modified individual behavior towards risk. It led to the emergence of precariousness and vulnerability in the daily life of the population living in the affected territories. This accident was a factor of profound de-stabilization of the social and psychological balance of the population directly and indirectly affected. It also de-stabilized the mechanisms which are the basis of social life.

The post-accident crisis is, first and foremost, a crisis in terms of responsibility. The unacceptable nature of the consequences of the accident comes into play as a force conflicting with the processes that were in place as a means of socially regulating collective action prior to the accident. Indeed, these are seen as failures, in that they were unable to prevent a major technological accident. There follows a crisis of legitimacy affecting the exercise of political or technical power in all its forms. In such a context, habitual processes of social mediation, under which responsibility is socially delegated, and which are the basis of social trust, are profoundly called into question. In particular, the result is a substantial loss of the community of experts' credibility.

A further characteristic of the post-accident situation is the loss of social cohesion and a climate of mistrust. In the Chernobyl context, the process of allocation of responsibility for the accident in the post-accident phase forms part of a complex set of social inter-reactions. In particular, it has been observed that the authorities were unwarrantedly euphemistic in their description of the consequences of the accident; other typical reactions included seeking scapegoats in the operators, or attempts at shifting the responsibility for the health, psychological, and social consequences of the accident onto the shoulders of the victims themselves, evidenced in the concept of radio-phobia, according to which the reaction of the population confronted with the accident situation was groundless, irrational, and self-induced. Other identifiable social trends are the segregation and social exclusion of the population relocated outside the contaminated areas.

Any focus on radiological consequences likely to modify the human environment in the long term is not easy to dissociate from overall reflection on the question of the acceptability of risk in the accident and post-accident situation. In this context, the main results of the post-Chernobyl research in the field of social sciences do not lead to the conclusion that living in the affected territories is impossible because of the contamination level, but point out the importance that should be given to the acceptability of the risk. This acceptability has to be considered not only according to physical terms, but according to its psychological, social, economic dimensions which evolve with time and largely depend on the national and local contexts.

Although most of the population living in the contaminated territories is now confronted with an annual dose below 1 mSv, living in these territories implies an adaptation of habits and daily practices because of the presence of the contamination. In this context, the return to normality has to be considered not in terms of a return to the ante-accident situation, but rather as a new reference situation accepted by the population. However, if the precautionary principle is applied for these situations, the exposures of the population cannot be considered insignificant, and justifies the adoption of a responsible and prudent attitude, based on an ALARA type approach.

The on-going confrontation of the population with continuing contamination is an underlying cause for deep-seated disturbance at the psychological and social levels. Radiological risk is perceived by the population as a radically new phenomenon, one which is invisible and a cause of anxiety. In a social climate characterized by mistrust, particularly of the experts who are the main sources of knowledge concerning radiation risk, contamination, irrespective of its actual level, remains a legitimate source of fear and anxiety. Aggravating this fear is the population's sentiment that it is unable to act effectively against the risk. Positive action is precluded both by a lack of direct and objective knowledge of the situation and by the lack of ability to take action at the personal level, at a time when people are far from reassured by the action undertaken at the collective level.

Classic post-accidental management, centralized and largely based on intervention criteria, is inefficient to cope with social post-accidental regulation because of the complexity of the situation associated with the long-term contamination of the territories. Efficient management of the post-accidental situation requires the definition of a more flexible framework for public policies allowing the development of local management. In fact, post-accidental regeneration implies the direct involvement of the populations concerned in the contaminated territories. For this purpose, ethical and legal frameworks have to be designed in order to accompany the share of responsibilities and collective requirements with regards to the populations involved in the regeneration of the territories.

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Résumé

Cette contribution présente les caractéristiques principales au plan social et psychologique de la situation post-accidentelle dans la zone contaminée autour de Tchernobyl.Elle est basée sur une série d'enquêtes faites dans les républiques de la CEI. Le niveau élevé de stress observé chez une grande partie de la population est lié à la perception que les individus vivant dans la zone durablement contaminée ont de la situation, mais aussi aux effets secondaires de certaines contremesures prises pour mitiger les conséquences de la situation radiologique ou prises en guise de compensation. Même si l'ampleur de la catastrophe et les conditions économiques et sociales qui existaient au moment et après l'accident ont déclenché des réactions maximales de la part de la population, il est possible de tirer bien des leçons en vue de la conduite des opérations lors d'accidents d'une moindre portée temporelle et spatiale.Ces leçons dépassent le contexte historique, culturel, politique, sociologique, économique, et technique dans lequel il a eu lieu On démontre que l'objectif qui consiste à vouloir retourner à la normalité,c-à-d. à la situation d'avant l'accident constitue un obstacle majeur à la solution de la situation post accidentelle.La perte de confiance sociale est un des facteurs clé conduisant à un dévelopement défavorable de la situation.Elle est en grande mesure liée à la confrontation directe de la population à la contamination persistante qui induit anxiété et stress.Elle est aussi liée à la perte de crédibilité des experts découlant des incertitudes scientifiques associées aux effets potentiels des faibles doses.Ces facteurs ont conduit à une situation complexe ingouvernable à long terme au plan politique et social.On présente les premiers éléments d'une nouvelle approche conceptuelle de gestion des situations post-accidentelles.En principe elle veut rétablir l'engagement individuel à l'échelle locale de ceux directement touchés par la seule voie possible qui est la décentralisation de la gestion de la situation.Une des lecons majeures de Tchernobyl a été que chaque fois que cela est possible,il faut rejeter les mesures imposées en faveur de celles qui, étant volontaires, sont acceptées délibérément individuellement et collectivement.

Samenvatting

Deze bijdrage handelt over de meest opmerkelijke trekken die de situatie karakteriseerde op het psychologisch en sociaal vlak in het besmette gebied rond Tjernobyl na het reaktor ongeval.Het betoog steunt op een aantal enquêtes in de getroffen gebieden van de GOS-republieken.Het hoge stresssniveau waargenomen bij een groot gedeelte van de bevolking is te niet alleen te wijten aan de perceptie van de toestand door diegenen die in een blijvend besmet gebied leven, maar ook aan het vaststellen van de neveneffekten die uit de maatregelen die werden genomen ter kompensatie of om de radiologische gevolgen te milderen.Hoewel de omvang van de katastrofe en de ekonomische en politische toestand na het ongeluk een maximale reaktie van de bevolking veroorzaakte, zijn er lessen te halen voor het geval van een ongeluk met kleinere ruimtelijke en tijdelijke omvang.Deze lessen reiken verder dan de historische, kulturele, politische, sociologische, economische en technische samenhang ten tijde van de gebeurtenis.Er wordt er naar verwezen dat het beogen van een terugkeer naar de normaliteit, met name naar de situatie van voor het ongeluk een zware hindernis was om de postaccidentele situatie op te lossen.Een verdere sleutelfaktor die tot aftakeling leidt is het verlies van het sociaal vertrouwen veroorzaakt door de langdurige confrontatie van de bevolking met de besmetting die gepaard gaat met angst- en stressgevoelens.Dat verlies hangt ook samen met het verlies aan geloofwaardigheid van de deskundigen gebonden aan de onzekerheid aangaande de potentiële gevolgen van blootstelling aan lage doses.Dat alles bewerkte een complexe situatie die sociaal en politisch niet te beheren valt.Hier worden de eerste elementen van een nieuwe conceptuele aanpak geschetst om de post-accidentele situaties te managen.Principieel gaat het erom de persoonlijke inzet van de plaatselijk getroffenen te herstellen en dat is alleen mogelijk door een volledig gedecentralizeerde management van de post-accidentele situatie.Eén van de hoofdlessen van Tjernobyl is wel dat, waar het enigzins mogelijk is, alle administratieve verplichte of beperkende maatregelen moeten verworpen worden ten gunste van vrijwillige akties bewust op collectief en individueel vlak goedgekeurd.

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UNE DECENNIE APRES TCHERNOBYL
Conférence de Vienne, 9-12 avril 1996

Ar. A. Cigna
Président de l'Union Internationale de Radioécologie

La conférence a été organisée conjointement par la Commission Européenne, l'Agence Internationale de l'Energie Atomique et l'Organisation Mondiale de la Santé pour faire le point de la situation dix années après l'accident. Elle a été suivie par 800 participants de 72 pays.

Le but de la conférence était de fournir une mise à jour et un cadre objectif concernant les multiples aspects liés à la situation, aussi bien pour la zone proche de l'accident que pour le reste du monde et ceci à la lumière des études et mesures effectuées.

Il est utile de rappeler que déjà immédiatement après l'accident, l'Union Internationale de Radioécologie, grâce à la présence d'un grand nombre de ses membres en Russie, Belarus et Ukraine a été en mesure d'établir les contacts et les réunions scientifiques pour tenter d'arriver à une connaissance améliorée de la situation en général et du comportement des radionucléides dispersés dans le milieu ambiant en particulier. Ainsi, il a été possible, par exemple, de focaliser l'attention sur les écosystèmes naturels et seminaturels qui ont fait l'objet par la suite de recherches approfondies dans le cadre du programme de radioprotection de la Communauté Européenne.

L'Union internationale de Radioécologie a pu se prévaloir de son statut d'organisation scientifique, internationale, apolitique et non-gouvernementale. Les contacts et la collaboration ont pu avoir lieu facilement sans les restrictions bureaucratiques liées aux contacts officiels qui étaient délicats suite à l'instabilité de la situation politique. Ainsi, des visites sur site furent organisées aussi bien à Tchernobyl que dans l'Oural, où en 1957 un autre accident grave avait eu lieu dont l'existence était restée cachée durant des décennies.

Les effets sanitaires

Pour ces effets, vers lesquels naturellement toute l'attention était dirigée, il a été possible de faire une évaluation quantitative fiable. Les groupes d'individus à prendre en considération sont au nombre de trois.

Le premier groupe est constitué par le personnel d'intervention, appelés les "liquidateurs", le deuxième est constitué par la population vivant dans les zones contaminées et le troisième groupe est constitué par les enfants de moins de 14 ans au moment de l'accident qui ont été contaminés par les Iodes radioactifs. Les premiers intervenants étaient un millier alors que le nombre total des liquidateurs est de plusieurs centaines de milliers dont environ 200.000 ont reçu des doses plus significatives (soit autour de 100 milliSieverts) pendant leur mise en oeuvre. La population totale résidant dans les zones contaminées s'élevait, elle, à 3.700.000 personnes.

Pour le millier de personnes du groupe des premiers intervenants on peut s'attendre à une augmentation de l'incidence de cas de cancers de l'ordre de 10 %, soit de quelques dizaines de cas supplémentaires par rapport à la prévalence naturelle.

Pour chacun des grands groupes, c'est-à-dire des "liquidateurs" et de la population des résidents on peut s'attendre à 2000 à 2500 cas de cancers supplémentaires dans les vingt années après l'accident pour une prévalence naturelle de 41.500 pour les "liquidateurs" et de 422.000 pour la population.

Cependant, à ce jour, aucun cas de leucémie dans le groupe des 200.000 "liquidateurs" n'a été observé alors que 200 auraient dû être constatés. Le taux de mortalité observé dans ce groupe est celui de la population en général.

135.000 personnes ont été évacuées des zones les plus contaminées. Elles ont reçu une dose moyenne de 10 mSievert. Jusqu'à présent aucune augmentation de l'incidence de cancers - si toutefois on exclut les cas des tumeurs de la thyroïde des enfants - ni des cas de leucémie n'a été observé alors que l'on aurait pu s'attendre à quelques 150 cas supplémentaires par rapport aux 20.000 cas dûs à des causes naturelles.

De toute manière, l'estimation épidémiologique est très difficile compte tenu de l'incidence très faible attendue et compte tenu d'autres dommages sanitaires qui étaient et sont en augmentation constante dans la population depuis avant l'accident, augmentation liée à la contamination générale du milieu ambiant. Cette augmentation a été observée aussi dans les zones non concernées par l'accident de Tchernobyl ou dans les zones contaminées à la suite de l'accident.

Tumeurs de la thyroide des enfants

Dans ce cas précis, on a pu constater une augmentation du nombre de cas dans le groupe des enfants ayant moins de 14 ans au moment du diagnostic pour la période 1990-1994 (la moyenne d'âge des enfants atteints était de 10 ans); environ 1.000.000 d'individus ont absorbé une dose moyenne à la thyroïde de 0,5 à 1 Gray et parmi eux on peut s'attendre à 4.000 à 8.000 cas de tumeurs contre les 10 à 40 cas attendus pour des causes naturelles. Jusqu'à présent, un millier de cas additionnels ont été observés.

Comme la mortalité liée aux tumeurs de la thyroïde est comprise entre 5 et 10 % on peut s'attendre à une mortalité accrue de 200 à 800 cas liés à cette cause.

La souffrance chronique due au stress ambiental.

Les conséquences les plus sévères se sont avérées être les dérangements observés dus au stress chronique qui ont provoqué chez un grand nombre de personnes un état de malaise attribué aux effets des radiations alors que les radiations pouvaient être exclues comme facteur de déclenchement. En réalité, il s'agit d'un effet psychosomatique dû à la désinformation sur les effets réels des radiations et à la profonde méfiance du public vis-à-vis des autorités. Malheureusement, les médias ont répandu des informations absolument non fondées qui n'ont pas été démenties ni par la communauté scientifique, ni par les experts des différents pays.

La passivité de ceux qui auraient dû prendre position et fournir les informations correctes ou corriger les informations erronées fournies par d'autres, a été stigmatisée durant la conclusion de la conférence.

Le sarcophage

La structure de confinement construite dans des conditions extrêmement difficiles autour du réacteur accidenté pourrait en cas d'écroulement provoquer une dispersion de poussières radioactives susceptibles de conduire à une exposition du personnel employé sur le site. Toutefois, dans la pire des hypothèses aucune conséquence n'est attendue en dehors de la zone des 30 km autour de la centrale. On peut estimer la dose à 50 mSievert par an due à ce qui pourrait rester dans un rayon de 2 km.

Problèmes de radioécologie

La consommation d'eau potable dans le bassin de Kiev et de poisson de la mer Noire ne comporte pas de risques significatifs puisque les niveaux de concentration des substances radioactives sont très inférieures aux niveaux considérés acceptables et continuent de diminuer.

La contribution due au Strontium et au Plutonium en dehors de la zone d'exclusion des 30 km à la dose aux personnes est très faible.

Au cours des années qui suivirent l'accident, les médias ont fait état d'une augmentation notable de malformations et de monstruosités observées chez les animaux: des études approfondies ont, au contraire, montré qu'il n'y avait aucune différence d'incidence entre les zones contaminées et non contaminées. Ce genre d'effet peut être catégoriquement exclu.

En ce qui concerne la contamination des sols, les experts en radioécologie estiment que les contre-mesures devraient être limitées à la récupération des dépôts contaminés constitués au cours de la phase d'intervention après l'accident.

On estime aussi qu'il ne faudrait pas intervenir sur les sols dont la contamination superficielle est supérieure à 1,5 Terabecquerel par km carré, ceci afin d'éviter une augmentation de la dose collective aux individus.

Pour les terrains moins contaminés, l'intervention peut être envisagée si la récupération répond à des motifs socio-économiques.

Dans ce contexte, les contre-mesures spécifiées dans le contrat "RESSAC" (réhabilitation des surfaces et des sols, après l'accident) effectué au cours des années passées dans le cadre du programme de radioprotection de la Communauté Européenne peuvent être appliquées.

Conclusions

Au cours de la session finale du congrès, il y a eu des interventions remarquées des journalistes scientifiques comme d'ailleurs des experts. Il a ainsi été possible de démentir les rapports non fondés concernant les milliers de morts dûs à des tumeurs, conséquence de l'accident, qui sont régulièrement repris par les médias. Les valeurs rapportées à la conférence devraient, une bonne fois pour toutes, permettre de revenir à la réalité et derejeter définitivement les élucubrations phantasmagoriques.

Evidemment ces considérations n'enlèvent rien à la gravité de l'accident ni à la gravité des mesures qui ont été prises. Deux experts, L.A. Ilyin et V.F. Demin qui ont préparé un rapport détaillé sur l'accident sur demande des autorités soviétiques ont failli payer de leur vie pour la franchise et l'honnêteté scientifique de leur rapport: seulement l'intervention directe de Gorbatchov, qui a exigé toute la transparence voulue, les a mis à l'abri de conséquences personnelles graves. Au contraire, il les a congratulés.

Il faut rappeler que les interventions en faveur des "enfants de Tchernobyl" sont louables, puisqu'elles permettent de donner à ces enfants des vacances et des conditions de vie meilleures que dans leur milieu d'origine. De telles initiatives pourraient aussi être prises en faveur des enfants en difficulté (ex-Yougoslavie, Ruanda, Liban, etc). Du point de vue des soins spécifiques liés aux effets des radiations ces séjours sont totalement inefficaces puisque ces soins devraient en principe aider à établir le diagnostic et ensuite permettre de procéder à la cure des tumeurs thyroïdiennes. Sauf cas exceptionnels, le traitement devrait être fait sur place dans un milieu connu des malades, c'est-à-dire sur place, ceci aussi pour éviter ne fut ce que les difficultés de communication qui sont souvent sérieuses.

Le Dr. J.R. Harrison du National Radiation Protection Board (G.B.) A résumé la situation en une phrase lapidaire: "immédiatement trop peu a été fait et puis trop ultérieurement".

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112. Mr. Pierre ST1EVENART, BNS
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113. Dr. Christian THIELEMANS, C.B.M.T.
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115. Prof. François TONDEUR, ISIB
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116. Mr. José VANBEGIN, Université Catholique de Louvain, INAN
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117. Dr. Christian VANDECASTEELE, SCK-CEN
Radiation Protection Research Section - Radioecology Section
Boeretang 200, 2400 Mol

118. Mr. Serge VANDERPERRE, Tractebel
Avenue Ariane 7 - 1200 Bruxelles

119. Mr. Etienne VAN DER STRICHT, ABR
Domaine de Brameschhof, L 8290 Kehlen

120. Mr. Marc VANDORPE, General Manager, Tecnubel
Boeretang 195 - 2400 Mol

121. Mr. Filip VANHAVERE, SCK-CEN
Boeretang 195 - 2400 Mol

122. Mrs. Valentine VANHOVE, NIRAS-ONDRAF
Place Madou 1 B25, 1210 Bruxelles

123. Mrs. Katrien VAN LAEKEN, Tractebel
Avenue Ariane 7, 1200 Bruxelles

124. Dr Hans VANMARCKE, SCK-CEN
Boeretang 200, 2400 Mol

125. Mrs Ingrid VAN REGENMORTEL, SCK-CEN
Boeretang 200, 2400 Mol

126. Mr. Theo VAN RENTERGEM, Engineer Director,
M.E.A.- Administration for Energy - NG III
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127. Mrs. Françoise VANTHEMSCHE, Tractebel
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129. Dr. Freddy VERREZEN, SCK-CEN
Boeretang 200, 2400 Mol
130. Mr. Fabian WAETERMANS, A.V.Nuclear
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131. Mrs. An WERTELAERS
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