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# Chernobyl at Twenty

## PROGRAM

Forty-Second Annual Meeting

April 3–4, 2006

Crystal Forum
Crystal City Marriott
1999 Jefferson Davis Highway
Arlington, Virginia

National Council on
Radiation Protection
and Measurements

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# Chernobyl at Twenty

The April 26, 1986 accident at the Chernobyl Nuclear Power Plant near Kiev in the Ukrainian Republic of the Former Soviet Union was the worst nuclear power accident in history. Large numbers of people and a vast amount of land were contaminated in the Ukraine Republic, Belarus Republic, Russia, Europe, and Scandinavia. More than 200,000 people in the Ukraine and Belarus Republics were evacuated and resettled as a result of significant fallout from the Chernobyl accident.

On the 20th anniversary of this disastrous event, the 2006 NCRP Annual Meeting will provide a comprehensive retrospective review and analysis of the effects of the Chernobyl nuclear accident on human health and the environment. Topics that will be discussed by international experts include:

1. the initial release, distribution and migration of radioactivity from Chernobyl;
2. efforts to cleanup, contain and dispose of radionuclides released by the accident;
3. health effects observed in emergency responders and cleanup workers;
4. exposures and health effects among populations living close to, and distant from, the Chernobyl reactor site;
5. lessons learned from the Chernobyl accident, including improved nuclear safety procedures, better preparedness for future nuclear accidents, and more effective management and mitigation of human health consequences of such events; and
6. international perspectives on the future use of nuclear technology and nuclear power in comparison with other power sources.

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# Program Summary

## Monday, April 3, 2006

### Opening Session

8:00 a.m. **Welcome**
Thomas S. Tenforde, *President*
National Council on Radiation Protection and Measurements

### Third Annual Warren K. Sinclair Keynote Address

8:15 a.m. **Introduction**
Thomas S. Tenforde

8:20 a.m. **Retrospective Analysis of Impacts of the Chernobyl Accident**
Mikhail Balonov
International Atomic Energy Agency

### Environmental Impacts and Mitigation of Residual Radiation

Lynn R. Anspaugh, *Session Chair*

This session will focus on the initial release, the distribution and migration, and efforts to clean up radionuclides released in the Chernobyl accident. Other topics of discussion include the environmental, agricultural and natural ecosystem effects of Chernobyl radiation.

9:10 a.m. **Chernobyl Radionuclide Distribution and Migration**
Yury A. Izrael
Institute of Global Climate and Ecology
Russian Academy of Sciences

9:40 a.m. **Chernobyl Radionuclide Distribution, Migration, Environmental and Agricultural Impacts**
Rudolf Alexakhin
Russian Institute of Agricultural Radiology and Agroecology

10:10 a.m. **Break**

10:30 a.m. **Radiation-Induced Effects on Plants and Animals: Findings of the United Nations *Chernobyl Forum***
Thomas G. Hinton
University of Georgia

11:00 a.m. **Cleanup, Containment and Disposal of Radionuclides Released by the Chernobyl Accident**
Bruce A. Napier
Battelle, Pacific Northwest Laboratory

## Dosimetry and Health Effects in Emergency Responders and Cleanup Workers

Elena Buglova, *Session Chair*

This session will describe the dosimetry and acute and delayed health effects in highly exposed emergency responders, cleanup workers, and workers involved in stabilizing the Chernobyl reactor sarcophagus. Acute radiation responses and the development of cancer and noncancer effects, including somatic tissue damage, reproductive effects, and psychological impacts, will be described.

11:30 a.m. **Physical Dosimetry and Biodosimetry in Highly Exposed Emergency Responders and Cleanup Workers**
Vadim V. Chumak
Scientific Center for Radiation Medicine
Ukraine Academy of Medical Sciences

12:00 noon **Acute Health Effects and Radiation Syndromes**
Fred A. Mettler, Jr.
University of New Mexico

12:30 p.m. **Lunch**

1:30 p.m. **Late Health Effects, Including Cancer and Noncancer Effects**
Victor Ivanov
Medical Radiological Research Center
Russian Academy of Sciences

2:00 p.m. **Worker Health and Safety Issues in Reinforcing the Entombment of the Chernobyl Reactor**
Ilya Likhtarov
Scientific Center for Radiation Medicine
Ukraine Academy of Medical Sciences

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## Population Exposures and Health Effects

John D. Boice, Jr., *Session Chair*

This session will describe the dosimetry and health effects of Chernobyl radiation on populations close to and distant from the site of the reactor. Special emphasis will be placed on discussing the high incidence of thyroid cancer, and data on other noncancer effects related to somatic tissue damage, reproductive effects, and psychological impacts among the affected populations.

2:30 p.m. **Radiation Dosimetry for Highly Contaminated Ukrainian, Belarusian and Russian Populations, and for Less Contaminated Populations in Europe**
Andre Bouville
National Cancer Institute

3:00 p.m. **Thyroid Cancer Among Exposed Populations**
Elaine Ron
National Cancer Institute

3:30 p.m. **Other Health Effects of the Chernobyl Accident, Including Nonthyroid Cancer and Noncancer Effects**
Geoffrey R. Howe
Columbia University

4:00 p.m. **Psychological and Perceived Health Effects of the Chernobyl Disaster**
Evelyn J. Bromet
State University of New York

4:30 p.m. **Break**

## Thirtieth Lauriston S. Taylor Lecture on Radiation Protection and Measurements

5:00 p.m. **Introduction of the Lecturer**
Robert O. Gorson

5:10 p.m. **Fifty Years of Scientific Investigation: The Importance of Scholarship and the Influence of Politics and Controversy**
Robert L. Brent
Alfred I. duPont Institute Hospital for Children

6:00 p.m. **Reception in Honor of the Lecturer**

# Tuesday, April 4, 2006

8:30 a.m. **Business Session**

9:30 a.m. **Break**

## Lessons Learned from Chernobyl

Lars-Erik Holm, *Session Chair*
Swedish Radiation Protection Institute

This session will summarize the lessons learned from the Chernobyl accident, including the need to implement improved nuclear safety technology, more effective preparedness for nuclear incidents, better understanding of the public response to such incidents, and managing and mitigating the health consequences in exposed populations. Research needs for more effectively capturing initial data following nuclear accidents and responding to such incidents will also be described.

10:00 a.m. **Rehabilitation of Living Conditions in Territories Contaminated by the Chernobyl Accident: The ETHOS Project**
Jacques Lochard
Centre d'etude sur l'Evaluation de la Protection dans le domaine Nucleaire

10:30 a.m. **Lessons Learned from Chernobyl and Other Emergencies: Establishing International Requirements**
Thomas McKenna
International Atomic Energy Agency

11:00 a.m. **Public Perception of Risks, Rehabilitation Measures, and Long-Term Health Implications of Nuclear Accidents**
Shunichi Yamashita
World Health Organization

11:30 a.m. **Ongoing and Future Research Needs for Achieving a Better Understanding of the Consequences of Nuclear Emergencies**
Elisabeth Cardis
International Agency for Research on Cancer

12:00 noon **Lunch**

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## International Perspectives on the Future of Nuclear Science, Technology and Power Sources

Frank L. Bowman, *Session Chair*

This session will focus on the international view toward the future of nuclear power in comparisons with other power sources. These comparisons will be based on potential environmental and health effects, source availability, public acceptance, and cost.

1:00 p.m. **New Reactor Technology and Operational Safety Improvements in Nuclear Power Systems**
Michael L. Corradini
University of Wisconsin

1:30 p.m. **Future Challenges for Nuclear Power Plant Development Research, and for Radiological Protection Sciences**
Edward Lazo
International Agency for Research on Cancer

2:00 p.m. **Moving to a Low-Carbon Energy Future: Perspectives on Nuclear and Alternative Power Sources**
M. Granger Morgan
Carnegie-Mellon University

2:30 p.m. **The Chernobyl Aftermath *vis-a-vis* the Nuclear Future: An International Perspective**
Abel J. Gonzalez
Autoridad Regulatoria Nuclear

3:00 p.m. **Break**

## Summary and Discussion of Major Findings from Chernobyl

Richard A. Meserve, *Session Chair*

3:30 p.m. **Session Chairs Present Brief Summaries of the Key Points Made by Speakers**

4:20 p.m. **Question and Answer Session**

5:00 p.m. **Closing Remarks**
Thomas S. Tenforde, *President*
National Council on Radiation Protection and Measurements

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# Abstracts of Presentations

## Monday, April 3, 2006

### Opening Session

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Thomas S. Tenforde, *President*
National Council on Radiation Protection and Measurements

### Third Annual Warren K. Sinclair Keynote Address

8:15 a.m. **Introduction**
Thomas S. Tenforde

8:20 a.m. **Retrospective Analysis of Impacts of the Chernobyl Accident**
Mikhail Balonov
International Atomic Energy Agency

The Chernobyl accident in 1986 was the most severe nuclear accident in the history of the world nuclear industry. However, the recently completed *Chernobyl Forum* concluded that after a number of years, along with reduction of radiation levels and accumulation of humanitarian consequences, severe social and economic depression of the affected Belarusian, Russian and Ukrainian regions and associated serious psychological problems of the general public and emergency and recovery operation workers had become the most significant problem.

The majority of the >600,000 emergency and recovery operation workers and five million residents of the contaminated areas in Belarus, Russia and Ukraine received relatively minor radiation doses which are comparable with the natural background levels. This level of exposure did not result in any observable radiation-induced health effects.

An exception is a cohort of several hundred emergency workers who received high radiation doses; of whom ~50 died due to radiation sickness and subsequent diseases.

In total, it is projected by statistical modelling that radiation has caused, or will cause, the premature deaths of

~4,000 people from the 700,000 affected by the higher radiation doses due to the Chernobyl accident. As about one-quarter of people die from spontaneous cancer, the radiation-induced increase of ~2 % will be difficult to observe. However, in the most exposed cohorts of emergency and recovery operation workers, some increase of particular cancer forms (*e.g.*, leukemia) in early time periods has already been observed.

Another cohort affected by radiation are children and adolescents who in 1986 received substantial radiation doses in the thyroid due to the consumption of milk contaminated with radioiodine. In total, ~4,000 thyroid cancer cases have been detected in this cohort during 1992 to 2002; more than 99 % of them were successfully treated.

The psychosocial and economic impacts were also devastating. One hundred and sixteen thousand people were evacuated immediately after the accident, and the total number of people who left severely contaminated areas eventually reached 350,000. While these resettlements helped to reduce the radiation dose, it was deeply traumatic for those involved. Persistent myths and misperceptions about the threat of radiation have resulted in “paralyzing fatalism” among both Chernobyl workers and residents of affected areas. As a result, mental health problems, poverty, and “lifestyle” diseases have come to pose a greater threat to affected communities than radiation exposure.

Radiation levels in the environment have decreased by a factor of several hundred since 1986 due to natural processes and countermeasures. Therefore, the majority of the land that was previously contaminated with radionuclides is now safe for life and economic activities. However, in the Chernobyl exclusion zone and in some limited areas of Belarus, Russia and Ukraine some restrictions on land use should be retained for decades to come.

Countermeasures implemented by the governments in coping with the consequences of the Chernobyl accident were timely and adequate. However, modern research shows that the direction of these efforts must be changed. Social and economic restoration of the affected regions, as well as the elimination on the psychological burden of the general public and emergency workers, must be a priority.

Another priority for Ukraine should be the decommissioning of the destroyed Chernobyl Unit 4 and the safe management of radioactive waste in the Chernobyl exclusion zone, as well as its gradual remediation.

The influence of the Chernobyl accident on the nuclear industry has been enormous. Chernobyl had not only cast doubt on the ability of nuclear power plant operators to prevent severe accidents, but had emblazoned itself on public consciousness as proof positive that nuclear safety was impossible. Some countries decided to reduce or terminate further construction of nuclear facilities, and the expansion of nuclear capacity came to a near standstill. It has taken nearly two decades of strong safety performance to repair the industry's reputation.

## Environmental Impacts and Mitigation of Residual Radiation

Lynn R. Anspaugh, *Session Chair*

9:10 a.m. **Chernobyl Radionuclide Distribution and Migration**

Yury A. Izrael
Institute of Global Climate and Ecology
Russian Academy of Sciences

To monitor terrestrial radioactive contamination from the Chernobyl accident, observational networks had been organized over territories of many countries as well as in many large cities and in particularly contaminated (dangerous) regions; a spectral aero-gamma surveying was carried out on the stations.

Mapping of radioactive contamination is being improved. An important description of the extent of contamination that is in the *National Atlas of Russia*, is now being developed in Russia. Apparently, this is the first time a section on radioactivity is being included into this *Atlas*. Information on radioactivity will be placed in the volume "Nature. Ecology," and this will show a history of formation of the radioactive contamination field on Russia's territory.

Estimates obtained from 1986 maps of the $^{137}Cs$ contamination on the European part of Russia's territory show that the total accumulation is 29 PBq (784 kCi). Fifty-six percent of this is from global contamination, which is rather uniformly present everywhere, but 38 % is the consequence of the accident at the Chernobyl nuclear power station (and the main part of this value falls on the European part of the country's territory, *i.e.,* ~90 %).

The idea to create the *Atlas* of radioactive contamination of the Northern Hemisphere and the whole world will be discussed. Certainly, this work can be done only on a basis of international cooperation.

Values of relative danger from the long-lived radionuclides after nuclear explosions as well as after the Chernobyl accident have been determined with account for their mobility and biological accessibility. It was found that the $^{137}$Cs danger at the Chernobyl accident was considerably greater (hundreds of times relative to $^{90}$Sr) than occurs after nuclear explosions.

The problem of "aging" of the field of contamination that has been formed will be discussed.

Collection of data characterizing the radionuclide migration has now resulted in a method for their classification with derivation of a new index of "half-removal of the radionuclide from one or another natural areas." For instance, for the Bryansk-Belarus forested lowlands we have found for the last 20 y the following: loamy sand soils of the outwash plains (forested lowlands) under the pine forests have unique ability to resist migration of $^{137}$Cs, firmly fixing it within a thin layer of a coarse humus soil, lying under a bedding (carrying away the cesium outside the upper 5 cm layer of soil of ~7 % for 20 y after the fallout). Thus, radioactive decay is the main process of decreasing the contamination levels in the landscape considered.

In hydromorphic soils of the forested lowlands, a considerable removal of cesium from the upper 5 cm layer takes place: it is from 27 to 46 % of the storage in alluvial soils with different degrees of gleying, while in soil of the flood plain swamp this removal is 70 %.

Recommendations.

- Due to the fact that the norms of the maximum-permissible contamination for $^{90}$Sr (3 Ci km$^{-2}$) and $^{239+240}$Pu (0.1 Ci km$^{-2}$), established in the Soviet Union in May 1986, were never revised, any return of population into zones with higher values should be prohibited.
- To introduce into the section "recommendations of the meeting" of the *Atlas*, a new paragraph "nuclear terrorism" in which the dangers of nuclear terrorism should be described and a recommendation to organize an international group for development of practical recommendations for prevention against any nuclear terrorism should be done.

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9:40 a.m. **Chernobyl Radionuclide Distribution, Migration, Environmental and Agricultural Impacts**

Rudolf Alexakhin
Russian Institute of Agricultural Radiology and Agroecology

The ecological impacts of the Chernobyl accident, as well as health effects, are among the first priorities in minimizing the Chernobyl consequences. In the Chernobyl accident there was a release into the environment of artificial radionuclides that covered huge areas with a wide landscape spectrum, and the dispersed radionuclides were involved into the biological chain of migration "soil-plant-animal-man." Radionuclide migration in different natural environments (agrosphere, terrestrial natural lands, forests, wetlands) depended on a large number of factors, with characteristic pronounced reduction over time in the physicochemical and biological mobility of radionuclides.

Long-term dynamics of radionuclide transport in the environment and their accumulation by plants and animals is dictated by the radionuclide physicochemical form, biological peculiarities of plants and environmental conditions. Specific features of radionuclide transfer *via* the trophic chains are responsible for the formation of ecological niches in landscapes and critical objects of the environment that show an increased accumulation of radioactive substances.

The radionuclides escaped to the environment were a source of radioactive contamination of environmental objects, on the one hand, and irradiation of plant and animal populations and ecosystems, on the other hand. The main radiological paradigm is the statement that the area where the radiation damage to plants and animals occurred is less than that in which restrictions have been imposed on the economic activity or it has been prohibited (including residence of the population), because of exceeding the permissible radionuclide levels. The area of radiation damage was confined by the 30 km zone around the Chernobyl Nuclear Power Plant (ChNPP), but the restrictions of human economic activity extended to hundreds of kilometers from the accident site.

The radiation damage showed itself at all levels of biological organization, from molecular through cellular to total destruction of natural ecosystems. It depended on plant and animal radiosensitivity that varied widely, the density of radioactive contamination, and other factors. At the level of individual organisms and ecosystems, visible radiation damage in the affected area appeared as death of ecosystems (pine forests) and living organisms (mammals). In the post-accident period three stages are identified in the development of processes of radiation-induced changes in nature: (1) acute (several weeks to six months) dominated by radiation damage, (2) intermediate (up to 2 y), and (3) long-term (dominated by processes of post-radiation recovery).

To mitigate consequences of the accident in the affected regions, rehabilitation measures were implemented on a large scale to reduce the intensity of radionuclide migration in the environment and dose burdens to the population. These protective countermeasures covered all natural environments (agricultural ecosystems, aquatic sites, forest stands, etc.). The radiologically and economically most significant efforts proved to be the remediation measures in the sphere of agricultural production. The introduction of organizational, agronomical and veterinary measures has resulted in manifold decreases in the concentration of the main dose-producing radionuclides in farm products and guaranteed the production of food stuffs that meet radiological standards, thus significantly reducing dose of internal (and therefore total) exposure of the population.

10:10 a.m. **Break**

10:30 a.m. **Radiation-Induced Effects on Plants and Animals: Findings of the United Nations *Chernobyl Forum***

Thomas G. Hinton
University of Georgia

The response of biota to Chernobyl irradiation was a complex interaction among radiation dose, dose rate, temporal and spatial variation, varying radiosensitivities of the different taxonomic groups, and indirect effects from other events. The radiation-induced effects to plants and animals within a 30 km zone around Chernobyl can be framed in three broad time periods relative to the accident. An intense exposure period during the first 30 d was dominated by gamma irradiation from short-lived radionuclides, and approximated an acute exposure for most biota living in the local area. Mortality and pronounced reproductive effects occurred during this initial exposure period. Dose rates from gamma emissions were >20 Gy $d^{-1}$. A second phase extended through the first year of exposure during which time the short-lived radionuclides decayed and longer-lived radioisotopes were transported to different components of the environment by physical, chemical and biological processes. Effects to several levels of biological organization occurred, including community-level effects to soil invertebrates. In general, ~80 % of the total dose accumulated by plants and animals was received within three months of the accident, and over 90 % was due to beta irradiation. The third and continuing long-term phase of exposure has been chronic, with dose rates <1 % of the initial values, and derived largely from $^{137}$Cs and $^{90}$Sr contamination. The doses accumulated and the observed effects on plants, soil invertebrates, and terrestrial vertebrates will be summarized. Physiological and genetic effects on biota, as well as the indirect effects on wildlife of removing humans from the Chernobyl area are placed in the context of what was known about radioecological effects prior to the accident. Recommendations for future research are suggested. (Presentation coauthored by Rudolf Alexakhin, Mikhail Balonov, Norman Gentner, Jolyon Hendry, Boris Prister, Per Strand, and Dennis Woodhead).

11:00 a.m. **Cleanup, Containment and Disposal of Radionuclides Released by the Chernobyl Accident**

Bruce A. Napier
Battelle, Pacific Northwest Laboratory

The destruction of the Unit 4 reactor at the Chernobyl Nuclear Power Plant (NPP) resulted in the generation of radioactive contamination and radioactive waste at the site and in the surrounding area (referred to as the exclusion zone). The future development of the exclusion zone depends on the strategy for converting Unit 4 into an ecologically safe system, *i.e.*, the development of a New Safe Confinement (NSC), the dismantlement of the current shelter, removal of fuel-containing material, and eventual decommissioning of the accident site.

In addition to uncertainties in stability at the time of its construction, structural elements of the shelter have degraded as a result of corrosion. The main potential hazard of the shelter is a possible collapse of its top structures and release of radioactive dust into the environment. An NSC with a 100 y service life is planned to be built as a cover over the existing shelter as a longer-term solution. The construction of the NSC will enable the dismantlement of the current shelter, removal of highly radioactive, fuel-containing materials from Unit 4, and eventual decommissioning of the damaged reactor.

In the course of remediation activities, large volumes of radioactive waste were generated and placed in temporary near-surface waste-storage and disposal facilities. Trench and landfill type facilities were created from 1986 to 1987 in the exclusion zone at distances 0.5 to 15 km from the NPP site. This large number of facilities was established without proper design documentation, engineered barriers, or hydrogeological investigations and they do not meet contemporary waste-safety requirements. To date, a broadly accepted strategy for radioactive waste management at the reactor site and in the exclusion zone, and especially for high-level and long-lived waste, has not been developed.

More radioactive waste will be generated during NSC construction, possible shelter dismantling, removal of fuel-containing materials, and decommissioning of Unit 4. According to the Ukrainian National Program on radioactive waste management, there are different options for proper disposal of different waste categories. The planned options for low-radioactivity waste are to sort the waste according to its physical characteristics (*e.g.*, soil, concrete, metal) and possibly decontaminate and/or condition it for beneficial reuse (reuse of soil for NSC foundations, melting of metal pieces), or send it for disposal. The long-lived waste is planned to be placed into interim storage. Different storage options are being considered, and a decision has not yet been made. High-level radioactive waste is planned to be partially processed in place and then stored at a temporary storage site until a deep geological disposal site is ready for final disposal. A specific investigation for exploring the most appropriate geological site in this area may begin in 2006. Following such planning, the construction of a deep geological disposal facility might be completed before 2035 to 2040. (Presentation coauthored by Eric Schmieman and Oleg Voitsekovitch).

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## Dosimetry and Health Effects in Emergency Responders and Cleanup Workers

Elena Buglova, *Session Chair*

11:30 a.m. **Physical Dosimetry and Biodosimetry in Highly Exposed Emergency Responders and Cleanup Workers**

Vadim V. Chumak
Scientific Center for Radiation Medicine
Ukraine Academy of Medical Sciences

Unexpected event of the reactor explosion at Chernobyl Nuclear Power Plant (ChNPP) Unit 4 on April 26, 1986 had far exceeded the scale of the maximum projected accident and, in turn, led to failure of routine dosimetry systems in place. As a result of this unfavorable development, NPP personnel and workers engaged in the accident localization and emergency response actions received high doses lacking any dosimetric monitoring. Moreover, even in later times, due to the enormous scale of the emergency and excessive number of cleanup workers (liquidators) engaged in activities within the 30 km exclusion zone, dosimetric monitoring of this cohort was conducted inadequately, both in terms of coverage and accuracy of dose assessment.

Therefore, two decades after the accident, there is a need for retrospective reevaluation of historical dose records as well as reconstruction of individual doses by means of retrospective dosimetry techniques. This need is caused by demands of post-Chernobyl radiation epidemiological studies (*i.e.,* Ukrainian-American studies on leukemia and cataract) as well as by the request for evaluation of the real impact of the Chernobyl accident on the most exposed cohort—cleanup workers.

This presentation offers a critical review of dosimetric monitoring practices at the time of Chernobyl cleanup and reports on development and application of retrospective dosimetry techniques.

The historical dose records, called also official dose records (ODR), were produced by several dosimetry services acting in Chernobyl in 1986 to 1990 and the quality of this data is variable, being determined by approaches to dose monitoring and the general culture of the respective dosimetry services. So, along with quality thermoluminescent dosimeter monitoring data produced by the highly professional Dosimetry Department of Administration of Construction No. 605 there were also dose assessments generated in the units of the Ministry of Defense—dose estimates obtained by imprecise "group dosimetry" (one dosimeter issued per group of liquidators) and "group estimation" (when a single dose value was assigned to a whole group of cleanup workers based on the results of dose estimation) methods. This dosimetric information can be applied in epidemiological studies only after proper verification and correction. The results of retrospective evaluation of dosimetry practices and verification of ODR will be presented.

Unfortunately, the coverage of the liquidator population with ODRs was insufficient (only ~50 % of cleanup workers included in the State Chernobyl Registry have dose records) and therefore there is a need for retrospective dose assessment. The arsenal of feasible retrospective dosimetry techniques include instrumental electron paramagnetic resonance (EPR) spectroscopy of tooth enamel, biodosimetric fluorescent *in situ* hybridization (FISH) and analytical ("time-and-motion") techniques. Each of these techniques has specific application limits determined by sensitivity thresholds (FISH, EPR), availability of samples (EPR), and accuracy of dose estimates (analytical methods). Therefore, application of these methods or their combination depends on the design of the epidemiological study and thus particular requirements for dosimetric support. The presentation discusses applicability of each of these techniques and gives examples of application of EPR and RADRUE (analytical technique) in the Ukrainian-American study of leukemia among Chernobyl cleanup workers. Another approach involving a combination of retrospective adjustment of ODR and assessment of beta doses to eye lens was applied in the framework of the Ukrainian-American Chernobyl Ocular Study.

12:00 noon **Acute Health Effects and Radiation Syndromes**

Fred A. Mettler, Jr.
University of New Mexico

The Chernobyl accident resulted in almost half of the reported accidental cases of acute radiation sickness reported worldwide. Cases occurred among the plant employees and first responders but not among the evacuated populations or general population. The diagnosis of acute radiation sickness was initially considered for 237 persons based on symptoms of nausea, vomiting and diarrhea. Ultimately, the diagnosis of acute radiation syndrome (ARS) was confirmed in 134 persons. There were 28 short-term deaths of which 95 % occurred at whole-body doses in excess of 6.5 Gy. The gastrointestinal syndrome was seen in 15 patients and radiation pneumonitis was seen in eight patients. Underlying bone-marrow failure was the main contributor to all deaths during the first two months.

The general treatment regimen included parenteral nutrition, antibacterial and antiviral agents, transfusions, correction of metabolic abnormalities, and topical skin therapy. Allogeneic bone-marrow transplantation was performed on 13 patients and an additional six received human fetal liver cells. All of these died except one individual who later was discovered to have recovered his own marrow and rejected the transplant. Two or three patients were felt to have died as a result of transplant complications.

Skin doses exceeded bone-marrow doses by a factor of 10 to 30 and some patients had skin doses in the range of 400 to 500 Gy. Beta burns significantly complicated the treatment of many of the patients who were suffering from severe bone-marrow depression. At least 19 of the deaths were felt to be primarily due to infection from large area beta burns. Internal contamination was of relatively minor importance in treatment and survival of the patients, with most patients having body burdens of <1.5 to 2 MBq. Evaluation of induced $^{24}Na$ showed that neutron exposure was a very small contributor to the total dose. Within 12 y of the accident an additional 11 ARS survivors died from various causes. Long-term treatment has included therapy for beta burn fibrosis and skin atrophy as well as for cataracts. (Presentation coauthored by Angelina Guskova and Igor Gusev).

12:30 p.m. **Lunch**

1:30 p.m. **Late Health Effects, Including Cancer and Noncancer Effects**

Victor Ivanov
Medical Radiological Research Center
Russian Academy of Sciences

In 1986 the USSR Ministry of Health Care initiated a program to establish the All-Union Distributed Registry (UDR) of persons exposed to radiation due to the Chernobyl accident. The computer center of the Research Institute of Medical Radiology, which is part of the Academy of Medical Sciences (AMS), located in the town of Obninsk in the Kaluga oblast, became the core of the Registry. The UDR was formed with contributions from all republics of the former Soviet Union, and from various scientific research institutions and organizations. Information was mainly supplied to the UDR by republican information computer centers of the Ministries of Health Care of Belarus, the Russian Federation, and Ukraine.

In 1992, after the disintegration of USSR, and on the basis of the UDR, the Russian National Medical and Dosimetric Registry (RNMDR) was set up in the Medical Radiological Research Center (MRRC) of the Russian Academy of Medical Sciences (RAMS) (former Research Institute of Medical Radiology). The principal objective of the Registry was the organization of long-term automated individual records of persons exposed to radiation due to the Chernobyl accident, and also their children and subsequent generations, as well as the assessment of their health status.

As of January 1, 2005, RNMDR contained individual medical and dosimetric data for 614,887 persons, including 186,395 emergency workers and 367,850 residents of four contaminated oblasts of Russia (Bryansk, Kaluga, Oryol and Tula).

The estimation of radiation risks of solid cancer for emergency workers is based on data from the cohort of male emergency workers from six regions in Russia, including 55,718 persons with documented external radiation doses in the range 0.001 to 0.3 Gy who worked within the 30 km zone in 1986 to 1987. The mean age at exposure for these persons was 34.8 y and the mean external radiation dose was 0.13 Gy. In the cohort 1,370 cases of solid cancer were diagnosed and three follow-up periods were considered: 1991 to 1995, 1996 to 2001, and 1991 to 2001. The second follow-up period was chosen to allow for a minimum latency period of 10 y, which is characteristic of solid cancers. The values of excess relative risk per unit dose (ERR $Gy^{-1}$) for solid malignant neoplasms have been estimated to be 0.33 (95 % CI: –0.39, 1.22) (internal control) for the follow-up period 1991 to 2001 and 0.19 (95 % CI: –0.66, 1.27) for 1996 to 2001.

The epidemiological assessment of radiation risks of leukemia covered a cohort of emergency workers living in the European part of Russia (71,870 persons) for whom personalized data were available on external radiation doses (the mean dose was 107 mGy). The follow-up periods that were considered include: 1986 to1996 and 1997 to 2003. If only two groups of emergency workers are compared: those with an external radiation dose <150 mGy and with a dose >150 mGy, it was found that during the first 10 y the leukemia incidence rate was 2.2 times higher in the second group than in the first. At the same time, no differences were detected in the leukemia incidence rates for these groups during the second follow-up period (1997 to 2003).

There are two main conclusions to be drawn from the above: first, only emergency workers who received a radiation dose more than 150 mGy should be considered as members of the risk group, and secondly, the risk of radiation-induced leukemias occurred during the first 10 y after the Chernobyl accident.

A radiation epidemiological analysis was conducted of cerebrovascular diseases in emergency workers. Special consideration was given to cerebrovascular diseases in the cohort of 29,003 emergency workers who arrived to the 30 km Chernobyl zone during the first year after the accident. The statistically significant heterogeneity of the risk of cerebrovascular diseases is a function of duration of staying in the 30 km zone: ERR $Gy^{-1}$ = 0.89 (95 % CI: 0.42; 1.35) for a duration less than six weeks and ERR $Gy^{-1}$ = 0.39 (95 % CI: 0.01; 0.77) on the average for all workers. The risk group with respect to cerebrovascular diseases are those who received external radiation doses more than 150 mGy in less than six weeks (RR = 1.18; 95 % CI: 1; 1.40). For doses above 150 mGy a significant risk of cerebrovascular diseases as a function of averaged dose rate (mean daily dose) was observed: ERR per 100 mGy $d^{-1}$ = 2.17 (95 % CI: 0.64; 3.69). The duration of staying in the 30 km zone itself, regardless of the dose factor, influenced the cerebrovascular disease morbidity very little: ERR per week = –0.002 (95 % CI: –0.004; –0.001).

2:00 p.m. **Worker Health and Safety Issues in Reinforcing the Entombment of the Chernobyl Reactor**

Ilya Likhtarov
Scientific Center for Radiation Medicine
Ukraine Academy of Medical Sciences

Activities on the stabilization of the sarcophagus (or object shelter) at reactor number 4 at the Chernobyl Nuclear Power Plant now are under intensive implementation. The existing sarcophagus was urgently built in a few months in 1986 under extremely harsh radiation conditions in order to isolate the destroyed structure from the environment. Now more than 150 tons of partially dispersed spent fuel with $^{239}Pu$ and $^{240}Pu$ specific activities of 10 GBq $kg^{-1}$ remains within the deteriorating object shelter. Approximately 1 TBq $kg^{-1}$ of beta, gamma emitters ($^{137}Cs$, $^{90}Sr$) are also stored inside the shelter. The current Shelter Implementation Plan (started in 1997) consists of two stages: reinforcing the former shelter and building the new safe confinement.

Currently the activities in the shelter are being carried out under conditions of simultaneous external and internal radiation exposures. Medical and dosimetry supervision has been developed in the shelter to ensure the radiation safety of the workers in the sarcophagus. In the framework of this supervision the following procedures are in place:

- Entry (check-in) medical control of the workers followed by permission to work in the shelter. The absence of diseases in a predefined list is verified prior to granting permission.
- Entry control of the radionuclides plutonium, americium and cesium present in the body.
- Routine control of external exposure of workers using dosimeters.
- Routine control of alpha and beta emitters measured in nose swabs.
- Routine daily control (during the period of work in the shelter) of the $^{137}Cs$ body burden.
- Routine control of transuranium radionuclides measured in daily excretion (fecal samples).

If the content of transuranium radionuclides in the daily fecal sample exceeds the investigation level, or in the situation of high radioactive contamination of nose swabs, special medical and dosimetry controls are initiated. Special control includes:

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- complete medical investigation in the clinic of the Center for Radiation Medicine, and
- three extra samplings of daily fecal and urine samples.

A decision on the possibility of work continuation in the shelter is made based on the special control results.

Up to October 1, 2005, more than 1,500 workers went through the entry control. Measurements were made of the average background level of alpha emitters that were present in daily fecal samples as a result of ingestion of food contaminated from the fallout of transuranium radionuclides in the Ukraine.

For ~50 % of persons who worked in the shelter during the first few months after the beginning of the Shelter Implementation Plan, measurements were made of the content of $^{239}Pu$ in daily fecal samples. Requirements for individual respiratory protection, and also the regulation of behavior in the shelter, led to a decrease in the number of persons with high levels of alpha emitters in daily fecal samples to 10 to 20 %.

Approaches for the interpretation of bioassay dosimetry control results, and the integrated data on the levels of external and internal exposure of the workers involved in the Shelter Implementation Plan, are considered in this presentation.

## Population Exposures and Health Effects

John D. Boice, Jr., *Session Chair*

2:30 p.m. **Radiation Dosimetry for Highly Contaminated Ukrainian, Belarusian and Russian Populations, and for Less Contaminated Populations in Europe**

Andre Bouville
National Cancer Institute

Explosions at the Chernobyl Nuclear Power Plant (ChNPP) in the Ukraine early in the morning of April 26, 1986 led to a considerable release of radioactive materials during 10 d. The cloud from the reactor spread many different radioactive nuclides, particularly those of iodine and cesium, over the majority of European countries, but the greatest contamination occurred over vast areas of Belarus, the Russian Federation, and Ukraine. Because of its short half-life, radioactive iodine ($^{131}I$) disappeared long ago. In contrast, surface contamination from radioactive cesium can still be measured in many parts of Europe.

The general public was exposed to radioactive materials externally from the radioactive cloud and later from radionuclides deposited in the soil and other surfaces, and internally from inhalation during the cloud's passage and from resuspended materials and consumption of contaminated food and water.

The massive releases of radioactive materials into the atmosphere brought about the evacuation of ~116,000 people from areas surrounding the reactor during 1986, and the relocation after 1986 of ~220,000 people from Belarus, the Russian Federation, and Ukraine. Vast territories of those three republics were contaminated to a substantial level. The population of those contaminated areas from which no relocation was required, amounts to about five million people. In other European countries, no relocation was necessary.

As the major health effect of Chernobyl is an elevated thyroid cancer incidence in children and adolescents, much attention has been paid to the thyroid doses resulting from intakes of $^{131}I$, which were delivered within two months following the accident. The thyroid doses received by the inhabitants of the contaminated areas of Belarus, Russia and Ukraine varied in a wide range, mainly according to age, level of ground contamination, milk consumption rate, and origin of the milk that was consumed. Reported individual thyroid doses varied up to ~50 Gy, with average doses of ~0.03 to 0.3 Gy, depending on the area in which people were exposed. In other European countries, the thyroid doses are estimated to have been much lower, but to exhibit a large degree of variability as well.

In addition, the presence in the environment of long-lived radioactive isotopes of cesium ($^{134}Cs$ and $^{137}Cs$) has led to a relatively homogeneous exposure of all organs and tissues of the body *via* external and internal irradiation, albeit at low rates. The whole-body (or effective) dose estimates for the general population accumulated during 20 y after the accident (1986 to 2005) range from a few millisievert to some hundred millisievert with an average dose of between 10 and 20 mSv in the contaminated areas of Belarus, Russia and Ukraine.

The methods used to estimate the thyroid and effective doses, their geographic distribution, their variability according to age and dietary and lifestyle habits, as well as the uncertainties attached to the dose estimates are described in this presentation.

3:00 p.m. **Thyroid Cancer Among Exposed Populations**

Elaine Ron
National Cancer Institute

As a result of the Chernobyl Nuclear Power Plant accident, massive amounts of radioactive materials were spewed into the environment and large numbers of individuals living in Ukraine, Belarus and Russia were exposed to radioactive iodines, primarily $^{131}I$. Iodine-131 concentrated in the thyroid gland of residents of the contaminated areas, with children and adolescents being particularly affected. In 1991, the first report of an unusually high frequency of thyroid cancer in Ukrainian children appeared in *Lancet*. Over the next decade, a substantial increase in thyroid cancer incidence was documented among exposed children in all three affected countries and compelling evidence of an association between pediatric thyroid cancer incidence and $^{131}I$ dose to the thyroid gland accumulated.

The limited data currently available suggest that thyroid cancer risk may decrease with increasing age at exposure in a manner similar to the pattern observed following external radiation; however, the data are not entirely consistent. Among nonexposed individuals, thyroid cancer incidence is about two to three times greater among women than men. Studies from Chernobyl do not demonstrate a significant difference in radiation-related relative risks by gender, but the absolute number of excess thyroid cancer is larger among women. Based on data from recent large case-control studies, iodine deficiency appears to enhance the risk of developing thyroid cancer following exposure from Chernobyl, whereas iodine prophylaxis appears to reduce the risk. Data on adult exposure are limited and not entirely consistent. Similarly, information on thyroid cancer risks associated with *in utero* exposure is insufficient to draw any conclusions. The lack of information on these two important population groups indicates an important gap that needs to be filled.

Twenty years after the accident, excess thyroid cancers are still occurring among persons exposed as children or adolescents. While the long-term risks cannot yet be quantified, we can expect an excess of thyroid cancers for several more decades if external radiation can be used as a guide. What is not certain is whether the risk will increase or stabilize over time. To date, thyroid cancers have been the main medical consequence of the Chernobyl accident. Since the survival rate of thyroid cancer is exceptionally high, the number of reported deaths from the disease has been relatively low (<1 %). However, due to uncertainties regarding the future, long-term follow-up is necessary.

3:30 p.m. **Other Health Effects of the Chernobyl Accident, Including Nonthyroid Cancer and Noncancer Effects**

Geoffrey R. Howe
Columbia University

There are two basic approaches to studying the long-term health effects of the Chernobyl accident. The first approach is to carry out epidemiologic studies within the affected populations, particularly in the contaminated areas of Belarus, the Russian Federation, and Ukraine. The second approach is to make use of risk projection models predicting risk from high-dose studies such as the atomic-bomb survivors and applying it to estimated doses received by the affected populations.

Direct studies in the affected populations have the main advantage that no extrapolation is needed from higher doses, high-dose rates, genetically different populations and differing underlying environmental conditions. However, these studies typically lack statistical power due to generally small doses (except the thyroid). Risk projection models, on the other hand, involve a measure of extrapolation with its corresponding uncertainty, but, because they are carried out generally at higher doses, their statistical power will be greater.

The major effect of the Chernobyl accident in terms of morbidity has been a large excess of thyroid cancer. Studies of thyroid cancer risk from exposure to radioactive iodines in young people illustrate the utility of direct studies within the affected populations as contributing to science, in particular for associations for which previously there have been little available data.

Of particular interest is also leukemia. Apart from liquidators, there is little evidence of any measurable increase in risk for those exposed *in utero*, those exposed as children and those exposed as adults, a finding which is consistent with the risk projections from high-dose studies, since doses received were too small to provide adequate statistical power for detecting differences.

Dr. Victor Ivanov (1:30 p.m.) has shown both dose estimates and occurrence of leukemia from Russian liquidators based on registry data. Two other studies are presently being conducted in Ukraine and in Belarus and Russia. In both studies cases and controls are identified from the state registries of liquidators. Chernobyl doses are estimated by eliciting from the individuals the time and places in which they were involved in the Chernobyl 30 km exclusion zone. The scientifically important question is whether risk of leukemia experienced by these liquidators is reduced compared to the risk seen in the atomic-bomb survivors due to the effect of dose and dose rate.

The only other cancer in which there has been some evidence of relationship to Chernobyl is breast cancer. This is based on an ecologic study in Ukraine which provided the suggestion of increased risk in young women, but the risk estimates are much in excess of those previously found in non-Chernobyl studies. Among noncancer diseases of particular interest are autoimmune thyroiditis, cardiovascular disease, and cataracts. Until further studies are carried out, these apparent associations must be regarded as equivocal.

In summary, many studies have been carried out of the Chernobyl accident, but apart from thyroid diseases in those exposed as children and leukemia amongst liquidators, they have not yet contributed substantially to the scientific evidence on radiation risks. This does not mean that population health effects are restricted to these diseases, but it seems more appropriate to rely on risk projections from other studies, together with Chernobyl doses, to estimate the total chronic disease burdens induced by exposure following the Chernobyl reactor accident.

4:00 p.m. **Psychological and Perceived Health Effects of the Chernobyl Disaster**
Evelyn J. Bromet
State University of New York

The mental health impact of Chernobyl is regarded by many experts as the largest public health problem unleashed by the accident to date. This presentation reviews the findings from general population studies of stress-related symptoms, research on the developing brain, studies of highly exposed cleanup workers, and mortality statistics on suicide. With respect to general population studies, depressive, anxiety (including post-traumatic stress symptoms), and medically unexplained physical symptoms were two to four times higher in Chernobyl-exposed populations compared to controls, although these symptoms rarely met the level of criteria for a psychiatric disorder. These symptom elevations were found as long as 11 y after the accident. Severity of symptomatology was significantly related to receiving a diagnosis of a “Chernobyl-related health problem” from a local physician as well as other Chernobyl-stress variables. The findings on the developing brain of exposed children who were *in utero* at the time of the accident have been inconsistent to date. The World Health Organization as well as American and Israeli investigators found no significant relationship between the exposure and neuropsychological functioning, but a Ukrainian group reported that Chernobyl increased the rate of mental retardation and organic brain disorders. It is worth noting that the lowest level of exposure in which mental retardation was found in the offspring of survivors of Hiroshima and Nagasaki was higher than the highest level of exposure reported for most Chernobyl populations. With respect to cleanup workers, Ukrainian researchers have reported that the most highly exposed surviving liquidators suffer from cognitive impairment, EEG changes, schizophrenia, dementia, and other signs of organic brain dysfunction. The methodology for this line of research was not transparent, and alcoholism and other confounders were not evaluated. Finally, a report from Estonia on mortality in cleanup workers through 1993 found that suicide was the leading cause of death. This finding has not yet been replicated in the other republics from which cleanup workers were recruited. In general, the results of the population morbidity studies are consistent with mental health patterns occurring after other disaster events, including the atomic bombings of Hiroshima and Nagasaki, the Three Mile Island accident, and other toxic environmental contaminations. The context of the Chernobyl accident, including the complicated series of events that ensued, the extreme stresses endemic in that part of the world, and the absence of baseline epidemiologic data, create difficulties in interpreting the findings. However, the magnitude and persistence of the adverse mental health effects are striking. Long-term psychosocial interventions might be helpful although preliminary research is needed to determine whether the Chernobyl-affected populations would avail themselves of such services. Physician education regarding the effects of the radiation exposure, as well as the effects of the numerous Chernobyl-linked stressors, is equally important.

4:30 p.m. **Break**

## Thirtieth Lauriston S. Taylor Lecture on Radiation Protection and Measurements

5:00 p.m. **Introduction of the Lecturer**
Robert O. Gorson

**Fifty Years of Scientific Investigation: The Importance of Scholarship and the Influence of Politics and Controversy**
Robert L. Brent
Alfred I. duPont Institute Hospital for Children

6:00 p.m. **Reception in Honor of the Lecturer**

# Tuesday, April 4, 2006

8:30 a.m. **Business Session**

9:30 a.m. **Break**

## Lessons Learned from Chernobyl

Lars-Erik Holm, *Session Chair*
Swedish Radiation Protection Institute

10:00 a.m. **Rehabilitation of Living Conditions in Territories Contaminated by the Chernobyl Accident: The ETHOS Project**
Jacques Lochard
Centre d'etude sur l'Evaluation de la Protection dans le domaine Nucleaire

The ETHOS Project emerged from different investigations, which had been conducted in the Ukraine, Russia and Belarus during the 1992 to 1995 period, aiming to better understand the living conditions of the populations in the contaminated territories by the Chernobyl catastrophe and to shed light on the wide-ranging social consequences of the accident remaining unresolved. It was a pilot research project supported by the radiation protection research program of the European Commission implemented in Belarus with the overall aim to initiate a new approach for the rehabilitation of the contaminated territories complementing the national program established in the early nineties in the newly formed Republic to mitigate the consequences of the catastrophe.

The objective of the project was primarily to improve the living conditions of the inhabitants based on their direct involvement in the day-to-day management of the radiological situation together with the local authorities and professionals and an interdisciplinary team of European experts with specific skills in radiation protection, agronomy, social risk management, communication, and cooperation in complex situations. The objective was not to produce new scientific knowledge but to apply existing knowledge to the development of a practical know-how for the populations. The approach addresses both technical and social aspects of the problems posed by the presence of the radioactive contamination in all human activities.

In a first phase of the project (1996 to 1998), the ETHOS approach was implemented in the village of Olmany located in the Stolyn district in the Southern part of Belarus. During this first phase, a few tens of villagers have been engaged in a step-by-step involvement process to progressively regain control of their day-to-day life. In the second phase of the project (1999 to 2001), the ETHOS approach has been extended to four localities inside the district (Belaoucha, Gorodnaya, Retchitsa and Terebejov) with the objective of studying the possibility and the conditions for its future diffusion by Belarus local authorities and professionals in the whole contaminated territories of the Republic.

The ETHOS experience has shown that the direct involvement of the population in the day-to-day management of the radiological situation was a necessary approach to complete the rehabilitation program implemented by public authorities in contaminated territories, especially in the long term. It also demonstrated that to be effective and sustainable, the involvement of the local population must rely on the dissemination of a "practical radiological protection culture" within all segments of the population, and especially within professionals in charge of public health and education.

This presentation will cover the main features of the methodological approach of the ETHOS Project. It also presents how it was practically implemented in the villages and what have been its main results, but also its limitation for the rehabilitation of living conditions in contaminated territories after a nuclear accident or a radiological event. These last issues led the Belarus authorities to develop the international CORE Program building on the key lessons of the ETHOS Project.

10:30 a.m. **Lessons Learned from Chernobyl and Other Emergencies: Establishing International Requirements**

Thomas McKenna
International Atomic Energy Agency

In the past 20 y, nuclear and radiological emergencies have occurred that cover much of the anticipated range of causes and types. The Chernobyl emergency involved a facility that could be identified in advance as warranting emergency preparations, whereas the Goiania emergency was at a totally unforeseen location. Emergencies similar to the one in Goiania could occur anywhere. In addition there have been numerous lesser nuclear and radiological emergencies involving lost and stolen sources, irradiation facilities, criticalities, and medical applications of radionuclide sources. The International Atomic Energy Agency (IAEA) has studied these emergencies and the experience gained forms the basis for IAEA efforts to develop international guidance and standards. This presentation lists some of the major lessons learned from dealing with these emergencies, followed by principles derived from these lessons. These principles steer the IAEA in development of international guidance.

The severity of all the major nuclear emergencies which have occurred to date was not recognized or comprehended by facility operators in the initial phase, even when there were indisputable indications of their severity in the control room. The reason for this situation was that severe emergencies were not considered in the preparedness process because their occurrence was considered to be inconceivable.

**Principle 1:** Emergency arrangements should address severe emergencies to include those of low probability.

In several major nuclear emergencies, the implementation of urgent protective actions was delayed for days or more. During the Chernobyl emergency, these delays could have resulted in deaths off-site, except that the plume impacted an uninhabited area. These delays also resulted in people off-site consuming milk and vegetables contaminated with radioiodine for several days as they were not aware of the hazard. This caused an increase in thyroid cancer, especially in children. This increase was seen at distances of more than 350 km from the site and could have been easily prevented if the population had been informed not to drink the local milk.

During the response to the Goiania and Chernobyl emergencies, it was impossible to establish justified criteria for the implementation of urgent and longer-term protective actions and other countermeasures (*e.g.*, compensation schemes) because they were only being developed after the start of the emergency, *i.e.*, during a period of heightened emotions and mistrust of officials and the scientific community.

> **Principle 2:** The criteria and policies for implementation of urgent and longer-term actions and for return to normality (ending countermeasures) should be established in advance as part of the preparedness process.

Experience shows that existing international guidance does not address all the necessary potential protective actions and countermeasures, which need to be based on radiation protection principles. These include personal monitoring and decontamination, decontamination of property, release of contaminated property and products, initial medical screening, long-term medical follow-up, counseling of pregnant women, and termination of countermeasures (return to normality).

> **Principle 3:** International guidance should be developed for the application of radiation protection principles for the conceivable range of countermeasures and emergency conditions.

The use of "conservative assumptions" during the Chernobyl and Goiania emergencies led to actions that many feel did more harm than good. Unnecessarily conservative assumptions were often used because it was not clear at the time how to deal with uncertainties and under which conditions the existing guidance should be applied. There is a general tendency to implement actions at levels below those recommended if it is unclear whether the guidance addresses the situation at hand.

> **Principle 4:** Guidance should be based on realistic assumptions and should include a clear statement of the conditions under which it applies.

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Public officials make decisions concerning the implementation of actions affecting the public. Many emergencies have demonstrated that decision makers must have the support of the public and other stakeholders to implement decisions effectively. Therefore, the decision makers must understand the guidance for dealing with the radiological risk and be able to explain it to the public and the stakeholders. At Goiania and other emergencies the public also wanted assurance that the actions being taken guaranteed the "safety" of all members of their families, including those as yet unborn. Following Chernobyl, Goiania and other emergencies, the public took inappropriate and in some cases harmful actions due to fear and misunderstandings concerning radiation risks and how to reduce them. These fears were in part due to the use of the linear-nonthreshold hypothesis by unofficial sources, the use of cryptic technical terms, and the reluctance of technical experts to provide the definitive guidance needed and wanted by the public.

**Principle 5:** The criteria for implementing actions should be accompanied by a plain language explanation that enables the decision maker to understand them, reasonably consider them, and explain them to the public and other stakeholders. The explanation must make it clear to the public which actions are appropriate and inappropriate, and how the recommended actions ensure their "safety" and that of all other family members, including unborn children.

Some decisions for countermeasures are based on measurements in the field (*e.g.*, mSv $h^{-1}$ from deposition). However, during many emergencies this was not possible because there were no default operational intervention levels (OILs) in place at the start of the emergency, according to which decisions could have been made based on these measurements. This resulted in delays, confusion and different protective actions being taken by states for the same measured levels.

Furthermore, different countermeasures were implemented simultaneously during a response. These included relocation, personal decontamination, medical screening, and long-term compensation. In some cases the criteria for implementation of these countermeasures were not based on internally consistent radiation protection principles. For example, in one case the deposition levels at which compensation was provided for those living in the area were below the OILs for implementation of other actions, such as relocation or medical follow-up. Such apparent inconsistencies resulted in confusion and an inflated perception of the risk among the public.

> **Principle 6:** Internationally endorsed default OILs should be established for implementation of possible protective measures and countermeasures, which are based on an internally consistent foundation.

Chernobyl, Goiania and other emergencies demonstrated that immediately after the emergency response there was immense pressure from the public, officials and the media to take actions to correct the problem and return the situation to normal. Experience during a wide variety of emergencies shows that officials, when under this intense pressure, take highly visible actions, even if these are only minimally effective or even counterproductive.

> **Principle 7:** International guidance should include a process for developing plans for the implementation of post-emergency countermeasures that are justified and optimized.

An internationally endorsed framework should be established for the development of integrated guidance for implementing justified protective actions and countermeasures for the full range of possible emergencies, including those of low probability, which will assure the public that they and their loved ones are safe.

11:00 a.m.

**Public Perception of Risks, Rehabilitation Measures, and Long-Term Health Implications of Nuclear Accidents**

Shunichi Yamashita
World Health Organization

The past two decades have witnessed dramatic changes in public health governance and international cooperation on the Chernobyl Nuclear Power Plant accident, especially after the end of the Cold War. The World Health Organization (WHO) has committed itself deeply in the public health issues around Chernobyl, and has participated in various health projects such as health monitoring and cancer screening. WHO has also been engaged in research activities such as the Chernobyl Tissue Bank (http://www.chernobyltissuebank.com), in close collaboration with the Ministries of Health in Belarus, Russia and Ukraine.

In addition to the official report of the *Chernobyl Forum* "Health Expert Groups" in 2005 (http://www.who.int/ionizing_radiation/en), the task of WHO is not only to analyze and clarify the global burden of Chernobyl-related illness, but also to promote the well-being of the local residents who suffered from radiation fallout at a low-level radiation exposure for a long period of time. The uncertainty of such low-dose radiation effects makes it difficult to communicate with the public concerning their perception of radiation risk. It is also controversial to develop concrete suggestions and guidelines for follow-up and long-term monitoring of the local residents.

First, public perception of radiation risks is easily influenced by other sources of information such as mass media. It is also true that the recognition of health concerns and health actions reaches far beyond medical care. Health opportunities and outcomes are determined by much broader economic, environmental, political and institutional arrangements, and health conditions can be tackled based on how effective they are.

One of the conclusions of the *Chernobyl Forum* on health issues is that each country must provide people with accurate information, not only on how to live safely in regions of low-level radioactive contamination, but also how to lead a healthy lifestyle and create new livelihoods; this is clearly a reassuring message from the international societies to Chernobyl.

Second, during the rehabilitation period, there should be measures to avoid any myths and misconceptions about the unnecessary threat of radiation among the residents of affected areas. Nevertheless, based on the experience and knowledge of the atomic-bomb survivors in Hiroshima and Nagasaki, long-term health monitoring and early disease detection and treatment are critically needed and beneficial for the target and high-risk groups who have been already identified in the *Chernobyl Forum* report. However, systems and services are often inefficient or inadequate in the task of delivering what is urgently needed on the site. Fading memories and reduced financial support from abroad create more difficulties in the support of such long-term health monitoring at the personal, domestic and national levels.

WHO can contribute to a new challenge at Chernobyl, probably the most difficult part, which is the uncertainty of complicated effects of environmental factors on human health, including mental health. WHO can work together with multiple partners to reduce the scientific and public knowledge gap, and to help the communities achieve an optimal level of physical, mental and social health and well-being. (Presentation coauthored by Zhanat Carr, Hajo Zeeb and Michael Repacholi).

11:30 a.m. **Ongoing and Future Research Needs for Achieving a Better Understanding of the Consequences of Nuclear Emergencies**

Elisabeth Cardis
International Agency for Research on Cancer

Today, 20 y after the Chernobyl accident, there is (apart from the dramatic increase in thyroid cancer incidence among those exposed in childhood and adolescence) no clearly demonstrated increase in the incidence of cancers in the most affected populations that can be attributed to radiation from the accident. Increases in incidence of cancers in general and of specific cancers (in particular breast cancer) have been reported in Belarus, the Russian Federation, and Ukraine, but much of the increase appears to be due to other factors, including improvements in diagnosis, reporting and registration.

Recent findings indicate a possible doubling of leukemia risk among Chernobyl liquidators and a small increase in the incidence of premenopausal breast cancer in the most contaminated districts, which appear to be related to radiation dose. Both of these findings, however, need confirmation in well-designed analytical epidemiological studies with careful individual dose reconstruction.

The absence of demonstrated increases in cancer risk–apart from thyroid cancer—is not proof that no increase has in fact occurred. Based on the experience of atomic-bomb survivors, a small increase in the relative risk of cancer is expected, even at the low to moderate doses received. Such an increase, however, is expected to be difficult to identify in the absence of careful large-scale epidemiological studies with individual dose estimates. It should be noted that, given the large number of individuals exposed, the absolute number of cancer cases caused by even a small increase in the relative risk could be substantial, particularly in the future.

At present, the prediction of the cancer burden related to radiation exposure from Chernobyl must be based on the experience of other populations exposed to radiation and followed up for many decades. Such predictions are uncertain, as the applicability of risk estimates from other populations with different genetic and environmental backgrounds is unclear.

It is essential therefore that monitoring of the health of the population be continued in order to assess the public health impact of the accident, even if, apart from leukemia among liquidators and possibly breast cancer in young women in the most contaminated areas, little detectable increase of cancers due to radiation from the Chernobyl accident is expected.

Studies of selected populations and diseases are also needed in order to study the real effect of the accident and compare it to predictions. Careful studies may in particular provide important information on the effect of exposure rate and type of radiation in the low- to medium-dose range, and on factors that may modify radiation effects. As such, they may have important consequences for the radiation protection of patients and the general population in the event of future nuclear emergencies.

12:00 noon **Lunch**

## International Perspectives on the Future of Nuclear Science, Technology and Power Sources

Frank L. Bowman, *Session Chair*

1:00 p.m. **New Reactor Technology and Operational Safety Improvements in Nuclear Power Systems**

Michael L. Corradini
University of Wisconsin

Almost 450 nuclear power plants are currently operating throughout the world and supplying ~17 % of the world's electricity. These plants perform safely, reliably, and have no free release of byproducts to the environment. Given the current rate of growth in electricity demand and the ever growing concerns for the environment, nuclear power can only satisfy the need for electricity and other energy-intensive products if it can demonstrate (1) enhanced safety and system reliability, (2) minimal environmental impact *via* sustainable system designs, and (3) competitive economics. The U.S. Department of Energy, in cooperation with the international community, has begun research on the next generation of nuclear energy systems that can be made available to the market by 2030 or earlier, and that can offer significant advances toward meeting these challenging goals; in particular, six candidate reactor system designs have been identified. These future nuclear power systems will require advances in materials, reactor physics and thermal-hydraulics to realize their full potential. However, all of these designs must demonstrate enhanced safety above and beyond current light water reactor systems if the next generation of nuclear power plants is to grow in number far beyond the current population. This presentation reviews the advanced Generation-IV reactor systems and the key safety phenomena that must be considered to guarantee that enhanced safety can be assured in future nuclear reactor systems.

1:30 p.m. **Future Challenges for Nuclear Power Plant Development Research, and for Radiological Protection Sciences**

Edward Lazo
International Agency for Research on Cancer

The promise of the future shines brightly for nuclear energy technology and production, yet also holds many challenges. This presentation will briefly discuss some of these challenges in the area of new reactor designs in general, and then will more specifically focus on challenges emerging in the areas of radiological risk assessment and management.

The Generation-IV International Forum (GIF), was chartered in May 2001 to lead the collaborative efforts of the world's leading nuclear technology nations to develop the next generation of nuclear energy systems to meet the world's future energy needs. The current GIF members are Argentina, Brazil, Canada, Euratom, France, Japan, Republic of Korea, Republic of South Africa, Switzerland, the United Kingdom, and the United States. Challenging technology goals for Generation IV nuclear energy systems are defined in four areas:

- *Sustainability*: Waste and radioactivity reduction, optimization of resource utilization;
- *Economy*: Decrease construction costs, achieve economic life-cycle and energy production goals;
- *Safety and Security*: Inherent safety features, minimization of accident consequences;
- *Non-Proliferation Resistance*: Physical protection, limitation of plutonium use, improved robustness.

Six concepts have been identified for which the key challenges will be briefly discussed:

- Gas-Cooled Fast Reactor System
- Lead-Cooled Fast Reactor System
- Molten Salt Reactor System
- Sodium-Cooled Fast Reactor System
- Supercritical-Water-Cooled Reactor System
- Very-High-Temperature Reactor System

More specifically in the radiological protection area, emerging potential challenges have also been identified. While still somewhat uncertain, radiation biology has consistently identified areas, circumstances and mechanisms that challenge the blanket use of a linear-nonthreshold model. Although still at the margins of "main-stream" radiological risk assessment science, phenomena such as the bystander effect, adaptive response, genomic instability, and genetic susceptibility show possibly significant effects at the cellular, tissue and even organism level. There is also emerging evidence that the dose-response relationship depends upon the nature of the exposure (*e.g.,* chronic or acute, internal or external) and the nature of the radiation (*e.g.,* high- or low-LET). Collectively, these developments could challenge the generic use of the concept of the sievert as an indicator of radiation detriment. Possible implications will be explored.

Finally, additional challenges are emerging in the area of radiological risk management. These are not based on new science, but rather on slowly evolving social demands for increased stakeholder involvement in many situations involving public, worker and environmental health and safety issues. These changes paint a broad new picture of the roles and responsibilities of the radiological protection professional, the key to which is the relationship between "judgment" and "science" as applied to a particular circumstance. Viewed through this framework, radiological protection can be seen in somewhat of a new light. The way radiation protection professionals work, and interact with stakeholders in decision framing and making has changed, and with it the way in which risks are identified and managed. In addition, the insistence of stakeholders has affected the way in which radiological protection institutions, both national and international, do business, from the development of fundamental radiological protection principles (*e.g.*, by the International Commission on Radiological Protection), to the translation of principles into standards and legislation (*e.g.,* international and national), to the way in which good practice is identified and implemented. The challenges posed by these changes, across the full radiological risk management spectrum, will be discussed.

2:00 p.m. **Moving to a Low-Carbon Energy Future: Perspectives on Nuclear and Alternative Power Sources**

M. Granger Morgan
Carnegie-Mellon University

This presentation will briefly review the current state of climate science in order to make the case that the United States (and ultimately the world) will need to dramatically reduce $CO_2$ emissions from the energy system over the next few decades. While transportation energy will be briefly considered, the primary focus will be on electric power. Today, the United States generates just over half of its electric power from coal. Many of the current fleet of coal plants are more than 25 y old and will have to be replaced in the next few years. If all that capacity were replaced with new conventional coal plants, this would commit the nation (and the world) to many more decades of high $CO_2$ emissions, or it would make the cost of meeting a future $CO_2$ emission constraint much higher than it need be. A range of low and no-carbon alternative technologies will be considered and their likely costs, and advantages and disadvantages will be discussed. Particular attention will be given to wind, distributed cogeneration, nuclear, and IGCC with CCS (technology to gasify coal and capture and sequester $CO_2$ in deep geological formations). Policy instruments, which will be needed to move the energy system to a low carbon future, will be discussed.

2:30 p.m. **The Chernobyl Aftermath *vis-a-vis* the Nuclear Future: An International Perspective**

Abel J. Gonzalez
Autoridad Regulatoria Nuclear

On April 26, 1986, a catastrophic explosion at Unit 4 of the Chernobyl Nuclear Power Plant (ChNPP) sent a very large amount of radioactive material into the atmosphere. The event was to become one of the most protracted and controversial themes of the modern technological era. The Chernobyl accident caused widespread concern over its radiological consequences, and also focused attention on nuclear safety in general. The accident's aftermath evolved together with the unfolding of glasnost and perestroika in the former USSR, and soon became bound up with many misunderstandings and apprehensions about the radioactive release and its real or perceived effects. Thus, the first casualty attributable to Chernobyl was the post-war consensus on atoms for peace, *i.e.*, the universal consent for a global dissemination of the societal benefits derived from the use of nuclear energy and its byproducts.

Two decades after the nuclear accident at ChNPP the time seems to be ripe to recapitulate the real consequences of the disaster from an international perspective. This presentation describes the main international initiatives to quantify factually the Chernobyl consequences. Soon after the accident an official report from the Soviet authorities was submitted to the International Atomic Energy Agency (IAEA) which made a preliminary evaluation of its predicted consequences. Five years later the USSR requested an international evaluation; thus, the so-called International Chernobyl Project produced the first peer-reviewed assessment of the consequences. A decade after the accident, in April 1996, more than 800 experts from 71 countries and 20 organizations (and observed by over 200 journalists) met to review the Chernobyl accident's actual and possible future consequences. They came together at the "International Conference on One Decade after Chernobyl—Summing Up the Consequences of the Accident," held at the Austria Center in Vienna, which was a model of international cooperation: six organizations of the United Nations (UN) family, including IAEA, and two important regional agencies were involved. The conference confirmed the main outcomes of the International Chernobyl Project, namely, that cancer effects over the natural incidence, except for thyroid cancer, would be difficult to discern among the public, even with large and well-designed long-term epidemiological studies.

These clear conclusions from the international scientific community were not accepted by the authorities and people of the affected Republics. Two decades after the event, people in the region still lived with wildly varying reports about what impact the accident will have on their families' future health and the environment. IAEA therefore launched a *Chernobyl Forum* comprising eight UN organizations, and Belarus, Russia and the Ukraine. The aim of the *Forum* was not to repeat the thousands of studies already done, but to support them with authoritative, transparent statements that show the factual situation in the aftermath of Chernobyl. People living in the affected villages were very distressed because the information they received was inconsistent. The *Forum* has been working over the last 2 y to change that picture and, recently, on September 6 – 7, 2005, in Vienna, its outcome was reported at the "International Conference on Chernobyl—Looking Back to Go Forwards Towards a United Nations Consensus on the Effects of the Accident and the Future." This latest, and hopefully definitive Chernobyl conference, informed governments and the general public about the *Chernobyl Forum*'s findings regarding the environmental and health consequences of the Chernobyl accident, as well as its social and economic consequences, and to present the *Forum*'s recommendations on further remediation, special health care, and research and development programs, with the overall aim of promoting an international consensus on these issues. The conclusions are basically the same as those of all previous international scientific events. They were summarized by the Conference Chairman as follows: "The majority of (people) … received radiation doses from Chernobyl … that were relatively low and unlikely to lead to widespread and serious health effects. The doses … are comparable to the background level of radiation to which everyone in the world is exposed. Some notable regions of high background radiation exist … the Chernobyl exposures are not unlike these naturally occurring areas that are not associated with discernible radiation health effects … Our conclusions are more than just valid, objective, scientific statements. They are a consensus of all of the scientists, international organization staff and representatives of governments who participated in the *Chernobyl Forum* and this conference. All of us agree on the basic underlying facts."

Finally, this presentation will explore the potential impact on the nuclear future of the consensus described above. The message seems to be simple: even a catastrophic nuclear accident, unprecedented as far as its development and aftermath, has consequences that are manageable and tolerable by society. While an appropriately stringent nuclear safety regime should make it impossible for catastrophes like Chernobyl to occur again, the possibility, however unlikely, of a nuclear accident should no longer be viewed as an impediment to a nuclear future.

3:00 p.m. **Break**

## Summary and Discussion of Major Findings from Chernobyl

Richard A. Meserve, *Session Chair*

3:30 p.m. **Session Chairs Present Brief Summaries of the Key Points Made by Speakers**

4:20 p.m. **Question and Answer Session**

5:00 p.m. **Closing Remarks**
Thomas S. Tenforde, *President*
National Council on Radiation Protection and Measurements

## The Program Committee

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Scientific Center for Radiation Medicine
Ukraine Academy of Medical Sciences

Shunichi Yamashita
World Health Organization

## Registration

Monday, April 3, 2006, 7:00 a.m. – 5:00 p.m.
Tuesday, April 4, 2006, 8:00 a.m. – 12:00 noon

There is no registration fee.

## 2007 Annual Meeting

April 16–17, 2007 in Arlington, Virginia

NCRP

**These organizations have supported the work of the National Council on Radiation Protection and Measurements during the period of January 1, 2005 to December 31, 2005.**

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Defense Threat Reduction Agency
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U.S. Nuclear Regulatory Commission

# Forty-Second Annual Meeting

# *Chernobyl at Twenty*

# Commentary No. 19
# Published in 2005

- ***Key Elements of Preparing Emergency Responders for Nuclear and Radiological Terrorism***
  **(Chair: J.W. Poston, Sr.)**

**Tutorial summary available at http://NCRPonline.org**

# Reports Published in 2005

- <u>**No. 150,**</u> ***Extrapolation of Radiation-Induced Cancer Risks from Nonhuman Experimental Systems to Humans*** **(Chair: D.G. Hoel)**
- <u>**No. 151,**</u> ***Structural Shielding Design and Evaluation for Megavoltage X- and Gamma-Ray Radiotherapy Facilities*** **(Chair: J.A. Deye)**

# Reports Published in 2005

- No. 152, *Performance Assessment of Near-Surface Facilities for Disposal of Low-Level Radioactive Waste* (Chair: D.C. Kocher)

# Electronic Publications

NCRP launched electronic publications and new publications website on January 24, 2005 –

http://NCRPpublications.org

# Proceedings of 40th Annual Meeting

- ***2004 Annual Meeting*, "Advances in Consequence Management for Radiological Terrorism Events"** **(Chair: William F. Blakely) (Health Physics 89(5), 447-588 (2005)**
- ***28th Lauriston S. Taylor Lecture*** **by Abel J. Gonzalez, *"Radiation Protection in the Aftermath of a Terrorist Attack Involving Exposure to Ionizing Radiation"* (Health Physics 89(5), 418-446 (2005)**

# Third Annual Warren K. Sinclair Keynote Lecture

**Dr. Mikhail Balonov**

*International Atomic Energy Agency*

Third Annual Warren K. Sinclair Keynote Address

# Retrospective Analysis of Impacts of the Chernobyl Accident

Mikhail BALONOV

IAEA

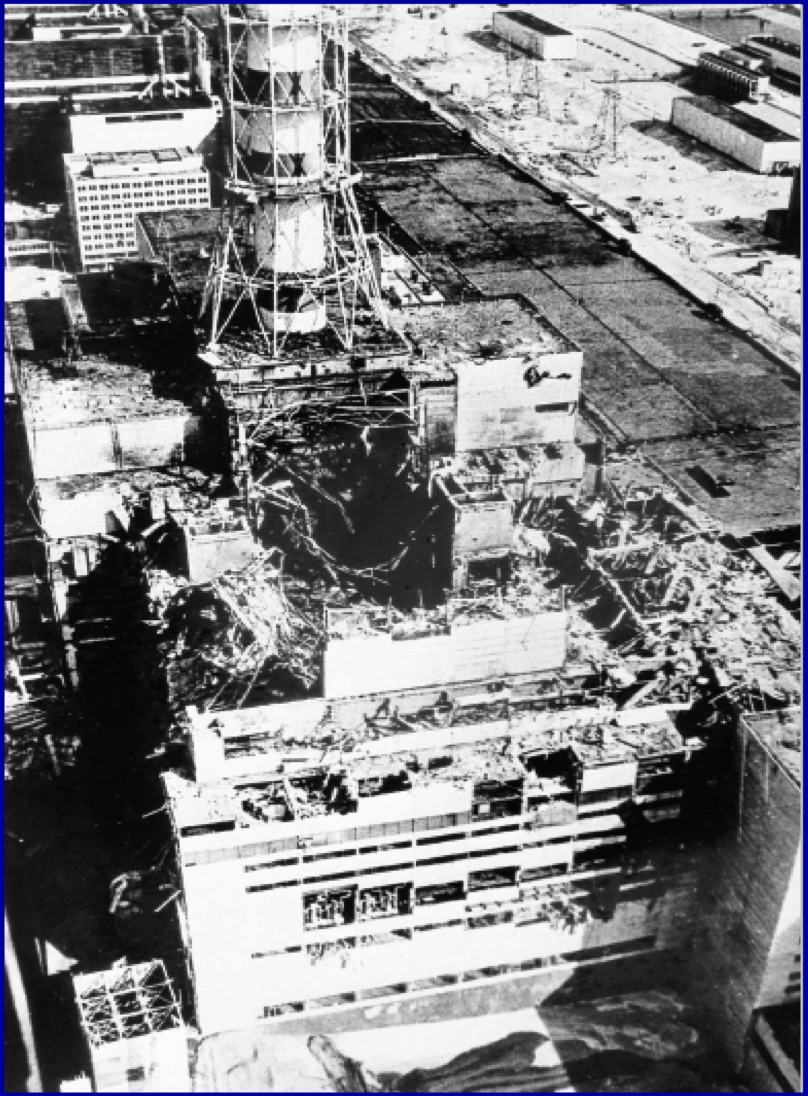
International Atomic Energy Agency

# Contents

- Brief description of the accident
- Accident's assessments
- The Chernobyl Forum:
  - Membership and Modus Operandi
  - Major scientific findings and recommendations for future actions
- Discussion:
  - Effectiveness of public protection
  - Forecast of health consequences
  - Comparison with nuclear bombings-1945 and global fallout
  - Chernobyl and science
  - Chernobyl and radiation protection
- Dissemination of Forum materials:
  - Conference in Vienna, September 2005
  - 60th Session of UN GA, November 2005

# The accident

- On 26 April, 1986, at 01:23 a.m. two explosions destroyed Unit 4 of the Chernobyl NPP located 100 km N from Kiev (~2.5 mln) and just 3 km from Pripyat (~50 ths.)
- The destroyed reactor got fire that continued for 10 days.



# Mitigation of the accident consequences

- Fire fighting
- Evacuation of 116 ths. residents of the most affected areas
- Construction of the Shelter by November 1986
- Decontamination of settlements
- Countermeasures in agriculture, water supply and forestry

# Enormous scale of the accident consequences

- Early health effects:
  - Two persons killed by explosion and thermal burns;
  - ARS in 134 emergency workers;
  - 28 of them died in 1986, 19 more died in 1987-2004
- More than 600 ths recovery operation workers exposed
- About $14 \times 10^{18}$ Bq radioactivity released; the most radiologically important radionuclides were $^{131}I$ and $^{137}Cs$
- More than 200,000 sq. km of Europe 'contaminated' with $^{137}Cs$, mostly in FSU countries
- 340 ths people evacuated or resettled
- More than 5 mln. people live in 'contaminated' areas
- Economic costs of hundreds billions USD

# Assessment of Chernobyl consequences

- National assessments:
  - Environmental – Acad. Yu. Izrael,
  - Agricultural – Acad-s R. Alexakhin and B. Prister,
  - Health – Acad-s L. Ilyin, A. Tsyb
  - Social and Economic - Acad. S. Belyaev
- Lack of credibility at the national level, because of early secrecy and for political reasons
- Substantial concern and controversy worldwide
- International assessments needed

# International assessments

- Post-accident review meeting – IAEA, August 1986
- International Chernobyl Project – IAEA, 1990
- UNSCEAR reports – 1988, 1993 and 2000
- IPHECA – WHO, 1991-1995
- EC + FSU joint research projects – 1992-1999
- International Conference "One Decade after Chernobyl: Summing up the Consequences" - IAEA, WHO and EC, 1996
- The Human Consequences of the Chernobyl Nuclear Accident – A Strategy for Recovery – UNDP, 2002
- **The Chernobyl Forum – 2003-2005**

# The Chernobyl Forum: political context

- Initiated by the IAEA DG Mr ElBaradei
- Contribution to the implementation of the UN “Strategy for Recovery”, 2002
- 8 UN organisations + 3 Governments (Belarus, Russia and Ukraine) involved
- An attempt to agree on fact interpretation and recommendations for future actions by 20th anniversary.
- The results considered by 60th UN General Assembly, Nov 2005.

# Major tasks of the Chernobyl Forum

- To generate authoritative consensual statements on the health effects attributable to radiation exposure and the environmental consequences induced by the radioactive materials released due to the accident;
- To provide advice on remediation and special health care programmes; and
- To consider the necessity for continued research, aimed at resolving the disputed issues.

# The Chernobyl Forum officers:

- **Dr Burton Bennett, RERF, Japan, Forum Chair**
- **Expert Group "Environment"**
  - Dr Lynn Anspaugh, USA, EGE Chair
- **Expert Group "Health"**
  - Dr Geoff Howe, USA, EGH Co-chair (Thyroid Studies)
  - Dr Elisabeth Cardis, France, EGH Co-Chair (Solid Cancers/Leukaemia studies)
  - Dr Fred Mettler, USA, EGH Co-chair (Non-cancer outcomes and health care programmes)
- **Scientific secretariat:**
  - Mikhail Balonov, IAEA
  - Mike Repacholi and Zhanat Carr, WHO
  - Louisa Vinton, UNDP

# Forum operation

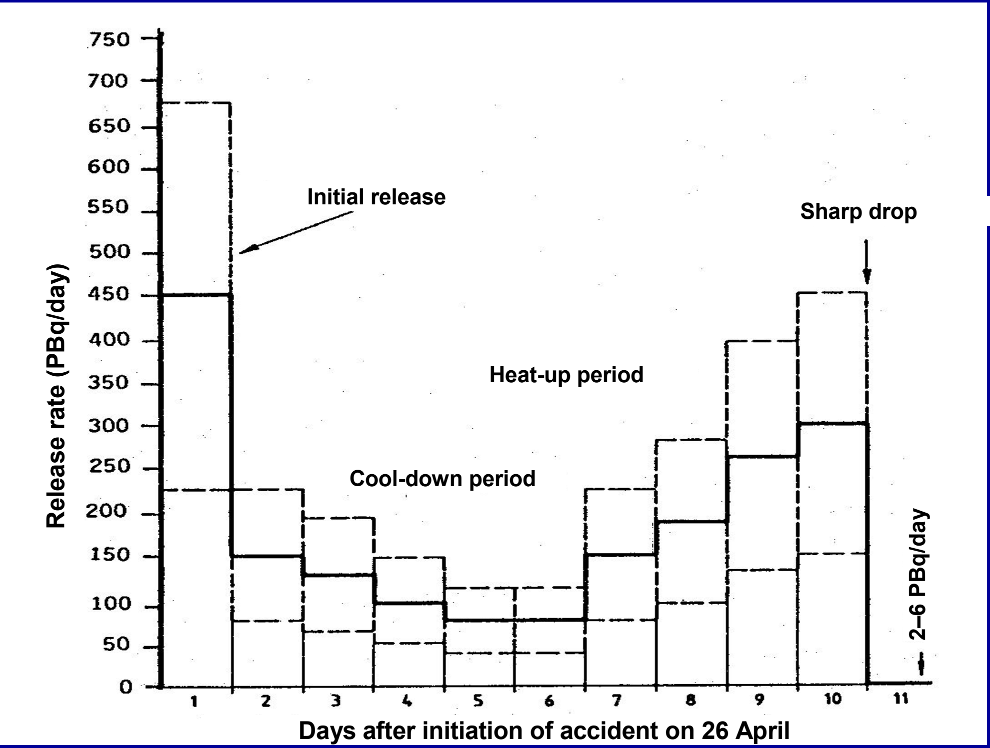
- Annual managerial meetings of senior officials from 8 UN organizations and the 3 affected States + observers
- Regular expert meetings on the environmental consequences organised by the IAEA (EGE) and on human health (EGH) organised by the WHO – in total 11 meetings
- More than 80 experts from 12 countries and 6 international organisations, such as UNSCEAR, IUR, IARC, etc.
- Forum reports on environment and health and the Digest report approved by consensus in April 2005
- UNDP complemented the Digest report with the social and economic issues based on UN, 2002

# Forum perspectives

- Past contamination, exposure and effects on humans and biota;
- Present radiation conditions and health effects;
- Future predictions and intervention needs: environmental remediation and health care;
- Substantial gaps in knowledge and corresponding subjects for research.

# Main conclusions of the Chernobyl Forum -1

- The accident at the Chernobyl NPP in 1986 was the most severe in the history of the world nuclear industry.
- Due to the vast release of radionuclides it also became the first magnitude radiological accident.

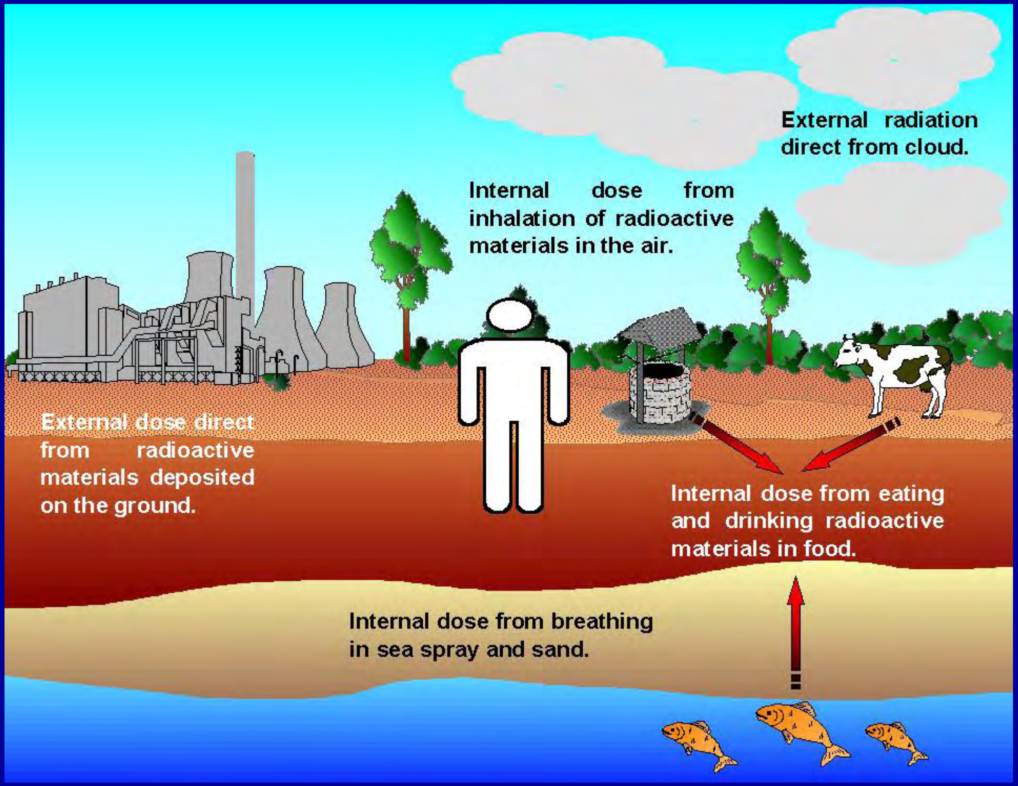


# Main conclusions of the Chernobyl Forum - 2

However, in the course of years, the most significant problems have become the severe social and economic depression of the affected Belarusian, Russian and Ukrainian regions and the associated serious psychological problems of the general public and emergency workers.

# Main conclusions of the Chernobyl Forum - 3

- The majority of the more than 600 ths. recovery operation workers and 5 mln. residents of the contaminated areas in Belarus, Russia and Ukraine received relatively minor radiation doses which are comparable with the natural background levels.
- This level of exposure did not result in any observable radiation-induced health effects.



# Summary of average accumulated doses to affected populations from Chernobyl fallout

| Population category | Number | Average dose, mSv |
|---|---|---|
| 'Liquidators' (1986-1989) | **600,000** | **~100** |
| Evacuees (1986) | **116,000** | **33** |
| Residents of SCZ (1986-2005) | **270,000** | **>50** |
| Residents of other 'contaminated' areas (1986-2005) | **5,000.000** | **10-20** |

Natural background dose during 20 y: 50 mSv (20-200 mSv)

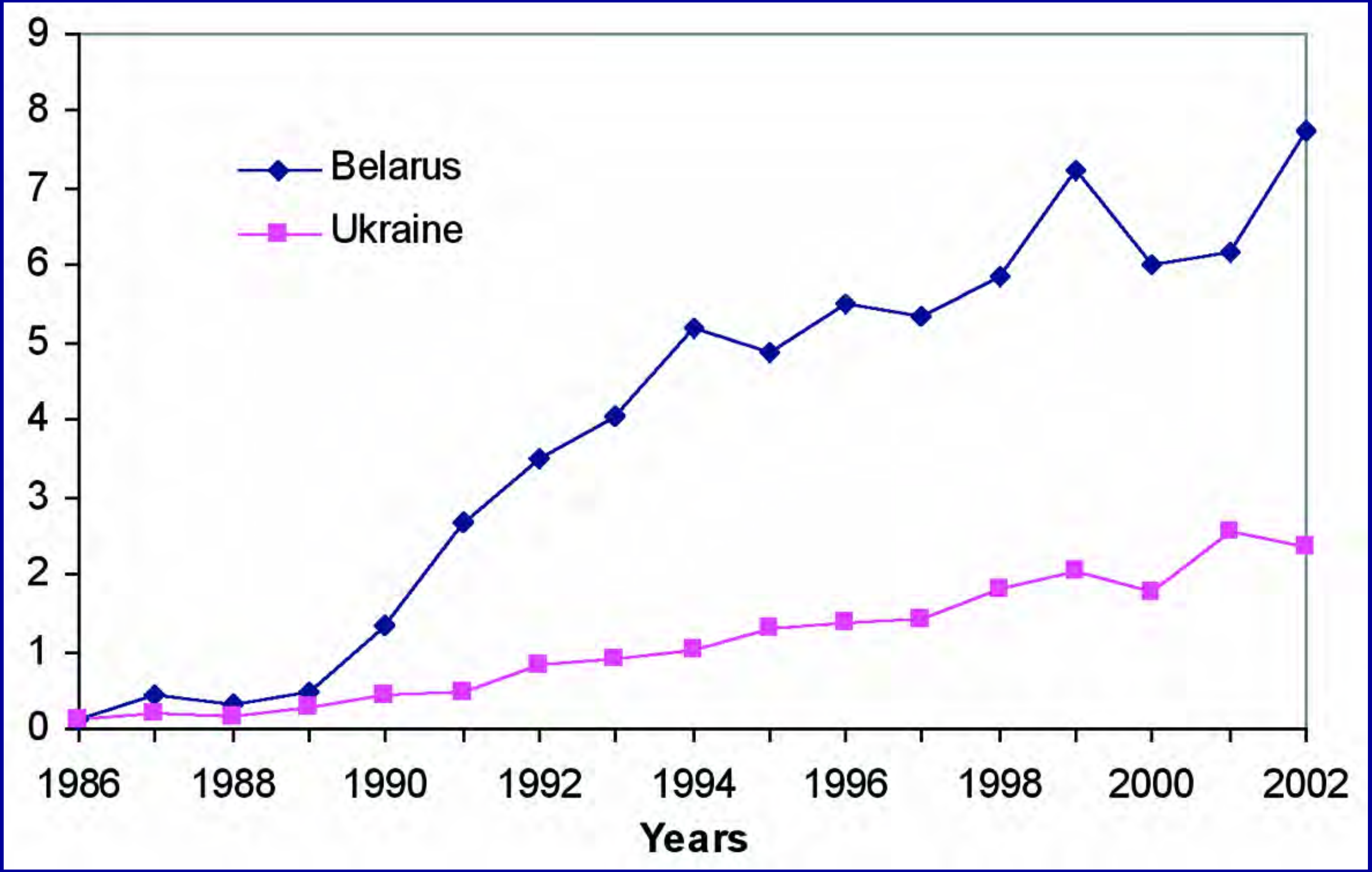
# Main conclusions of the Chernobyl Forum – 4

- An exception is a cohort of several hundred emergency workers who received high radiation doses; of whom near 50 died due to radiation sickness and subsequent diseases.
- According to bio-statistical forecast, radiation has caused, or will cause, the premature deaths of around 4000 people from the 600 000 affected by the higher radiation doses due to the Chernobyl accident.

# Main conclusions of the Chernobyl Forum - 5

- Another cohort affected by radiation are children and adolescents who in 1986 received substantial radiation doses in the thyroid due to the consumption of milk contaminated with radioiodine.
- In total, about 4000 thyroid cancer cases have been detected in this cohort during 1992–2002; more than 99% of them were successfully treated, but fifteen persons died (as of 2004).

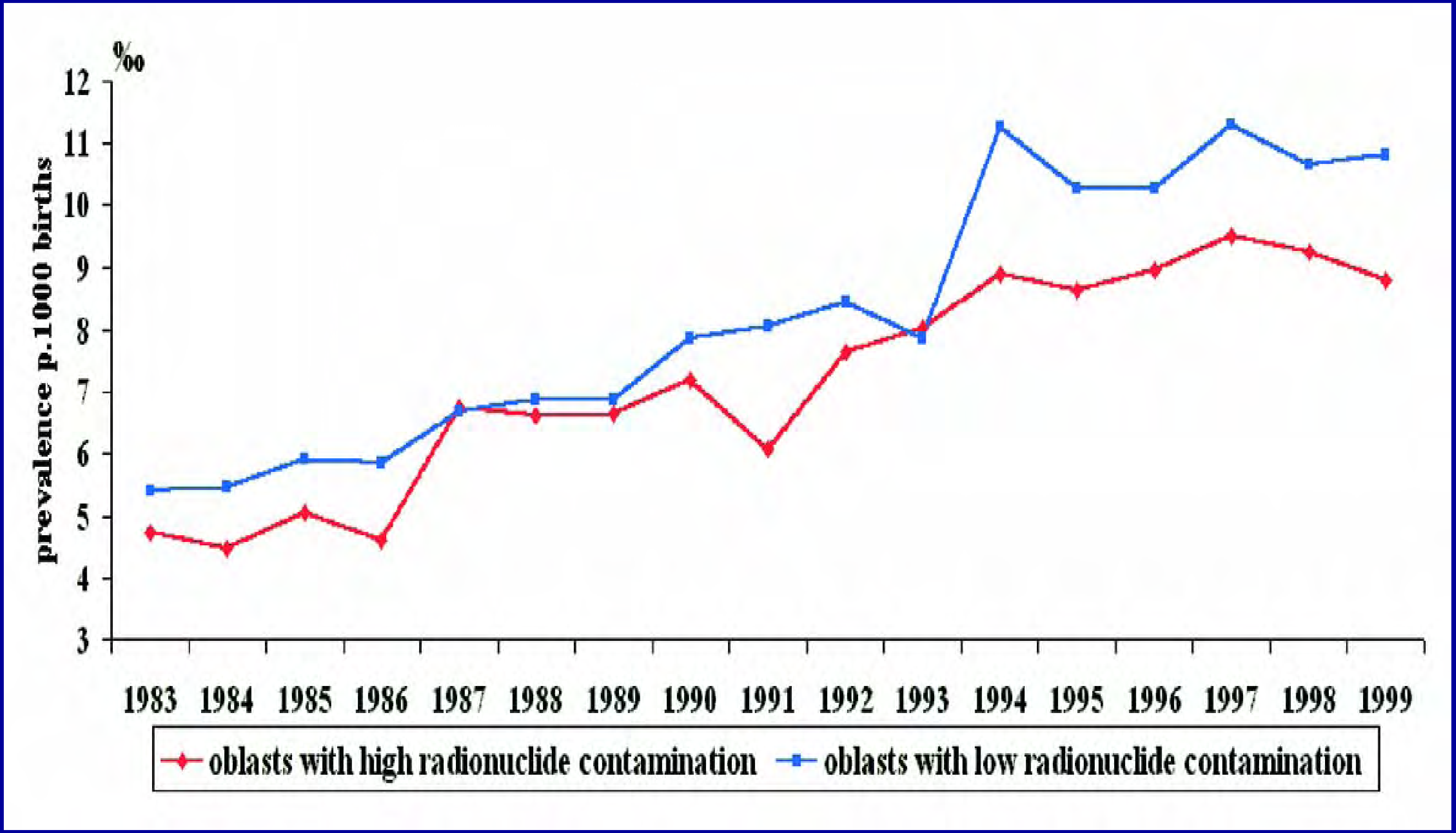
# Incidence rate of thyroid cancer per 100,000 children and adolescents as of 1986 (after Jacob et al., 2005)



# Other diseases resulted from the Chernobyl radiation exposure

- **Russian emergency and recovery operation workers, according to RNMDR (Ivanov et al. 2004):**
  - **Doubling of leukaemia morbidity in workers with D>150 mGy,**
  - **Some increase of mortality (~5%) caused by solid cancer and cardiovascular diseases,**
  - **Increased cataract frequency.**
- **Residents of contaminated areas:**
  - **No reliable data on increased incidence of any somatic disease except of thyroid cancer in children and adolescents (considered above),**
  - **According to bio-statistical forecast, substantial increase of radiation-induced somatic morbidity in the future is unlikely.**

# Prevalence of malformations at birth in 4 oblasts of Belarus with high and low levels of radionuclide contamination (Lazjuk GI et al., 1999)



# Main conclusions of the Chernobyl Forum – 6

## Psychological consequences:

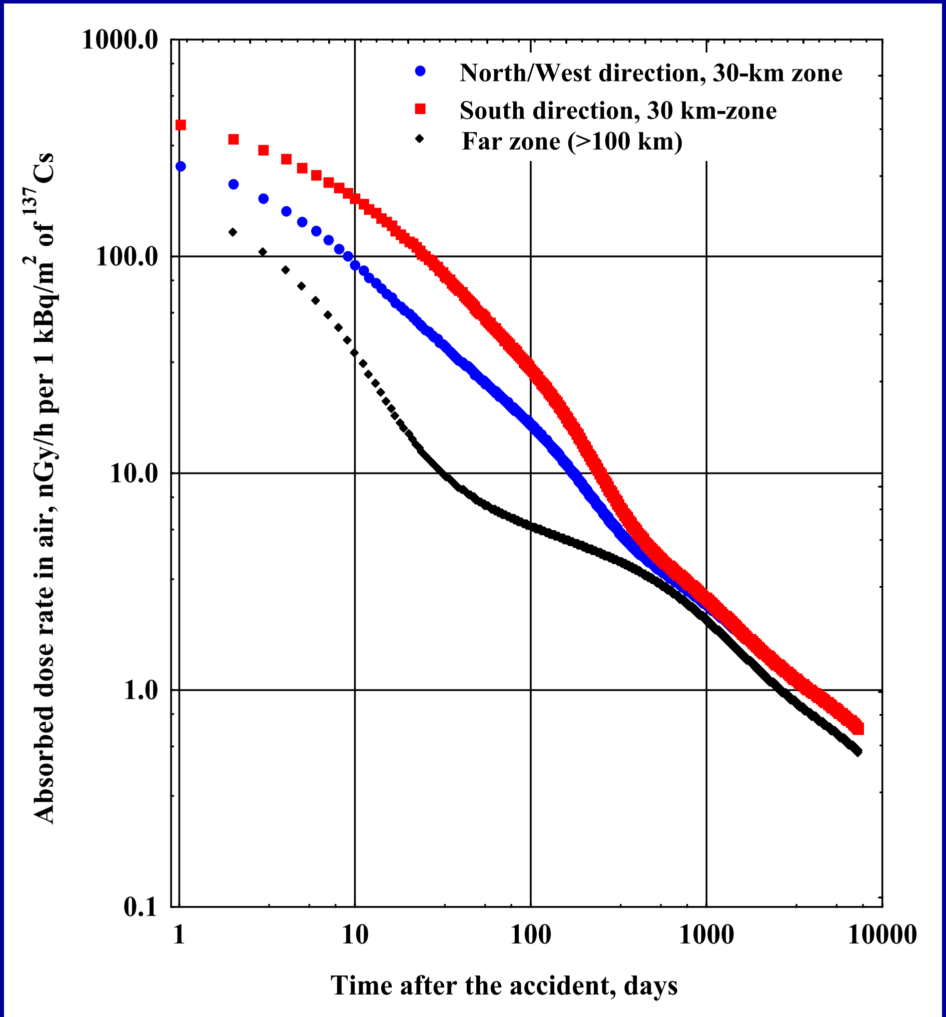
- Many people have been traumatised by the relocation, the breakdown in social contacts, fear and anxiety about what health effects might result.
- Elevated anxiety and unexplained physical symptoms among affected people reported.
- Self-perception as “Chernobyl Victims or Invalids” and not the “Chernobyl Survivors”.
- Renewed efforts at risk communication, based on accurate information about the health and mental health consequences of the disaster, should be undertaken.

# Recommendations on health care and research

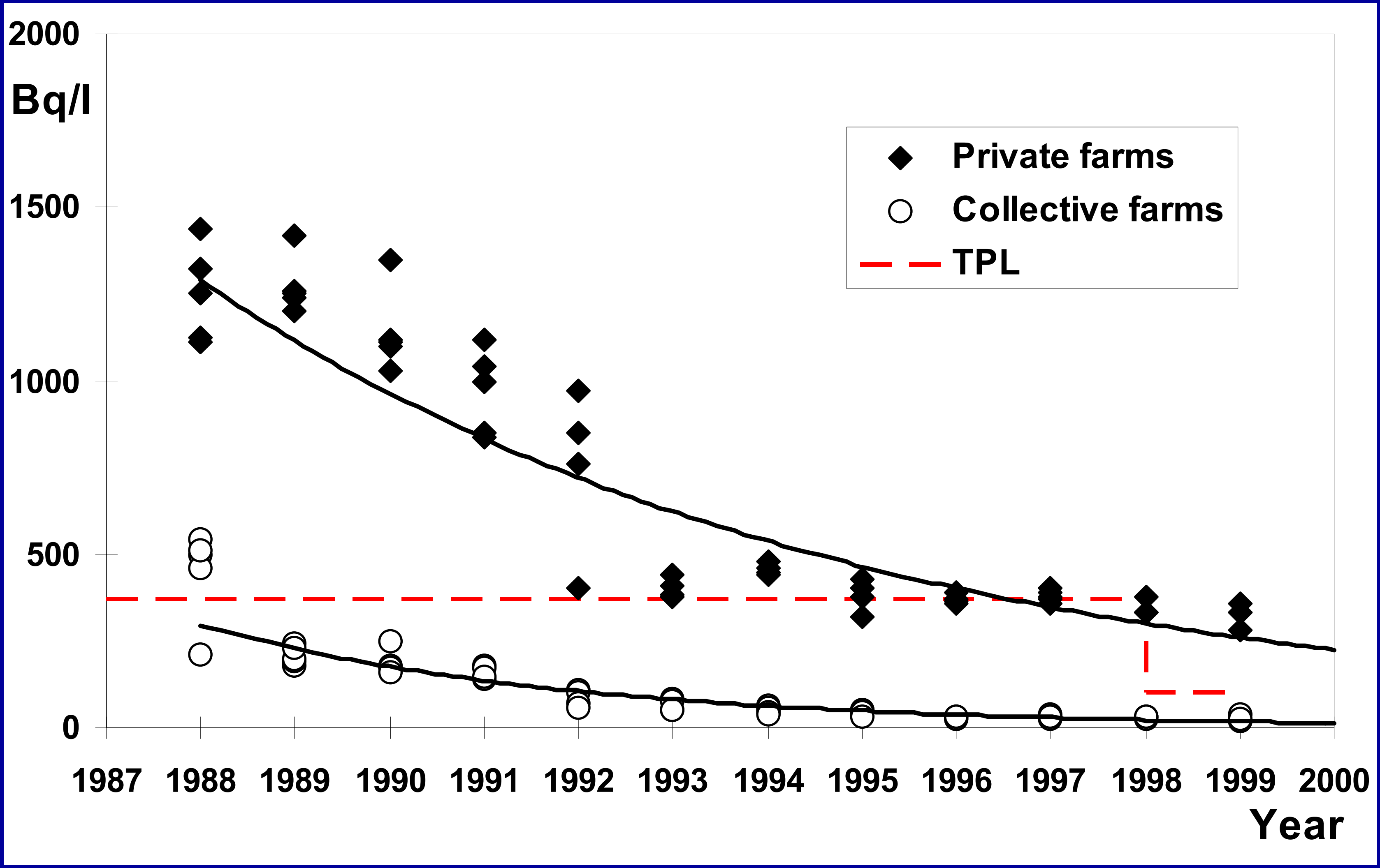
- Medical care and annual examinations of the highly exposed emergency workers, including those recovered from ARS should continue.
- Current follow-up programmes for persons with whole-body doses of less than 1 Gy should be reconsidered relative to necessity and cost-effectiveness.
- Resources might more profitably be directed towards reduction of infant mortality, alcohol and tobacco use, detection cardiovascular disease and improvement of mental health status of the affected population.
- Screening for thyroid cancer of children and adolescents, who resided in 1986 in the areas with radioactive fallout, should continue.
- A number of other targeted recommendations.

# Main conclusions of the Chernobyl Forum – 7

- Radiation levels in the environment have reduced by a factor of several hundred since 1986 due to natural processes and countermeasures.
- Therefore, the majority of the land that was previously contaminated with radionuclides is now safe for life and economic activities.

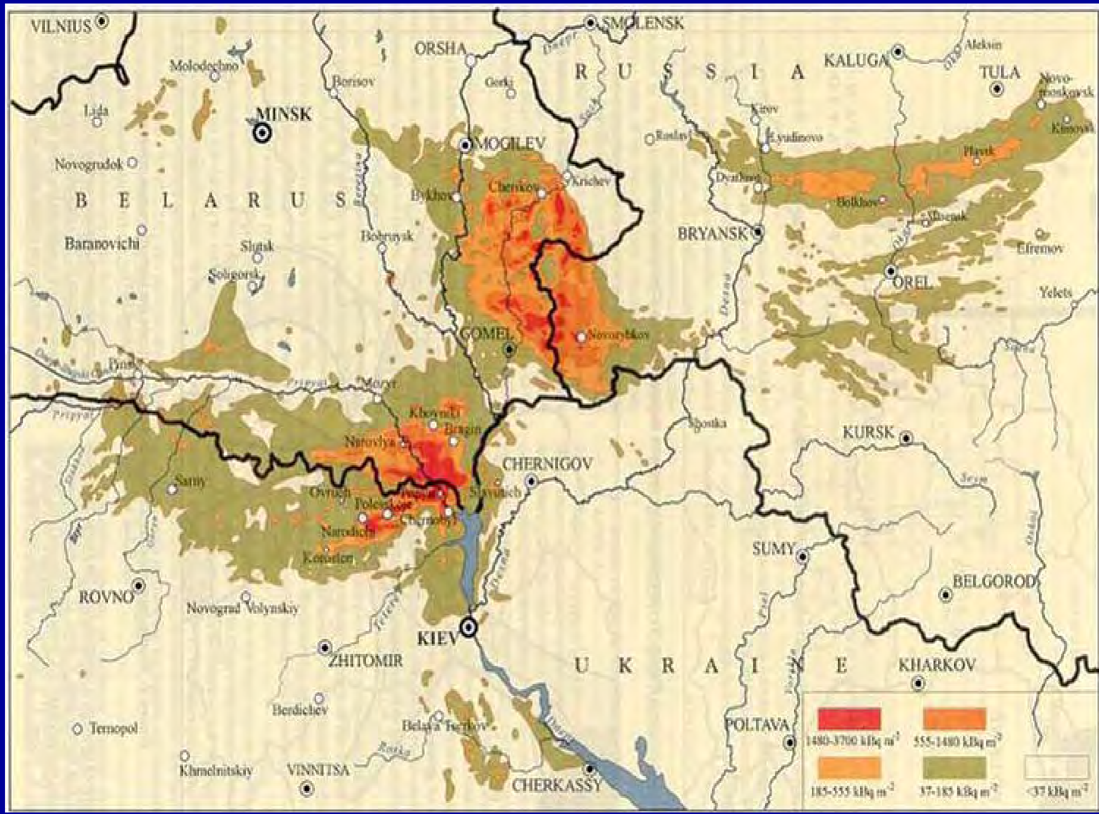


# Typical dynamics of Cs-137 activity concentration in milk with a comparison to TPL, Rivno region, Ukraine



# Main conclusions of the Chernobyl Forum – 8

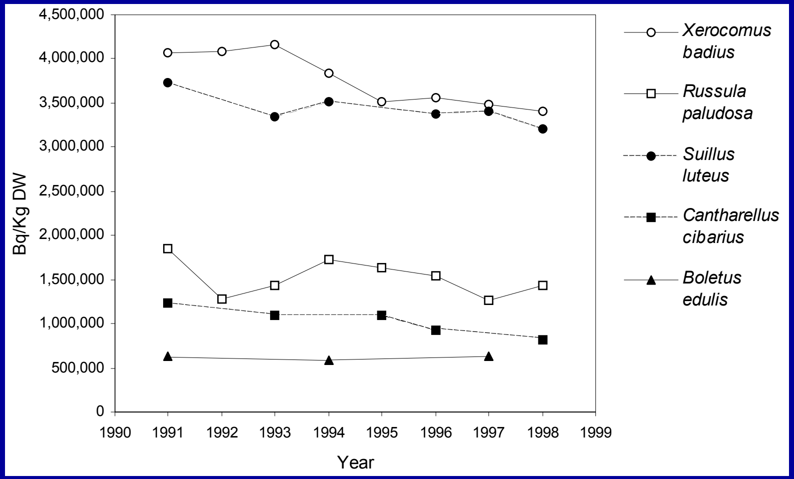
However, in the Chernobyl Exclusion Zone and in some limited areas of Belarus, Russia and Ukraine some restrictions on land-use should be retained for decades to come.

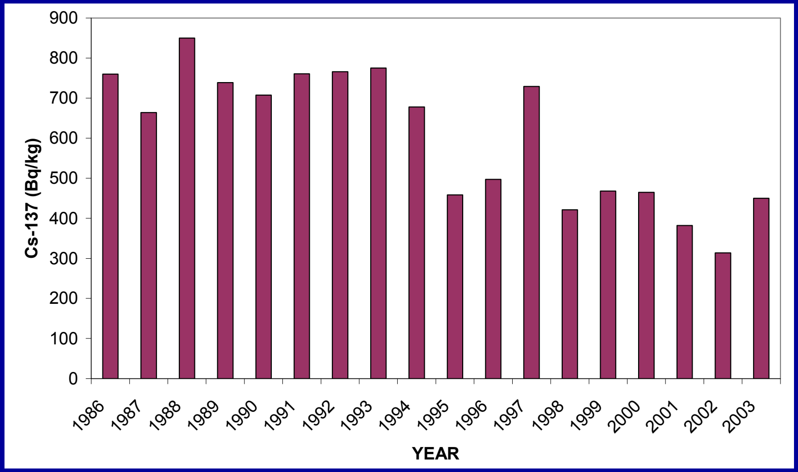


# Main conclusions of the Chernobyl Forum – 9

- Particularly high $^{137}Cs$ activity concentrations have been found in mushrooms, berries, and game;
- These high levels have persisted for two decades, and this can be expected to continue for several decades.

Mushrooms, Ukraine




Moose, Sweden

# Main conclusions of the Chernobyl Forum – 10

## Radiation-induced effects on plants and animals

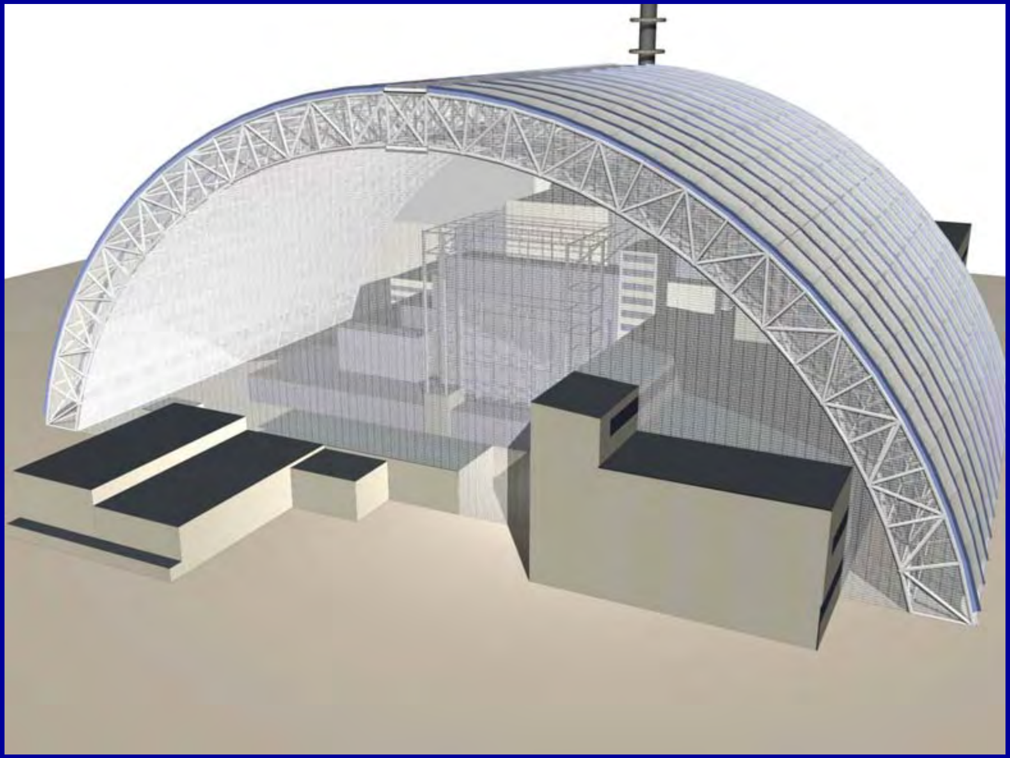
- Irradiation caused numerous acute adverse effects on the plants and animals living up to 10-30 kilometres from the release point.
- The following effects caused by radiation-induced cell death have been observed in biota:
  - Increased mortality of coniferous plants, soil invertebrates and mammals; and
  - Reproductive losses in plants and animals.
- A few years were needed for recovery from major radiation-induced adverse effects in populations of plants and animals.
- Due to removal of human activities, the Exclusion Zone has paradoxically become a unique sanctuary for biodiversity.
- There is nothing that can be done to remedy the radiological conditions for plants and animals residing in the Exclusion Zone that would not have an adverse impact on plants and animals.

# Recommendations on environmental monitoring, remediation and research

- There is no need for major new research programmes on radioactivity; but it is of use to continue limited targeted monitoring of some specific areas.
- To inform the public on persistent high contamination of wild food products (fungi, game, berries, etc.) and on simple cooking procedures aimed at reducing internal exposure.
- The number and frequency of sampling and measurements can be substantially reduced.
- Remediation measures remain efficient mainly in areas with poor (sandy and peaty) soils where there is a high radiocaesium transfer from soil to plants.
- Technologically based remediation measures applied to forests and surface waters will not be practicable on a large scale.

# Main conclusions of the Chernobyl Forum – 11

Priority for Ukraine should be the decommissioning of the destroyed Chernobyl Unit 4 and the safe management of radioactive waste in the Chernobyl Exclusion Zone, as well as its gradual remediation.



# Socio-Economic Impact of the Chernobyl Accident - 12

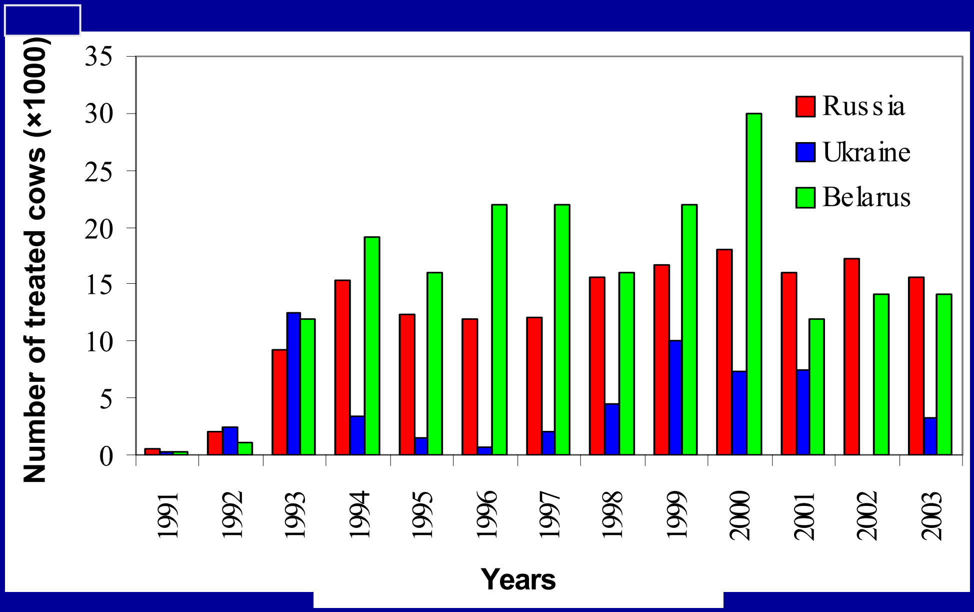
- Enormous damage to economy of the USSR and its successors, Belarus, Russia and Ukraine, due to direct and indirect costs,
- Depression of local economy in the affected regions,
- Destruction of local communities due to resettlement of 340 ths. people,
- Psychological distress of people, development of the “Chernobyl victim” complex,
- Compensating exposure to risk rather than actual injury to health or economy,
- Difficulties in implementation of expensive investment programmes, particularly in market conditions.

# Chernobyl-related construction, 1986-2000 (thousands)

| | Belarus | Russia | Ukraine | Total |
|---|---|---|---|---|
| Houses and flats | 65 | 37 | 29 | 130 |
| Schools (places) | 44 | 18 | 49 | 112 |
| Kindergartens (places) | 19 | 4 | 11 | 34 |
| Outpatient health centres (visits/day) | 21 | 8 | 10 | 39 |
| Hospitals (beds) | 4.2 | 2.7 | 4.4 | 11.2 |

# Main conclusions of the Chernobyl Forum – 13

- Countermeasures implemented by the Governments in coping with the consequences of the Chernobyl accident were on the whole timely and adequate.
- However, recent research shows that the direction of these efforts must be changed. Social and economic restoration of the affected Belarusian, Russian and Ukrainian regions must be a priority.



# Main conclusions of the Chernobyl Forum – 14

- Targeted research of some long-term environmental, health and social consequences of the Chernobyl accident should be continued for decades to come.
- Preservation of the tacit knowledge developed in the mitigation of the accident consequences is essential.

# Main conclusions of the Chernobyl Forum – 15

- The Forum report is the most complete on the Chernobyl accident because it covers environmental radiation issues, human health and socio-economic consequences. About 100 recognised experts in the field of Chernobyl-related research from many countries, including experts from Belarus, Russia and Ukraine, have contributed to it.
- This report is a consensus view of the eight organisations of the UN family and of three affected countries.

# Discussion 1: Efficiency of public protection

- ARS in general public avoided by timely evacuation of 116 ths. persons (t. Pripyat, etc.).
- Later resettlement of 220 ths. persons was justified rather by social and psychological than by radiological rationales.
- Attempt to protect people against radioiodine intake with food (mainly, milk) failed due to management passivity.
- Intensive countermeasures (decontamination, provision of non-contaminated food, agricultural c/m-s) reduced dose and risk up to a factor of two.
- Optimisation approach was not applied explicitly but was used implicitly, in the present ICRP spirit.

# Discussion 2a: Forecast of the accident's health consequences

- **Objective:** planning of special health care and informing the public (but not justification of human radiation protection!)
- Should be based on sound science, i.e., on risk models validated with experimental data for exposure conditions under consideration.
- Cautious approach unnecessary, it's not a protection issue.
- Adverse health effects not proved below individual acute doses of 100-200 mSv (LSS, etc).
- Therefore, number of predicted stochastic effects:

$$N = RRC \cdot CD\ (>0.1\ \mathrm{Sv}),\ \text{cases}$$

**(RRC=0.1 $Sv^{-1}$ for acute and 0.05 $Sv^{-1}$ for chronic exposure)**

# Discussion 2b: Comparison with earlier assessments and with observations

**Forum assessment with regard of radiation-induced cancer morbidity and mortality is:**

- *Same as international assessment made in 1996;*
- *In sensible agreement with national forecast made in 1986;*
- *Confirmed by 20-year observation of:*
  - *Thyroid cancer in children;*
  - *Leukemia and solid cancer in emergency/recovery workers.*

# Discussion 3: Comparison with nuclear bombings and global fallout

| Event, year | $^{137}Cs$ release, PBq | Collective dose, $10^3$ pers-Sv | | Nr of projected deaths | Nr of casualties |
|---|---|---|---|---|---|
| | | Total | > 0.1 Sv | | |
| Bombing of Japanese cities, 1945 | 0.2 | (~30, in survivors) | (~20, in survivors) | (~ 2000) | 150,000 to 220,000 |
| Global fallout, since 1950s | ~1000 | ~5.000 | -- | -- | -- |
| Chernobyl accident, 1986 | 85 | (~200) | (~80) | (~ 4000) | 30 |

# Discussion 4: Chernobyl and science

- Nuclear safety:
  - Control of reactor operation and human factor
  - Mechanisms of severe nuclear accidents
- Radioecology:
  - Post-Chernobyl era (A. Aarkrog, 1993)
  - Migration of I, Cs, Sr, Pu, etc. in various ecosystems
  - Effects on biota in the 30-km zone; dose reconstruction is still needed
- Countermeasure and remediation experience:
  - Various methodologies: effectiveness, cost and public acceptance
  - Development of recommendations and codes (e.g., RODOS)
- Radiation medicine:
  - ARS treatment and follow-up
  - Epidemiology and its practical applications:
    - ✓ New information on thyroid cancer risks
    - ✓ Validation of bio-statistical prognoses

# Discussion 5: Chernobyl and radiation protection

Substantial influence at both international and national levels:

- International Conventions on emergency notification and assistance (IAEA, 1987) and on nuclear safety (IAEA, 1996)
- ICRP in 1990s:
  - Intervention philosophy and criteria (Publ. 60, 63)
  - Data for dose assessment of the public (Publ. 51, 56, 67, etc.)
  - Protection against prolonged exposures (Publ. 82)
- IAEA:
  - Converted ICRP recommendations in safety standards (BSS in 1996, specific standards)
  - Guidance on countermeasures and remediation
  - Center for emergency response worldwide in operation
  - Programme for emergency preparedness implemented
- Radionuclides in foods:
  - USSR and EC guidance since 1986
  - CAC guidance (1989; 2006/7)

# International Conference “Chernobyl: Looking Back to Go Forwards”

- Held 6-7 September 2005 in Vienna
- About 250 participants from 41 country and 20 organisations:
  - summarized the Forum’s work,
  - informed decision-makers, mass media and the general public, and
  - promoted the proposed actions
- Accompanied by extensive press campaign

# 60th Session of the UN General Assembly

- Considered on 14 November 2005 the report A/60/443 of the Secretary-General on Chernobyl that includes, *inter alia*, the results of the Chernobyl Forum.
- Accepted Resolution A/60/L.19, in which:
  - Noted consensus reached among members of the Chernobyl Forum regarding assessment of the accident consequences and future actions;
  - Noted the necessity to widely disseminate Forum's findings and recommendations;
  - Requested to organise further studies consistent with the recommendations of the Chernobyl Forum.
- <u>Thus, for the first time the Chernobyl Forum reached highest international consensus in the assessment of the accident consequences and recommendations for future actions.</u>

# Chernobyl Radionuclide Distribution and Migration

Academician Yu.A.Izrael
Institute of Global Climate and Ecology of Rosgidromet and Russian Academy of Sciences, Russia

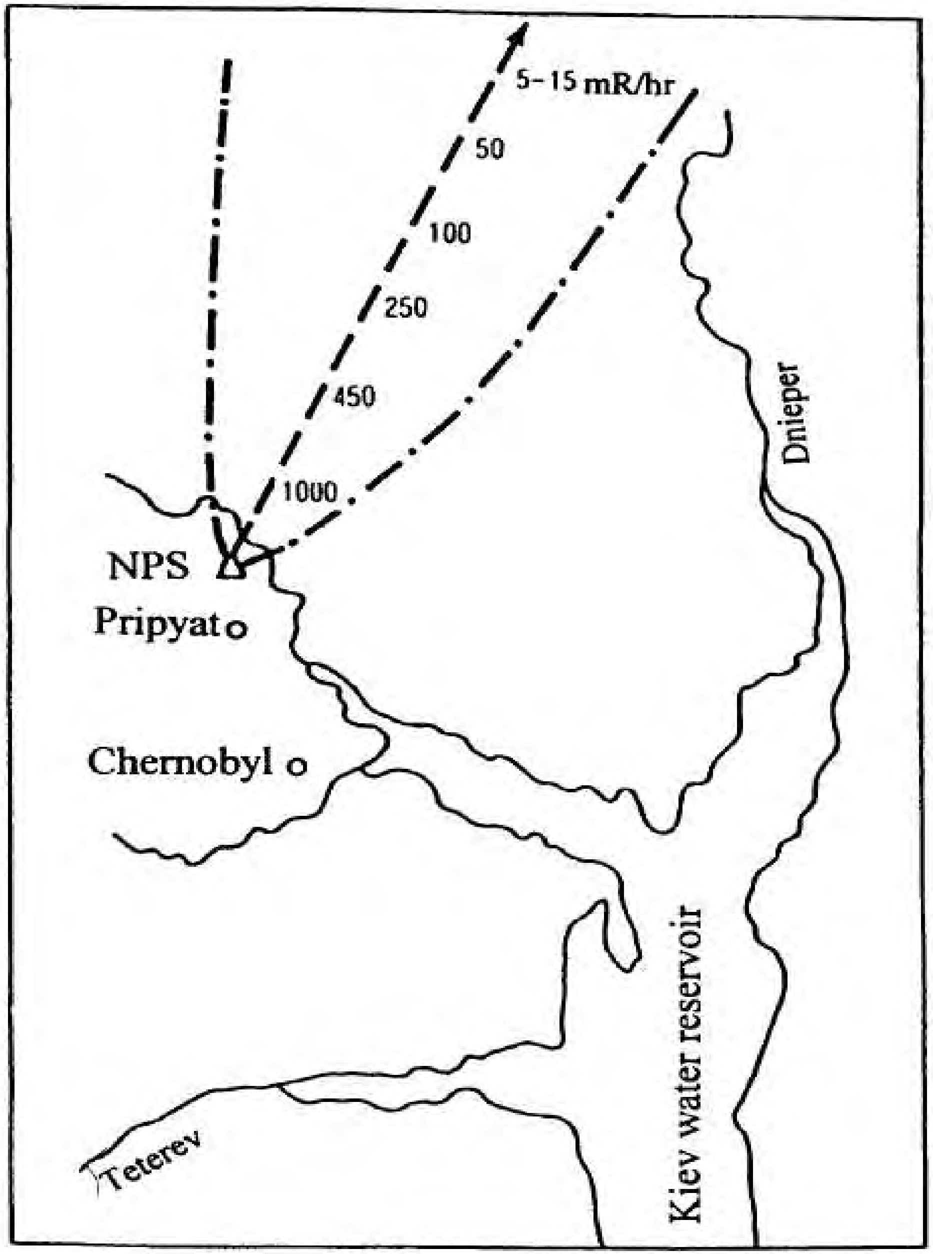



Fig.1. First measurement of distribution of dose rite (mR/hr) in a plume of radioactive products at a height of 200 m on the morning April 27, 1986.

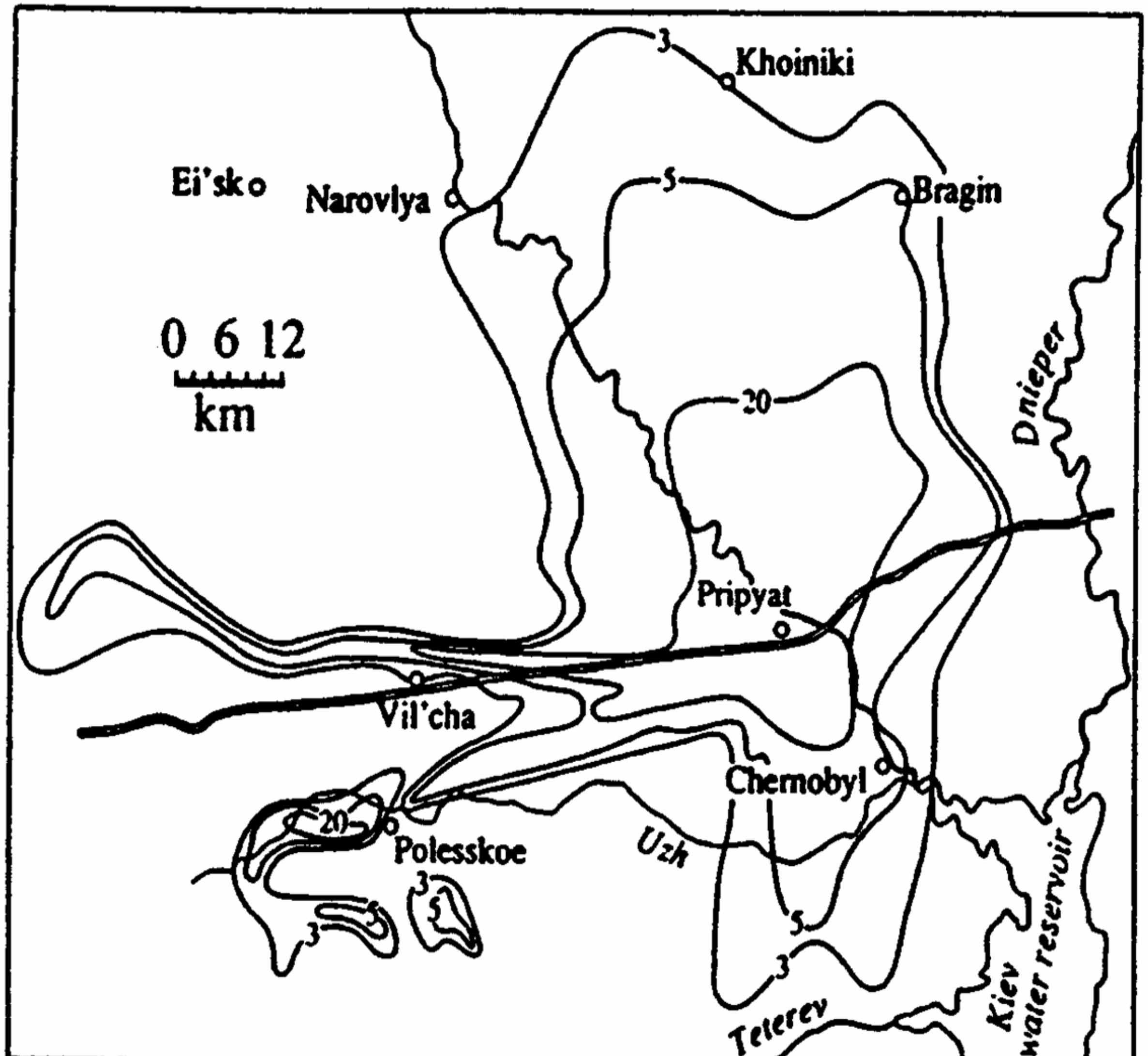



Fig.2. Map of γ-radiation dose rate (mR/hr) on May 10, 1986.

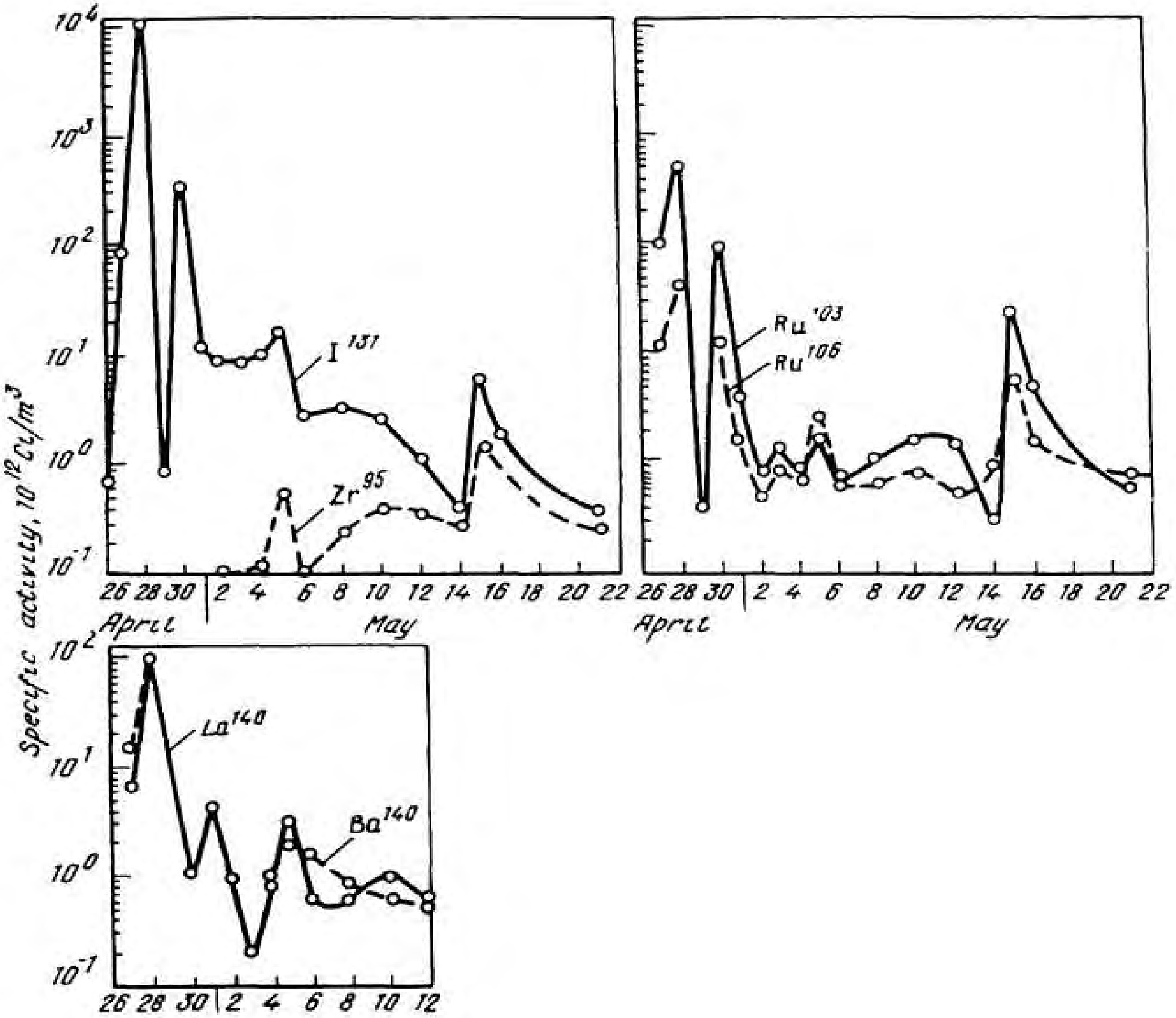



Fig.3. Specific activity of I-131 and Zr-95, Ru-103 and Ru-106, La-140 and Ba-140 in the atmospheric air at the background monitoring station in the Beresina biosphere reserve.

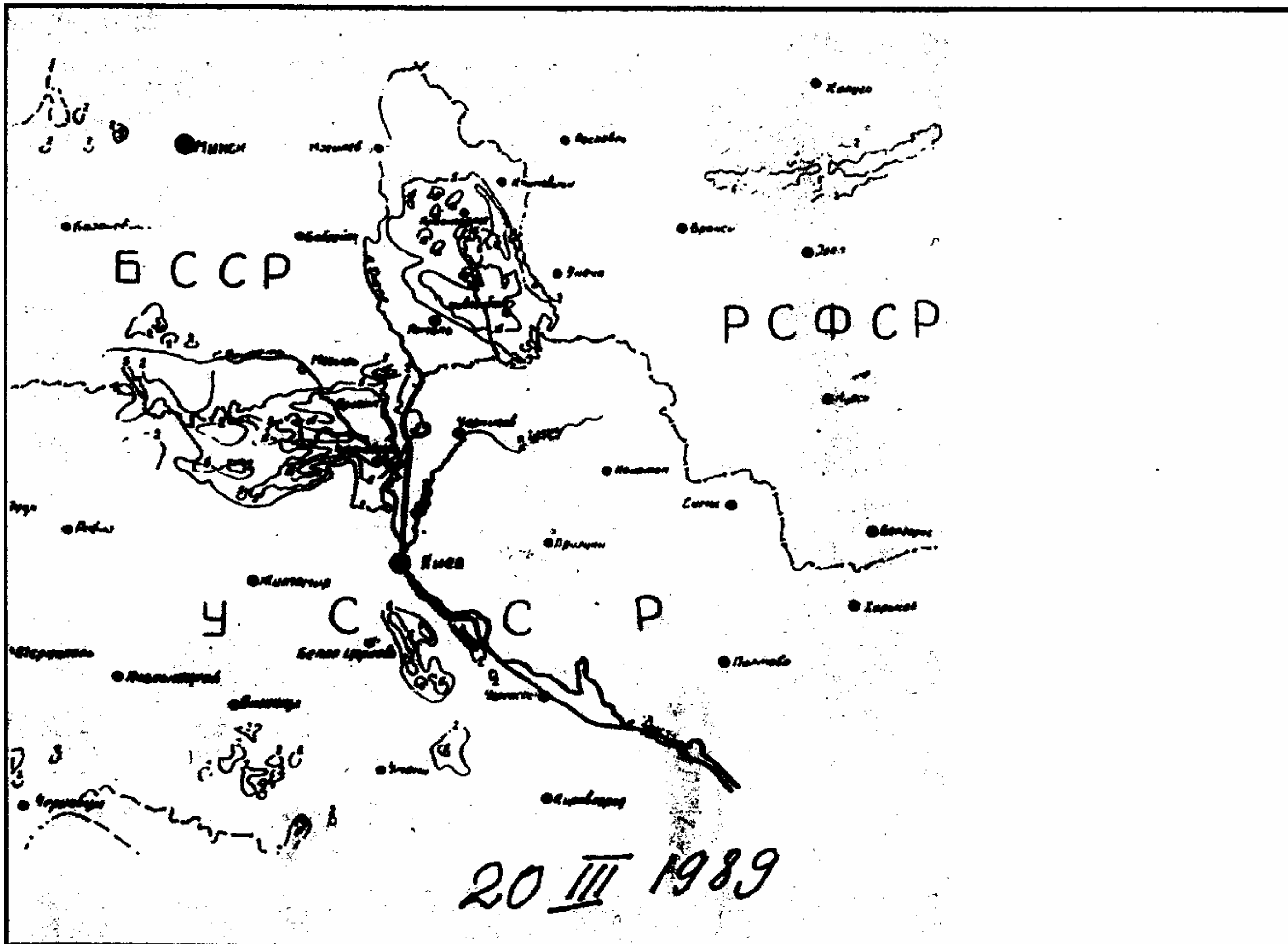



Fig. 4. First published map of contamination of Cs-137 («Pravda» 20.03.1989).

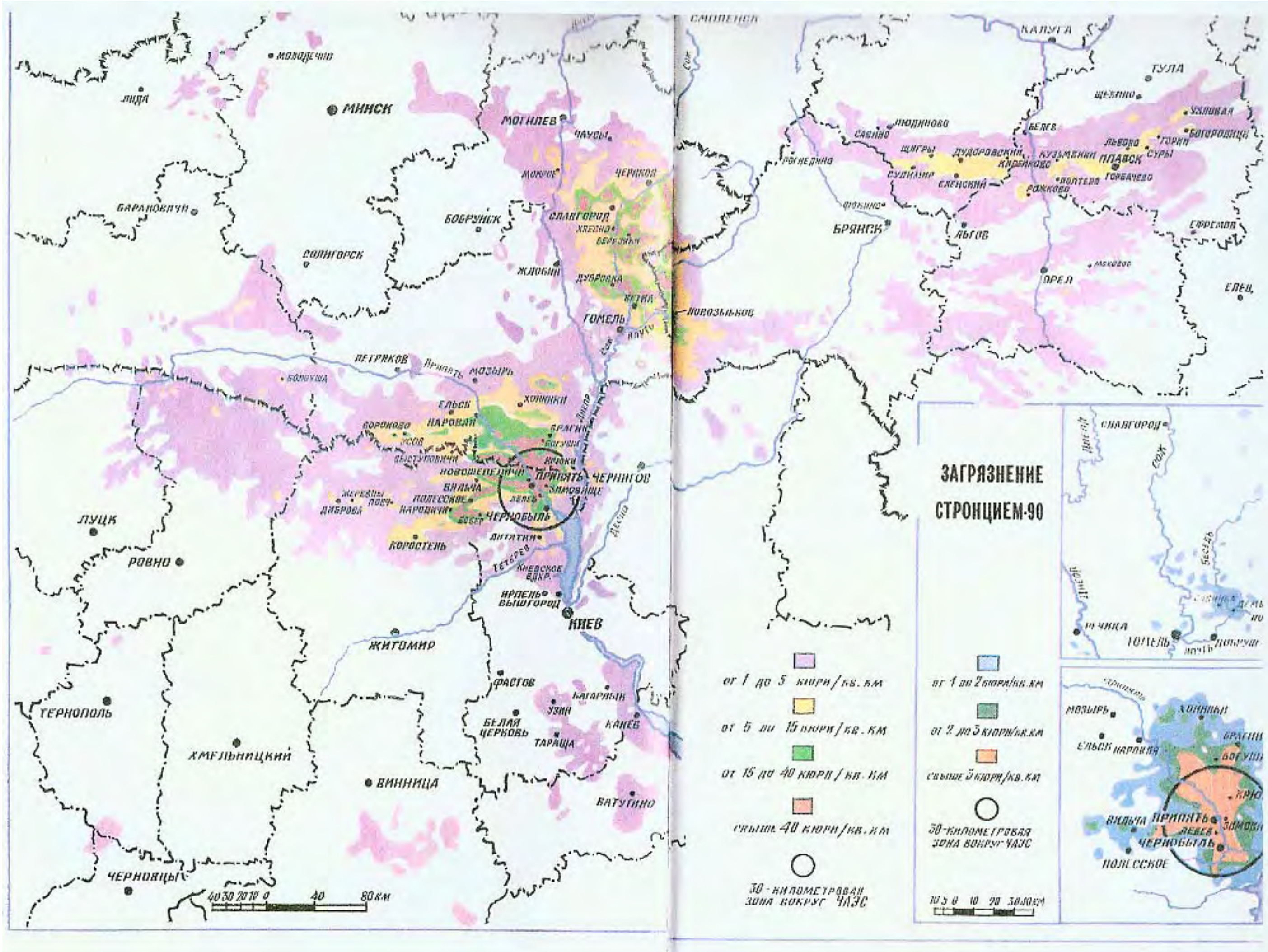



Fig. 5. Detailed first published maps of contamination Cs-137 and Sr-90 over the Russian part of USSR (Russian "Science and life", Nauka I zgizn, N9, 1990).

рис 6

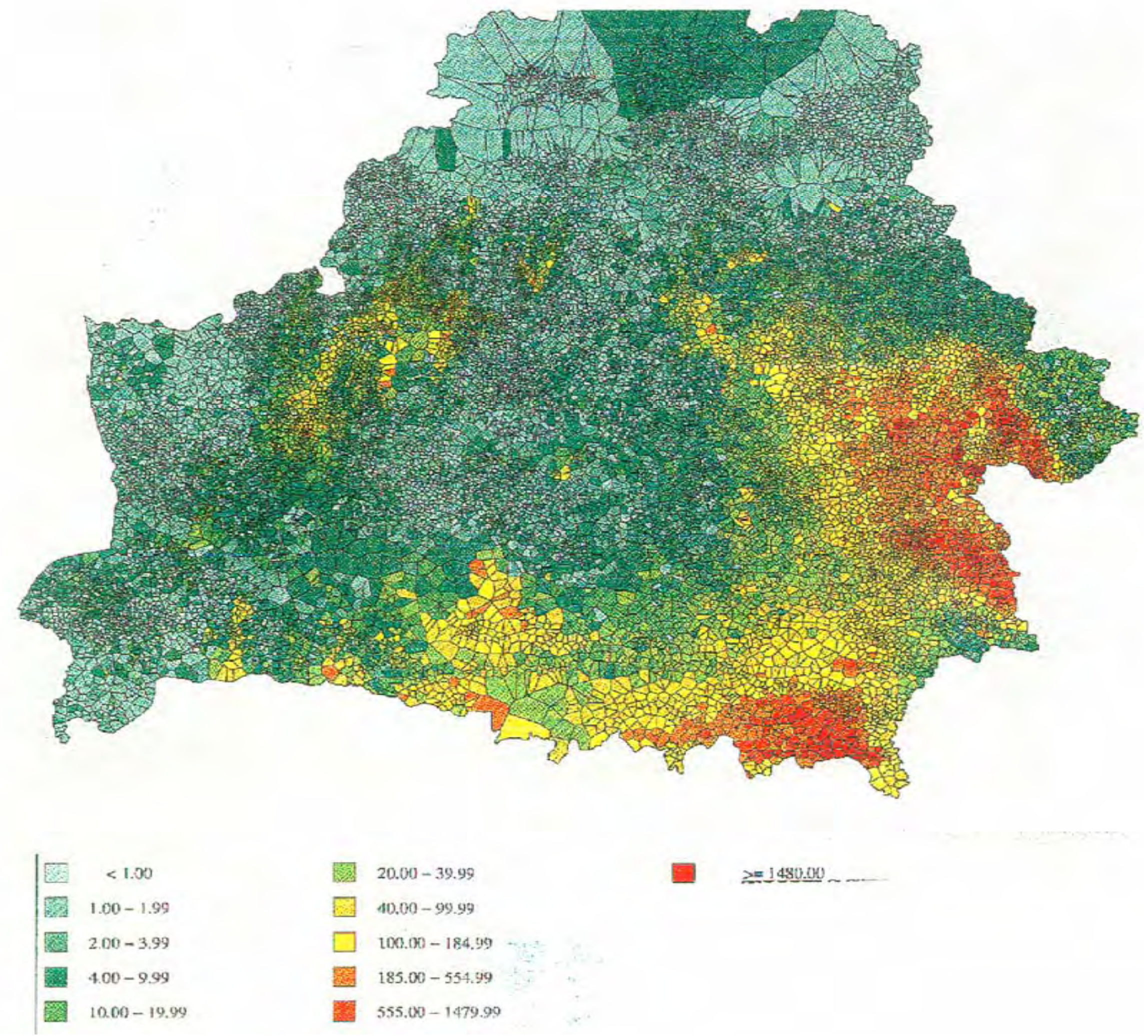



Fig. 6. Detailed map of the contamination of Cs-137 territory of Belarus

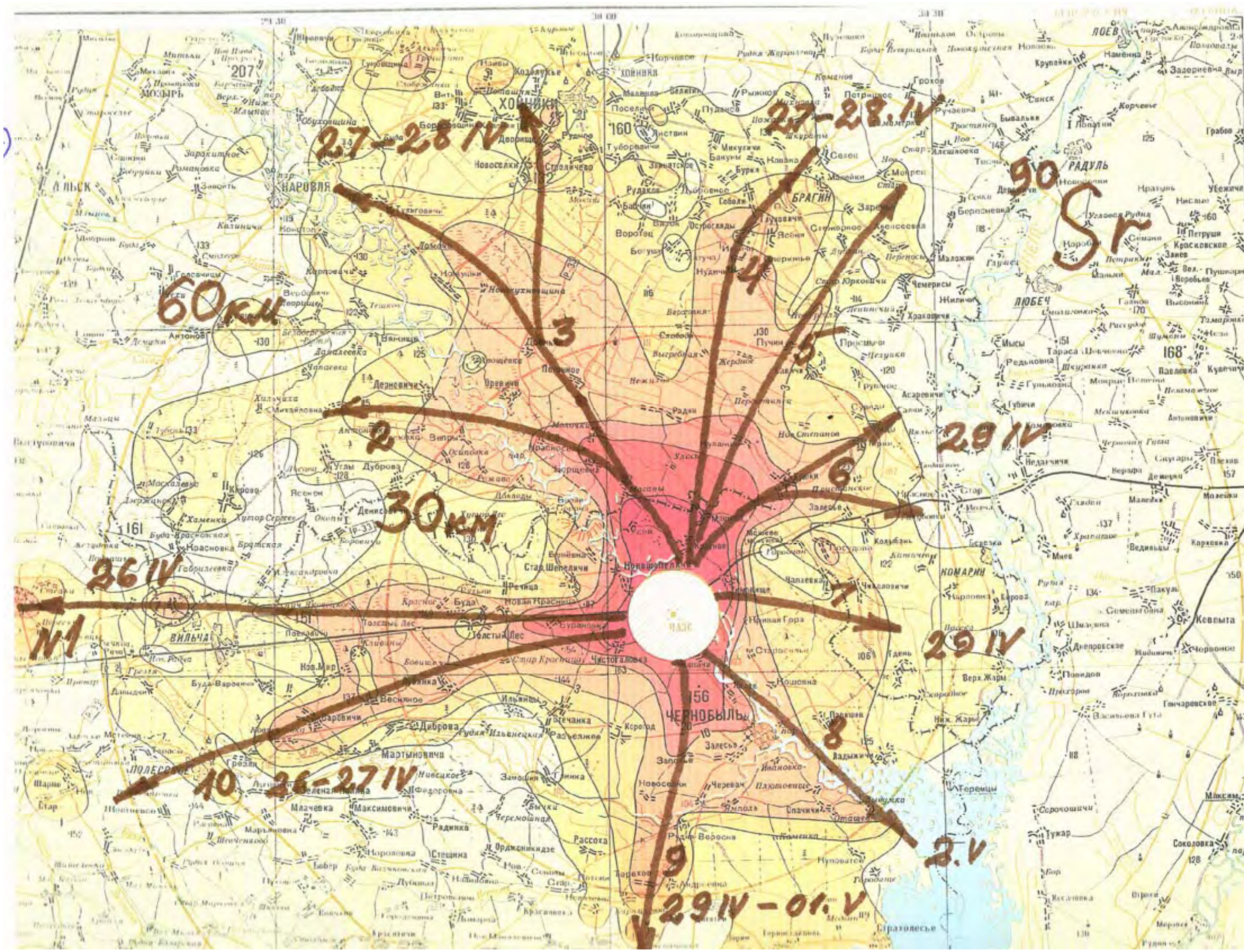



Fig.7. Detailed map of radioactivity patterns of Sr-90 in the 60-km close – in zone after the Chernobyl accident.

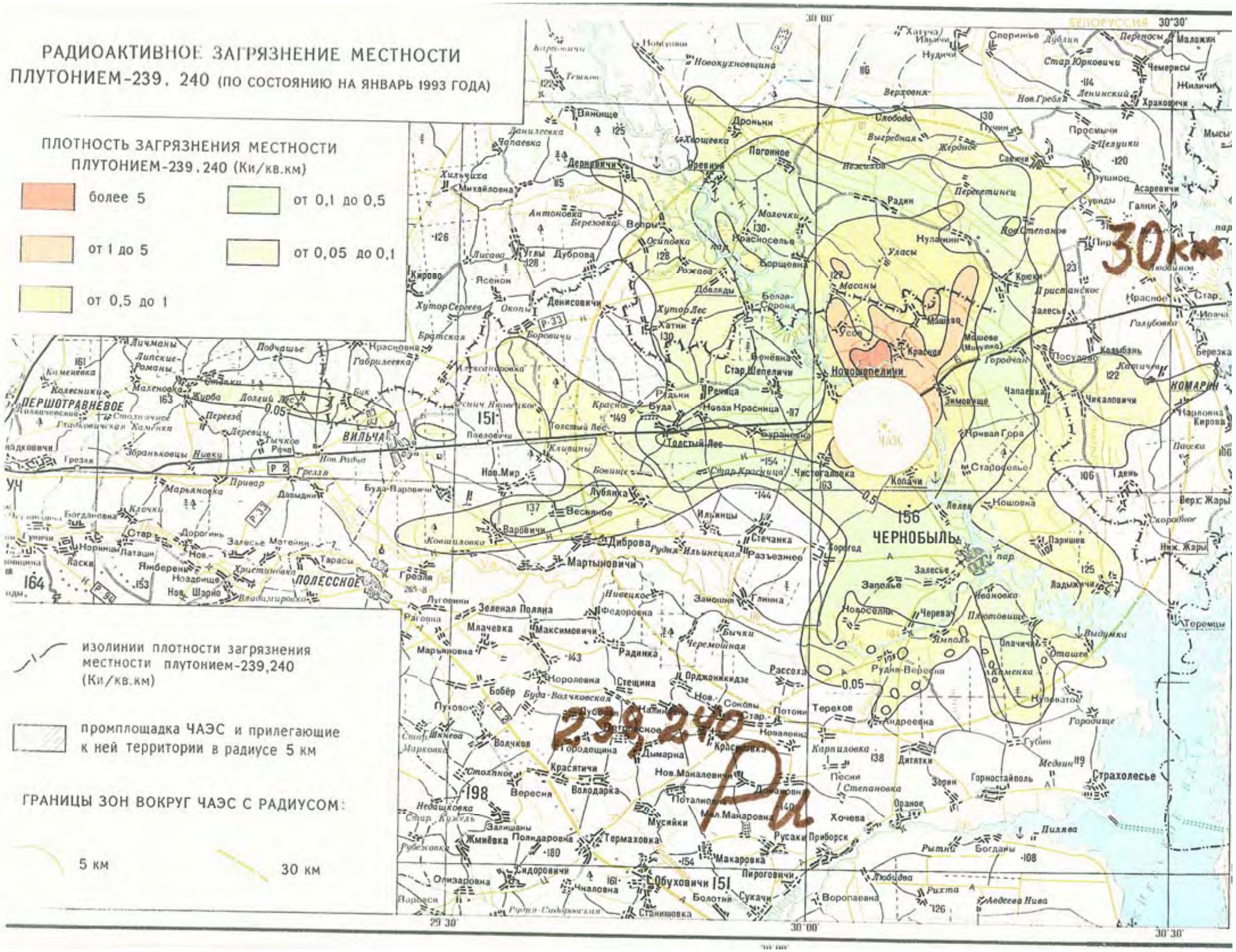



Fig.8. Detailed map of radioactivity patterns of Pu-239,240 in the 30-km close – in zone after the Chernobyl accident.

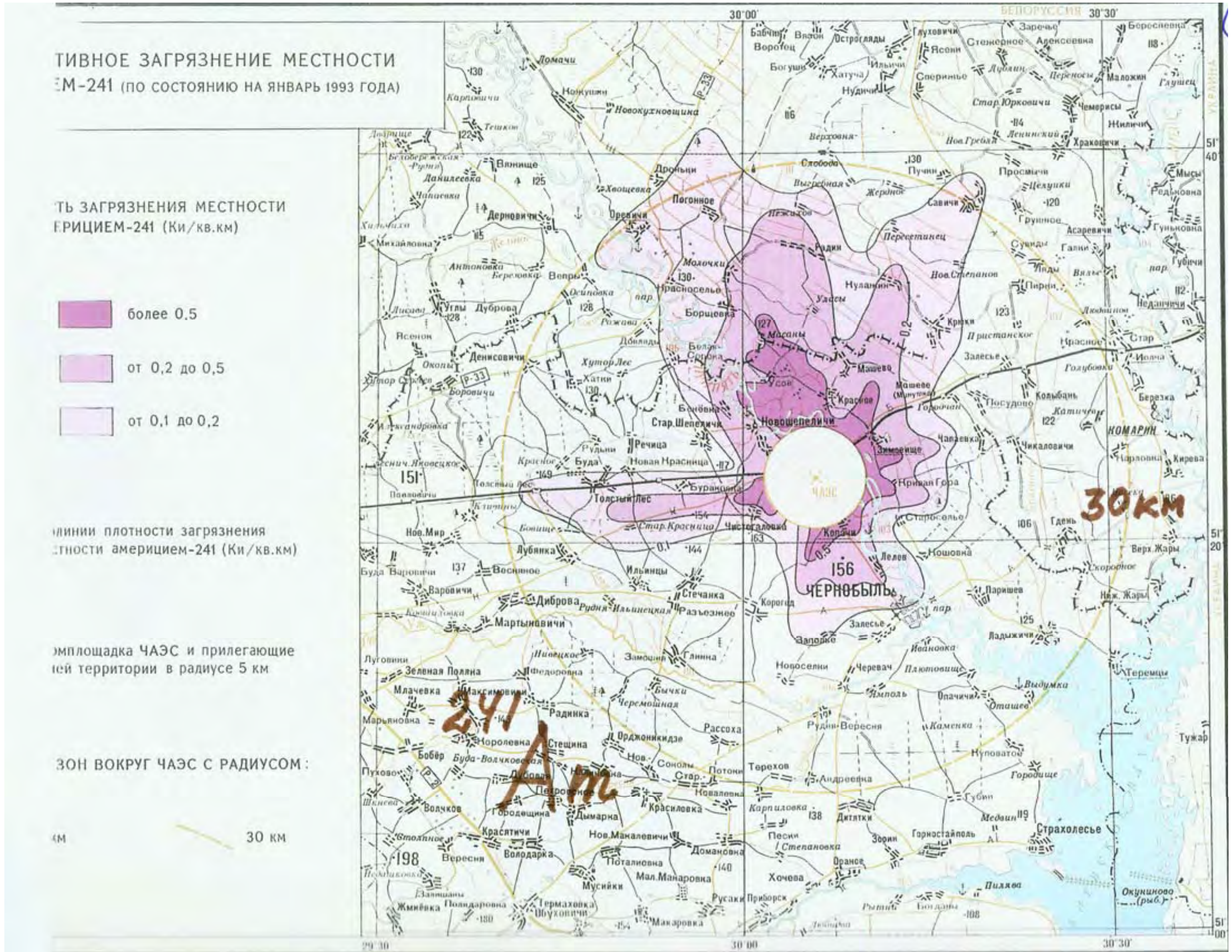



Fig. 9. Detailed map of radioactivity patterns of Am-241 in the 30-km close – in zone after the Chernobyl accident.

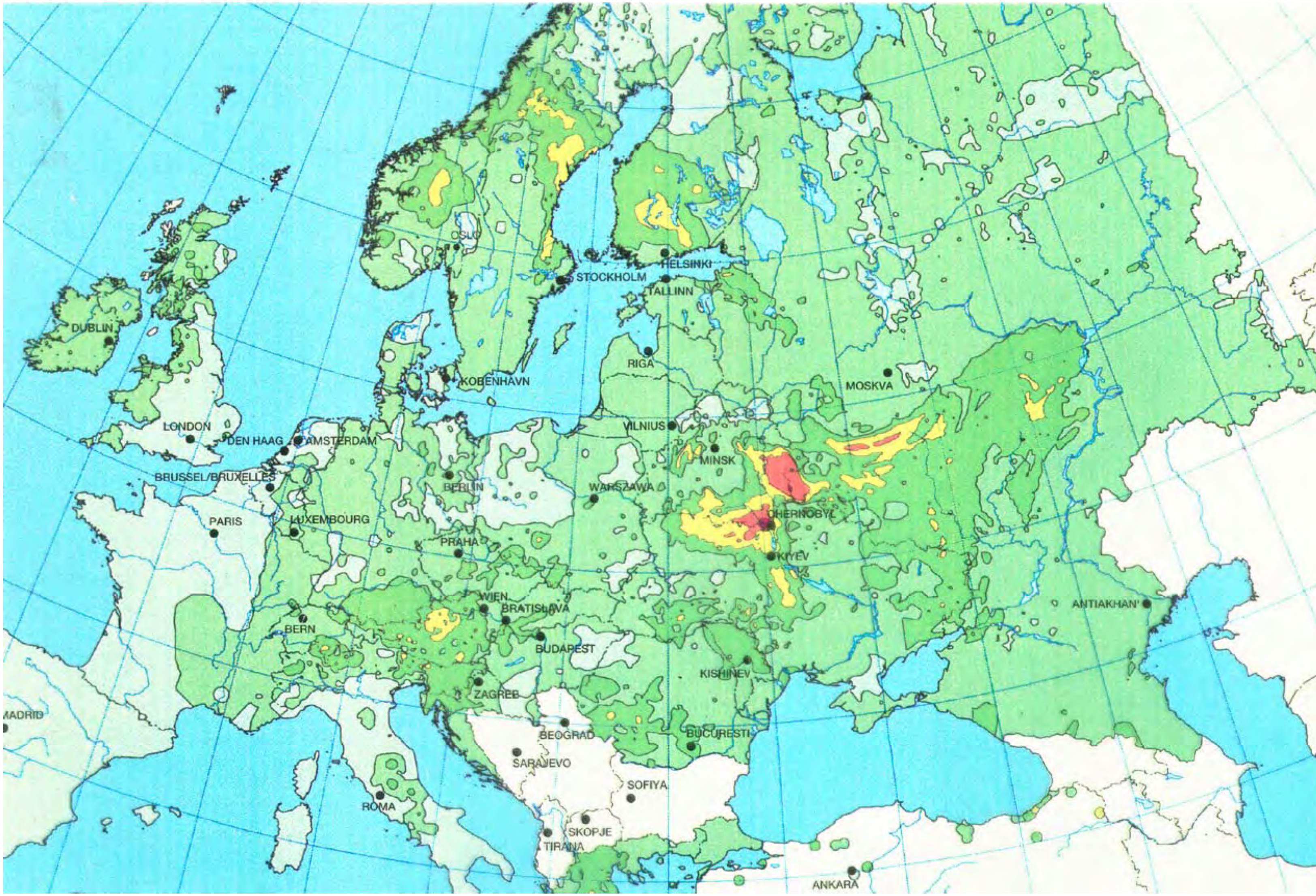



Fig. 10. Detailed map of the contamination of the territory of Europe by Cs-137.

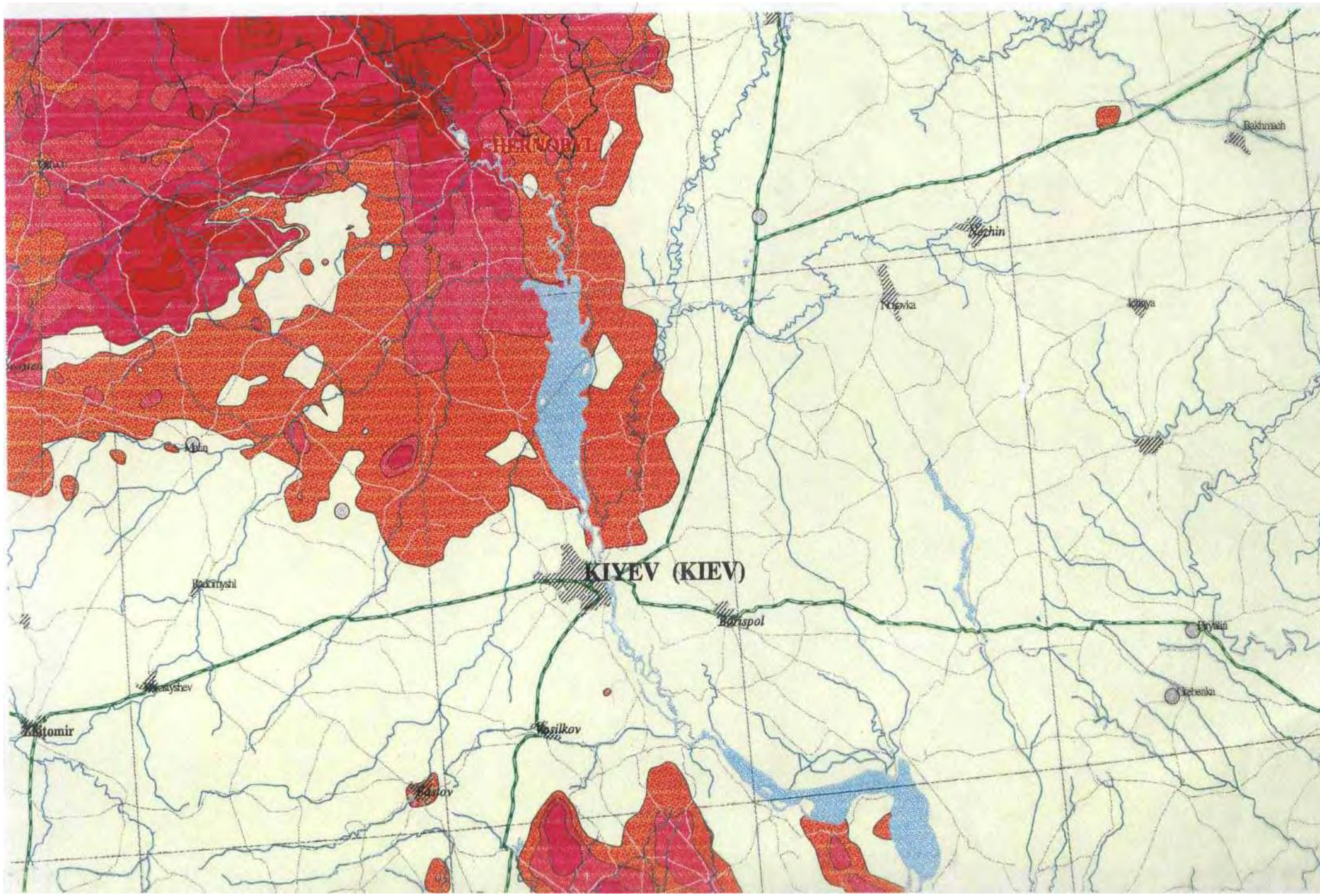



Fig. 11. Contamination of territory in Kiev region (Cs-137).

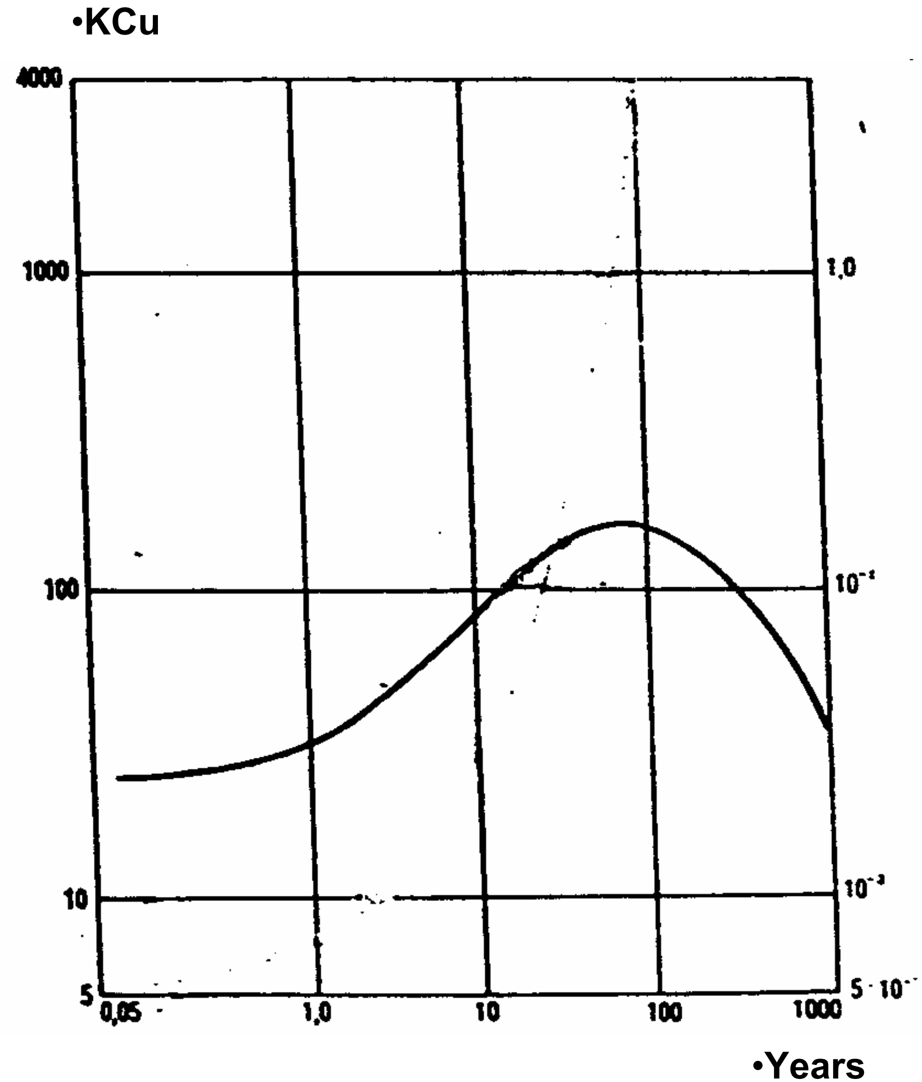



Fig. 12. Change of Am-241 in time.

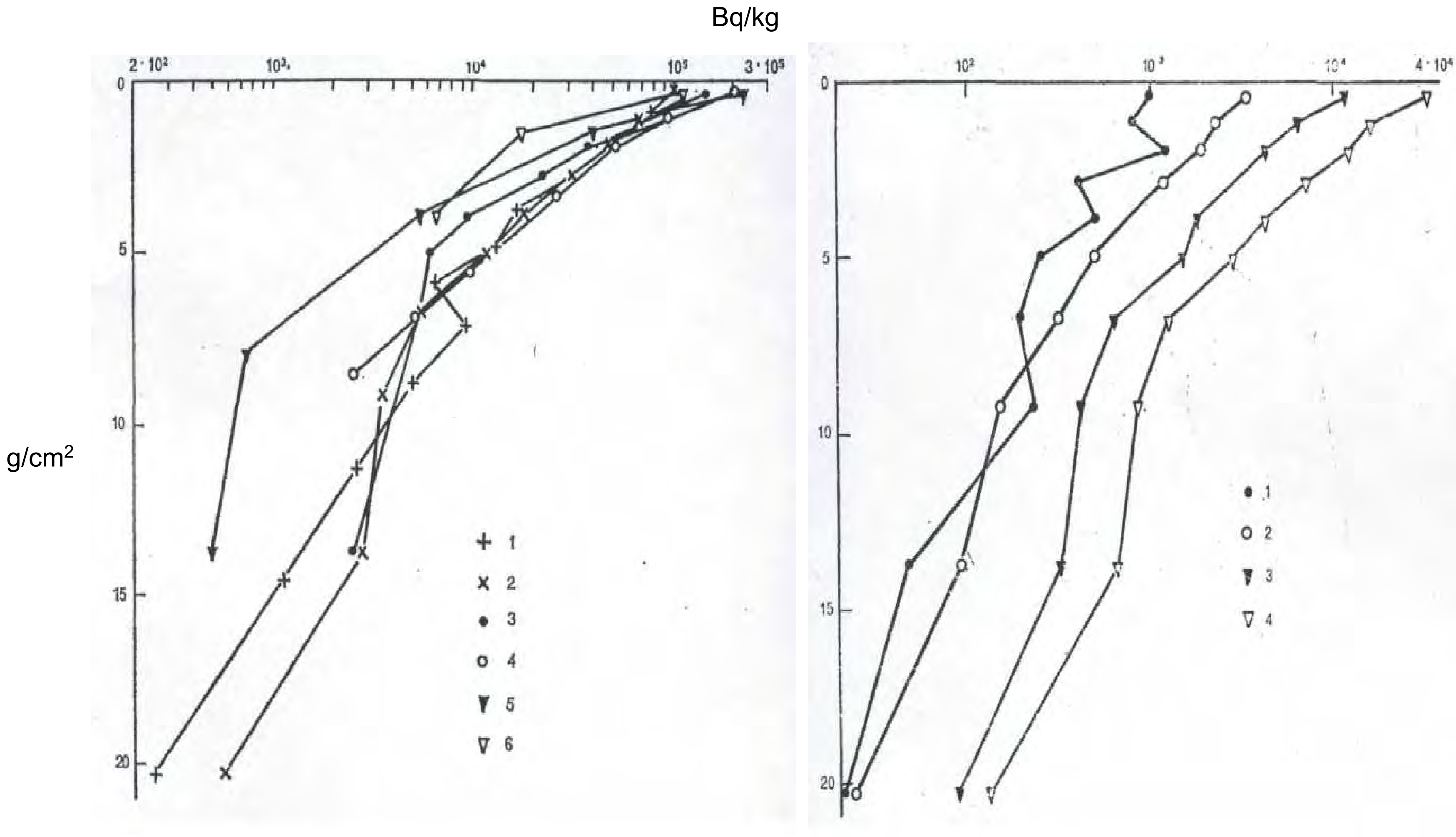



Fig. 13.Migration of radionuclides in different condition

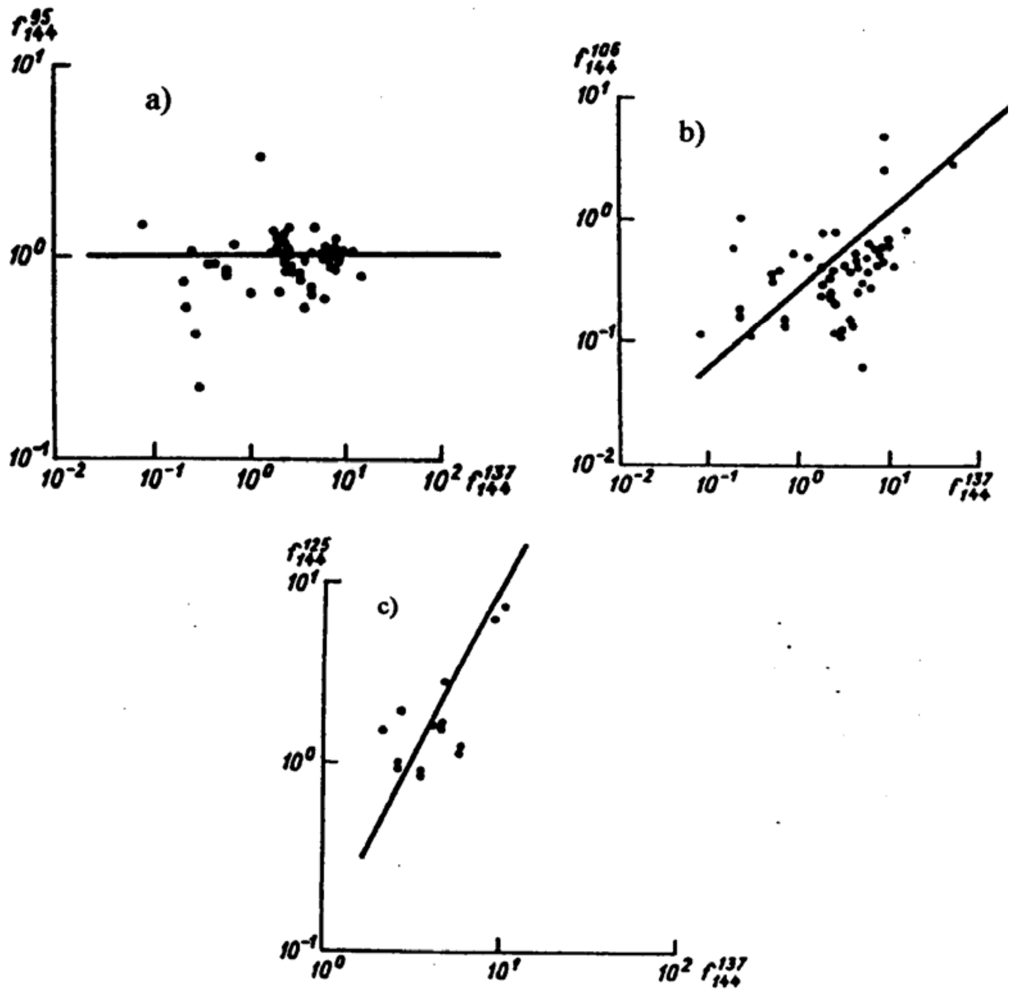



Fig. 14. Correlation between fractionation factors of different radionuclide for aerosol particles.

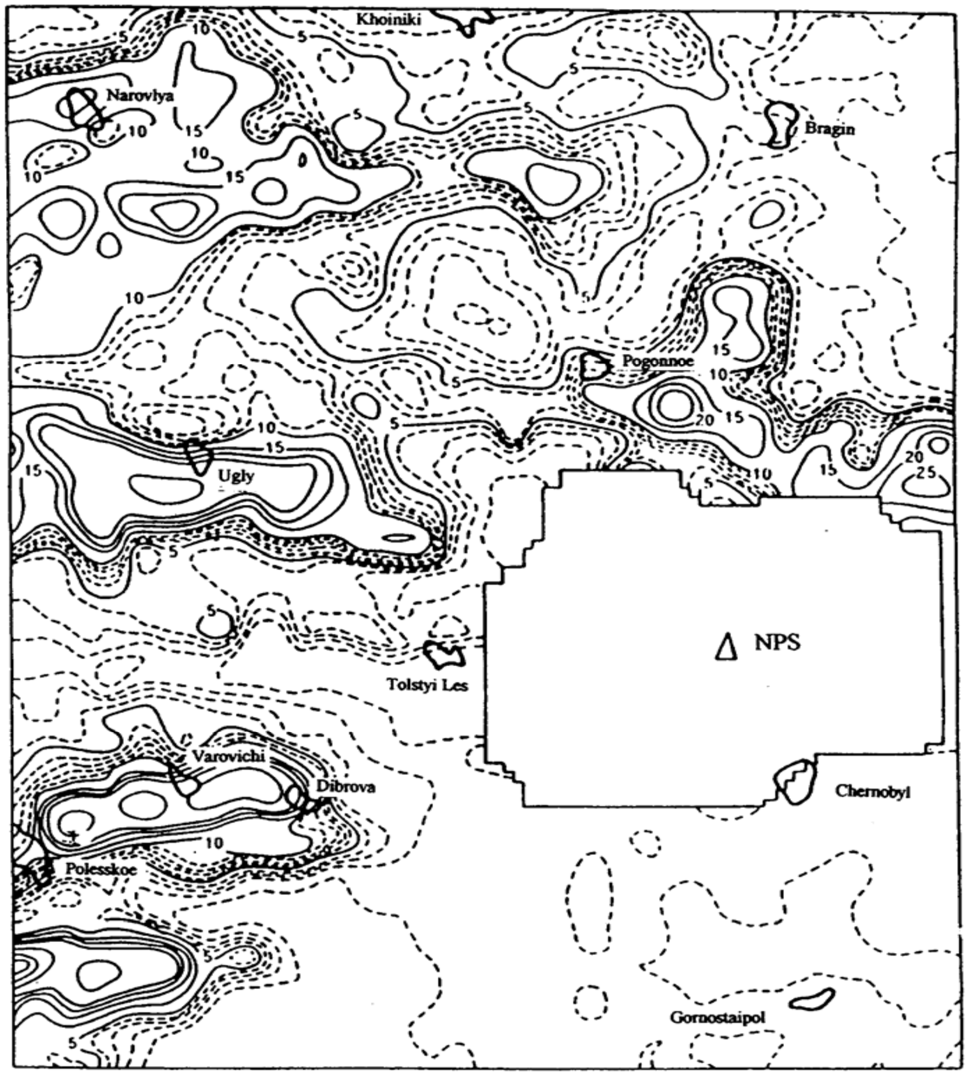



Fig. 15. Map of the distribution factor f137144 in close-in zone of accident.

# Chernobyl Radionuclide Distribution, Migration, and Environmental and Agricultural Impacts

**R.M. Alexakhin**

**Russian Institute of Agricultural Radiology and Agroecology, Russia, Obninsk**

*National Council on Radiation Protection and Measurements*
*Chernobyl at Twenty*
*Forty-Second Annual Meeting*
*April 3-4, 2006*
*Arlington, Virginia*

# Aspects of the Chernobyl NPP accident

- Economic
- Medical
- *Agricultural*
- *Ecological*
- Social-demographic

# *Accident at the Chernobyl nuclear power plant in 1986 – large anthropogenic catastrophe*

**Total release of radionuclides (without inert gases) – $1.85 \times 10^{18}$ Bq (50 MCi)**

**Affected area (region with a contamination density above 37 kBq/m$^2$ – 1 Ci/km$^2$) – 150000 km$^2$**

**$^{137}$Cs deposition distribution in the USSR ($4 \times 10^{16}$ Bq):**

**Russia 35%**

**Belarus 41%**

**Ukraine 24%**

**Other republics < 1%**

## Radioactive contamination of the environment – a source of *radionuclide accumulation* in objects of the natural environment (including plants and animals) and source of their *irradiation*

The main ecological effects of the Chernobyl accident
(2 groups of effects):
Radioactive contamination of the environment and
Radiation damage to populations of living organisms and ecosystems (*contamination* vs *damage*)

# The basic paradigm of radioecology

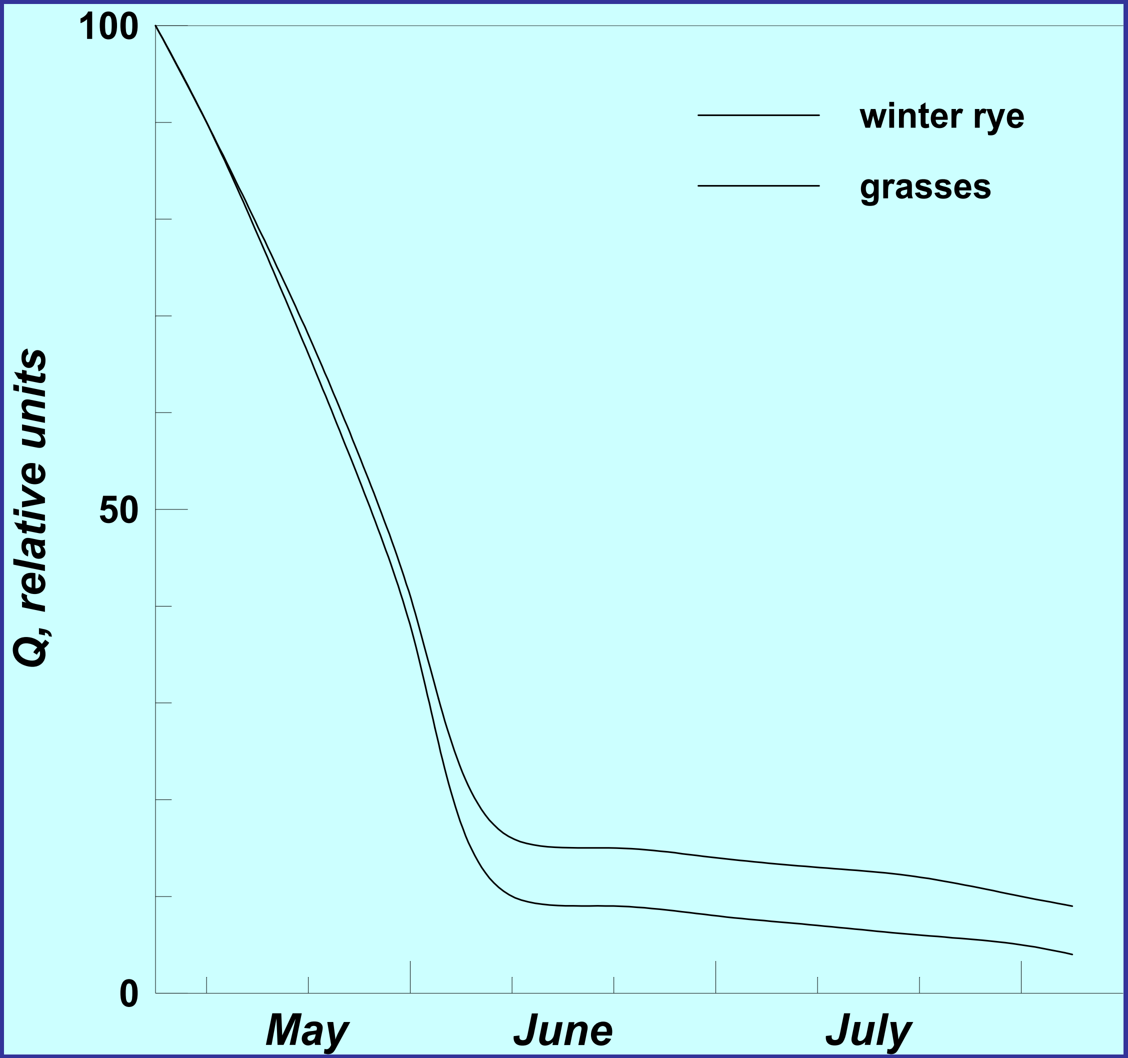
*In the accidental zone, the area where ecologically important radiation injury of plants and animals is observed is considerably smaller than the area where the human economic activity is restricted or excluded (including residence), because concentrations of radionuclides in environmental objects (primarily in agricultural products) exceed the permissible standards*

# Distribution and Migration of Radionuclides in the Environment

## I. Terrestrial ecosystems

1. Aerial contamination in the first stage of radioactive fallout

# Dynamics of total amount of $\gamma$-emitting nuclides in plant vegetative mass in 1986



# Distribution and Migration of Radionuclides in the Environment

2. Soil is the main depository of radionuclides in terrestrial ecosystems (up to 90 % of the radionuclide inventory)
3. Root uptake of radionuclides from soil is the main pathway of radionuclide transport to plants in terrestrial ecosystems
4. Factors responsible for radionuclide accumulation in plants:
   a) Soil properties
   b) Biological peculiarities of plants
5. Forest ecosystems
   a) Long-time radionuclide retention
   b) Slow crown self-clearance
   c) Long-term accumulation type
   d) Role of forest litter as a radionuclide accumulator

# Distribution and Migration of Radionuclides in the Environment

## I. Water ecosystems

1. Sediments as a depository of radionuclides in water ecosystems (up to 90 % of the inventory)
2. Water self-clearance in aquatic ecosystems
3. Radionuclide accumulation by hydrobionts

# Agricultural Impact

I. The accident at the Chernobyl NPP as a "rural" disaster
II. Protective countermeasures in the agroindustrial complex
III. The dynamics of changes in $^{137}Cs$ concentration in farm products
IV. Reduction in exposure doses to the population as a result of countermeasure application in agriculture
V. Current status of the agrosphere in Russia (the contaminated region)

# Agricultural Impact

## The Chernobyl NPP accident as "rural accident"

I. Agricultural products that contain radionuclides as the key source of irradiation of the population

The contribution of consumption of radionuclide containing farm products (internal exposure) to the total dose of irradiation of the population

Peaty soils – up to 70-80%

Soddy-podzolic (sandy and sandy loam) soils – 50%

Grey forest, chernozemic, soddy-podzolic sandy loam soils – up to 20%

# Agricultural Impact Cont'd

## The Chernobyl NPP accident as "rural accident"

II. The major population contingent in the affected area is rural (rural type of nutrition)

III. Irradiation of the rural population is higher than urban (way of life, protective barriers)

IV. Regulation of radionuclide fluxes in the environment and exposure doses to the population is economically and technologically more effective for internal irradiation

V. The total system of countermeasures for mitigating consequences of the accident is dominated by agricultural countermeasures

# The Chernobyl accident and agroindustrial complex

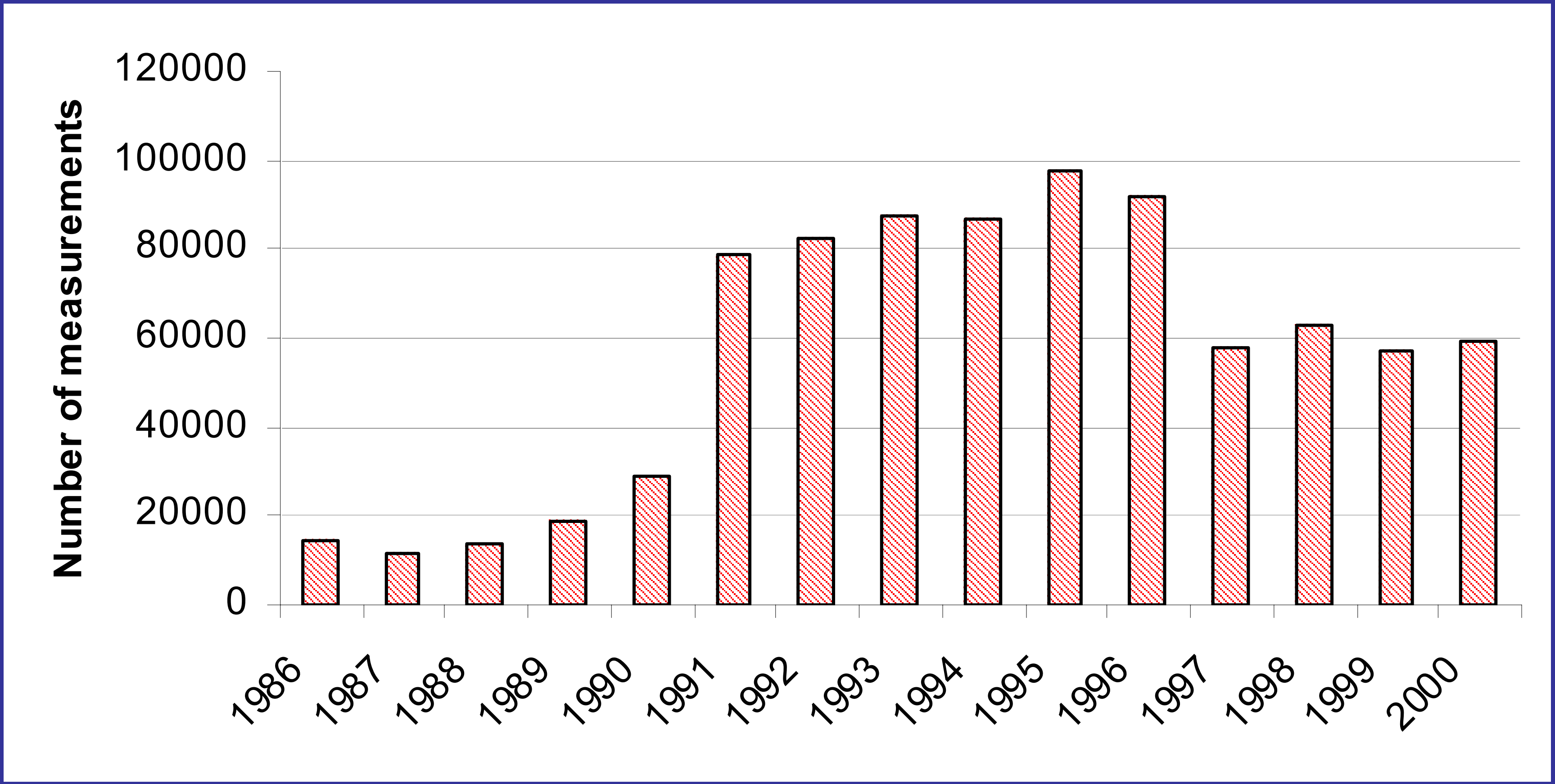
I. Accidental region – agroindustrial

II. Radionuclide composition – the presence of biologically mobile radionuclides ($^{90}Sr$, $^{131}I$, $^{134,137}Cs$)

III. Time of the accidental release – late spring-early summer – critical period for agriculture (in terms of radioactive contamination)

IV. Agricultural sphere in the affected area – prevalence of low in fertility (soddy-podzolic sandy and peaty) soils in the soil cover

# Radiation monitoring of the agricultural production sphere




Number of measurements made during the radiation central of agricultural products in the Bryansk region (Russia)

# Radiological principles of agricultural production

Division of agricultural lands into zones

- by radioactive contamination density
- by exposure dose (considering internal irradiation)

# Division of agricultural production into periods – initial, intermediate and long-term

## *Protective countermeasures in agricultural production*

I. Prohibitive
II. Restrictive
III. Organizational
IV. Constructive

# Protective countermeasures in the agroindustrial complex

*Aim – reduction in radionuclide concentration in the agricultural production*

- Land cultivation
- Plant production
- Animal production
- Processing branches

# Effectiveness of agrotechnical and agrochemical countermeasures for reducing $^{137}Cs$ accumulation in plant products

| Countermeasure | Reduction factor of radionuclide accumulation in plants, times |
|---|---|
| Plowing | 1.5-2.5 |
| Plowing with layer turnover | Up to 5-10 |
| Liming | 1.5-2.0 |
| Application of increased doses of P-K fertilizers | 1.5-2.0 |
| Application of organic fertilizers | 1.5-2.5 |
| Complex application of ameliorants | Up to 5.0 |

*Average reduction in $^{137}Cs$ concentration – 1.5–2.5 times*

# Effectiveness of countermeasures for reducing $^{137}Cs$ accumulation in plants on meadows

| Countermeasure | Reduction factor of $^{137}Cs$ content in grass stand, times |
|---|---|
| Removal of the upper contaminated layer | 5-15 |
| Plowing | 1.8-16 |
| Disking and rototilling | 1.2-1.8 |
| Improvement | 1.6-6.2 |
| Drainage and improvement | 2.5-10 |
| Application of non-conventional ameliorants (zeolite, palygorskite, vermiculite, etc.) | 1-2.5 |

*Range of $^{137}Cs$ reduction factor in grass stand on meadows – 1.2-16 times*

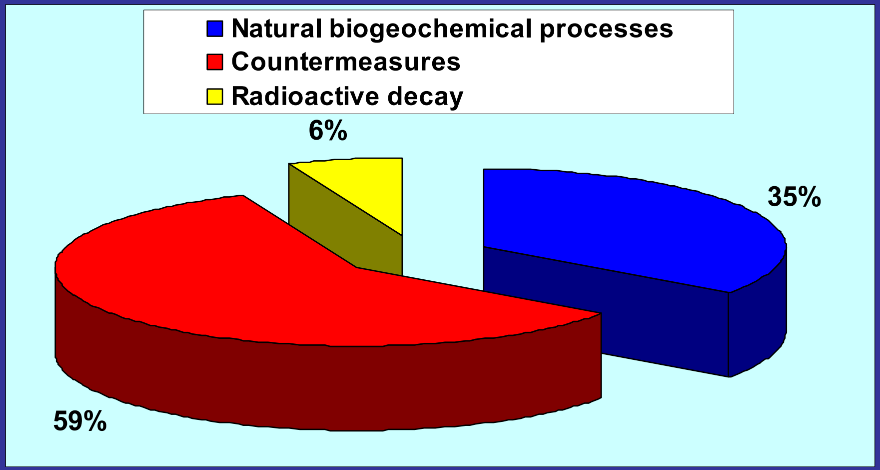
In the natural environment (and in the agrosphere) a range of *biogeochemical processes* are acting that lead to changes (mainly reducing) in the availability of radionuclides during their movement via food chains. Changes in the radionuclide contents in plants and animals result from both *radioactive decay* and application of *countermeasures.* The reduction in the radionuclide content in plants and animals is estimated by an effective half-life period of radionuclide concentration decrease.

# Ageing of radionuclides in soils (half-life periods of $^{137}Cs$ concentration decrease in agricultural products, years)

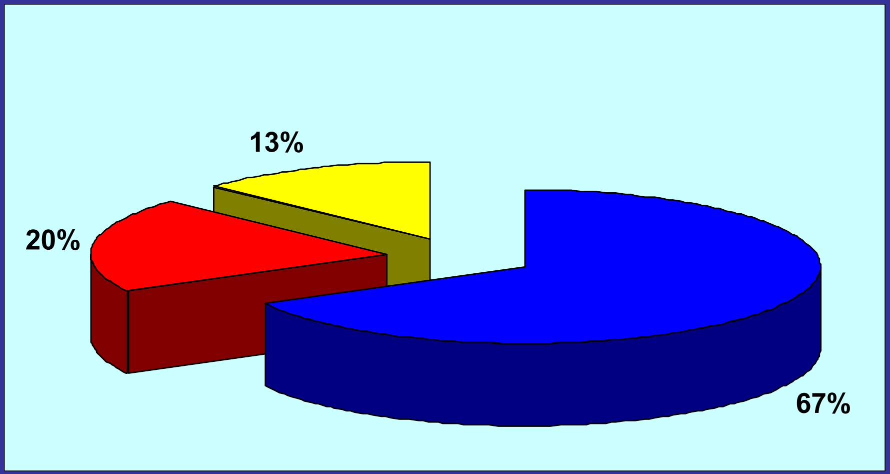
| | |
|---|---|
| Potato, root crops | 7.0-10.0 |
| Sown grasses | 6.4-17.3 |
| Natural grasses | 5.8-18.0 |
| Milk | 1.7-4.8 |

# Contribution of factors responsible for $^{137}Cs$ content reduction in farm products

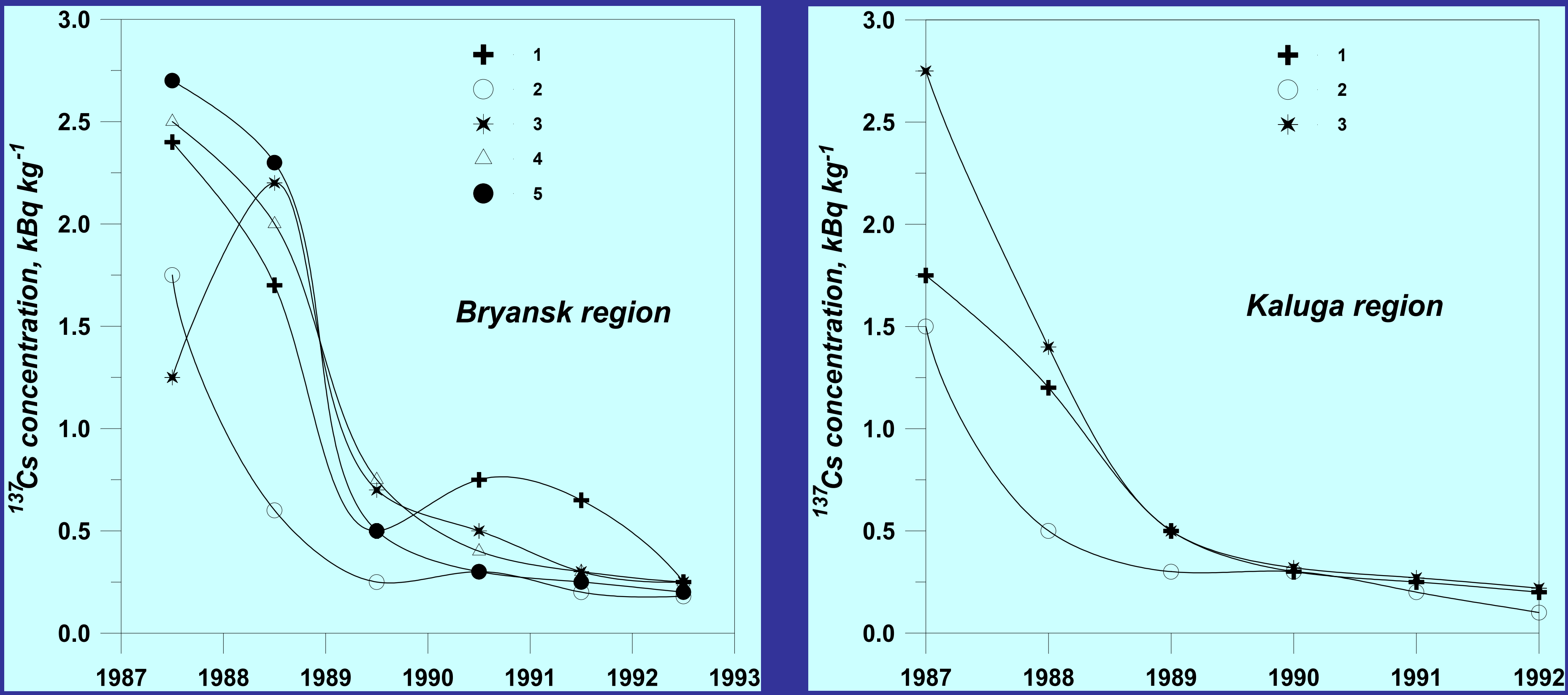
## Regions with active countermeasure application (Bryansk region)




## Regions with limited countermeasure application (Kaluga region)

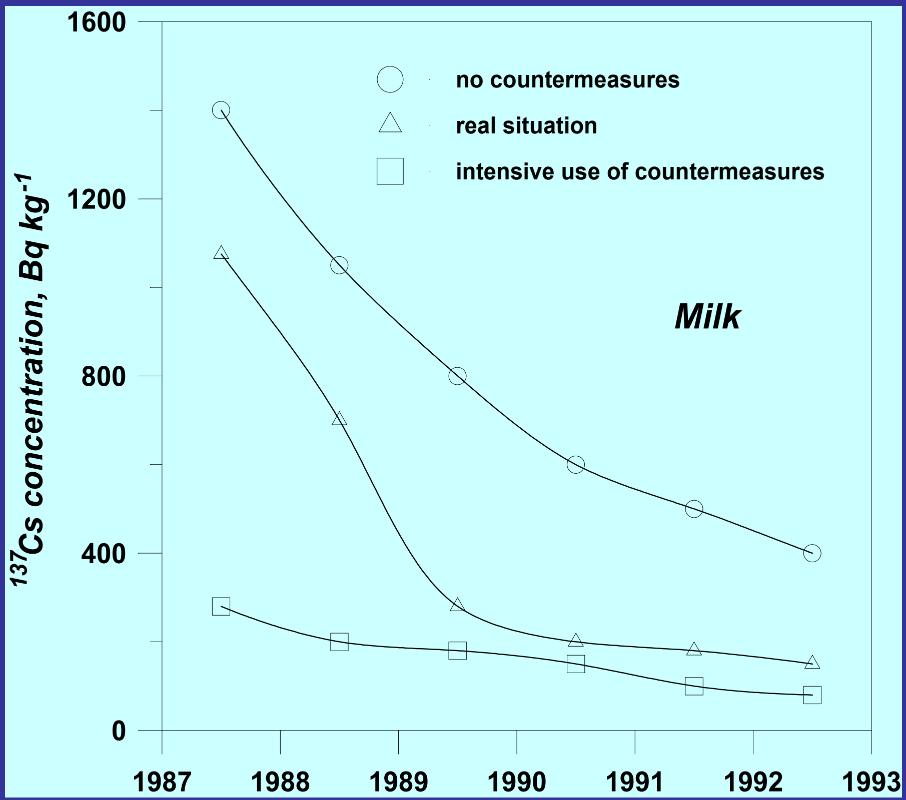


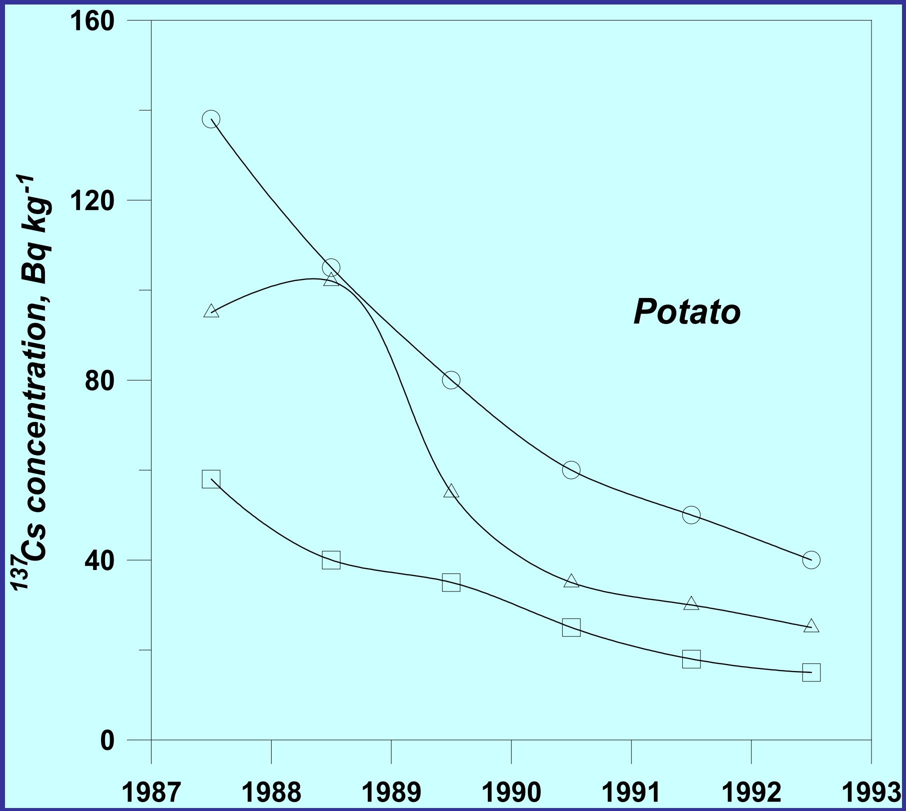
# Dynamics of $^{137}Cs$ content in milk in regions of Russia affected by the Chernobyl accident



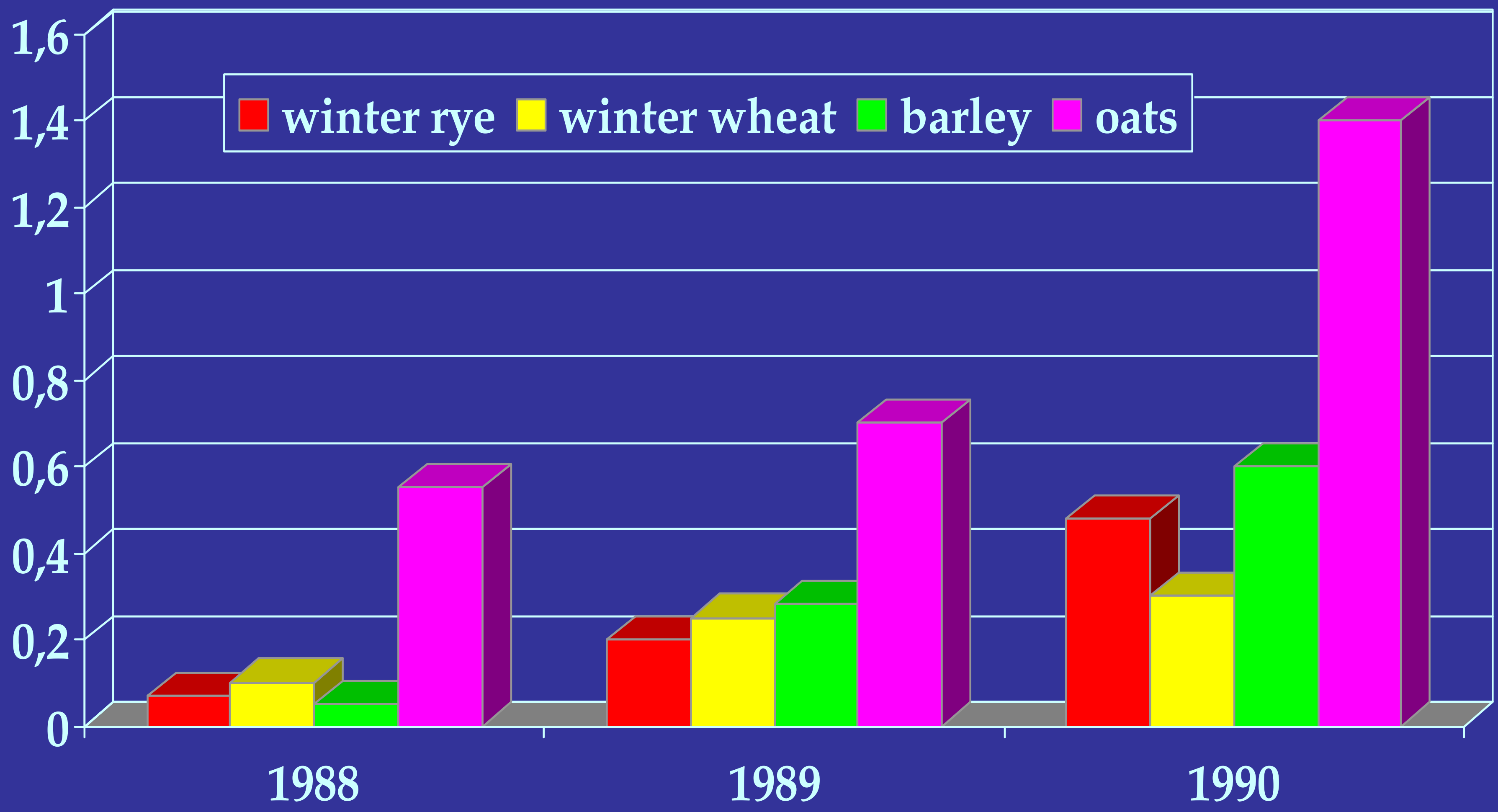

a) Bryansk region: 1 – Gordeyevsky district; 2 – Klimovsky; 3 – Klintsovsky; 4 – Krasnororsky; 5 – Novozybkovsky; b) – Kaluga region: 1 – Ulianovsky district; 2 – Zhizdrinsky; 3 - Khvastovichsky

# Dynamics of $^{137}Cs$ concentration in milk and potato under different countermeasure strategies

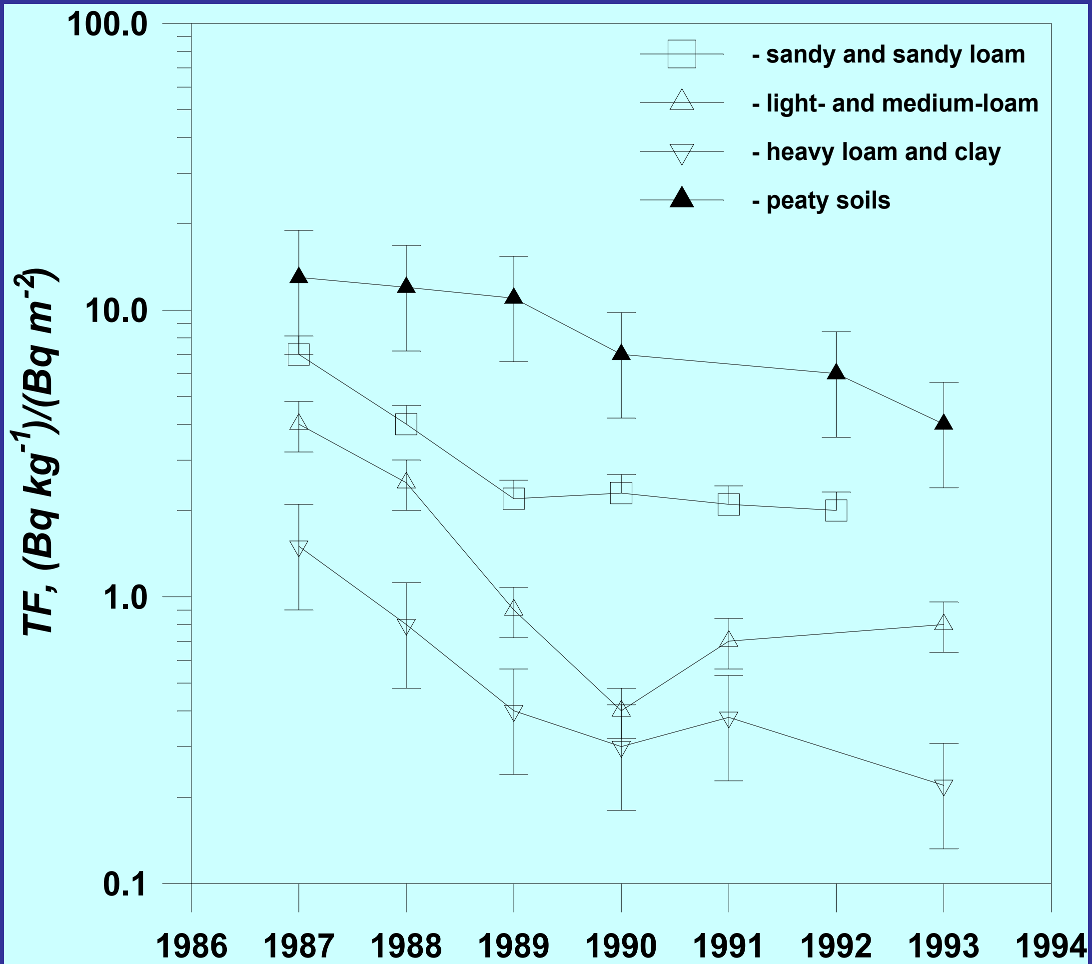


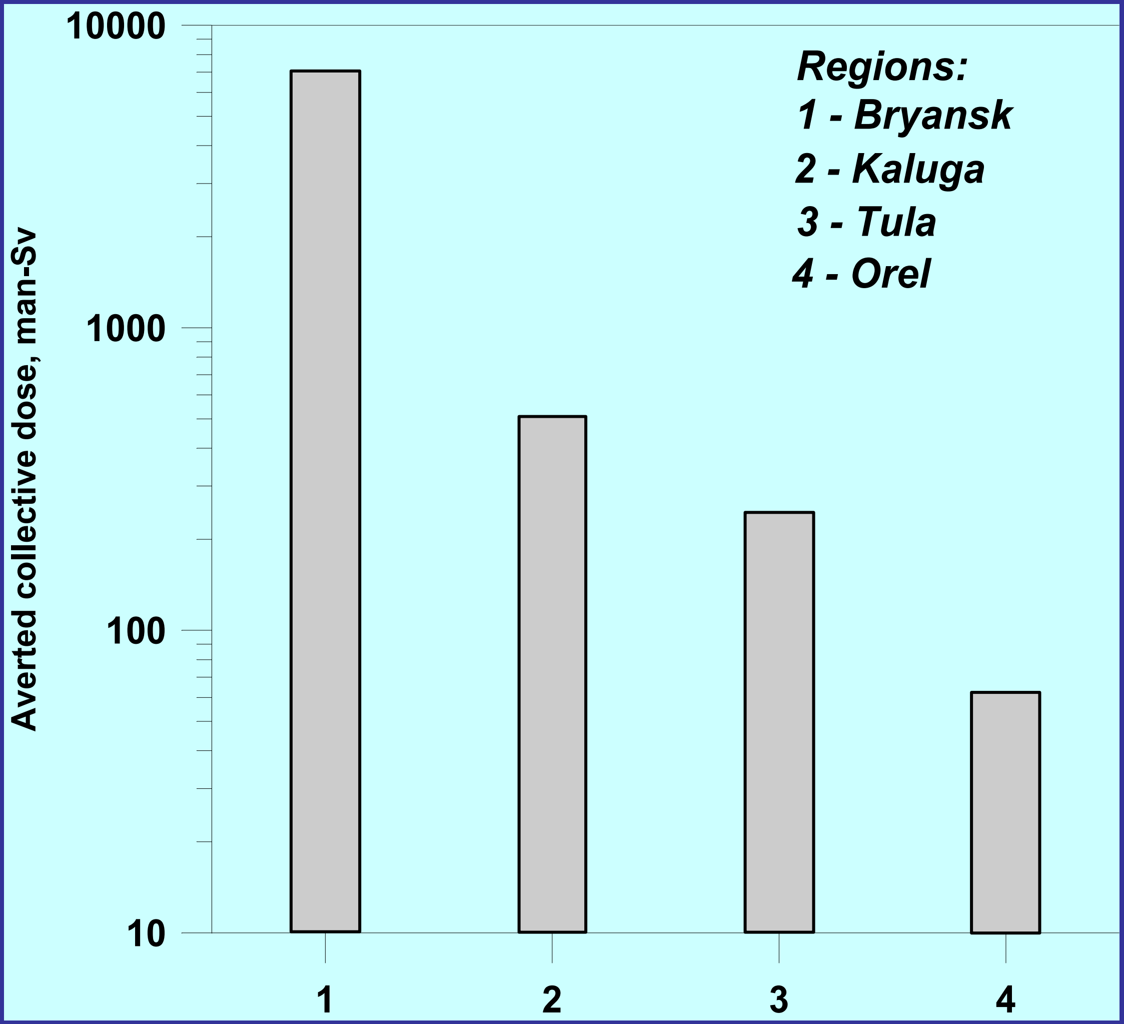
# Dynamics of $^{90}Sr$ concentration factors in grain of cereal crops (30-km zone, soddy-podzolic soil)



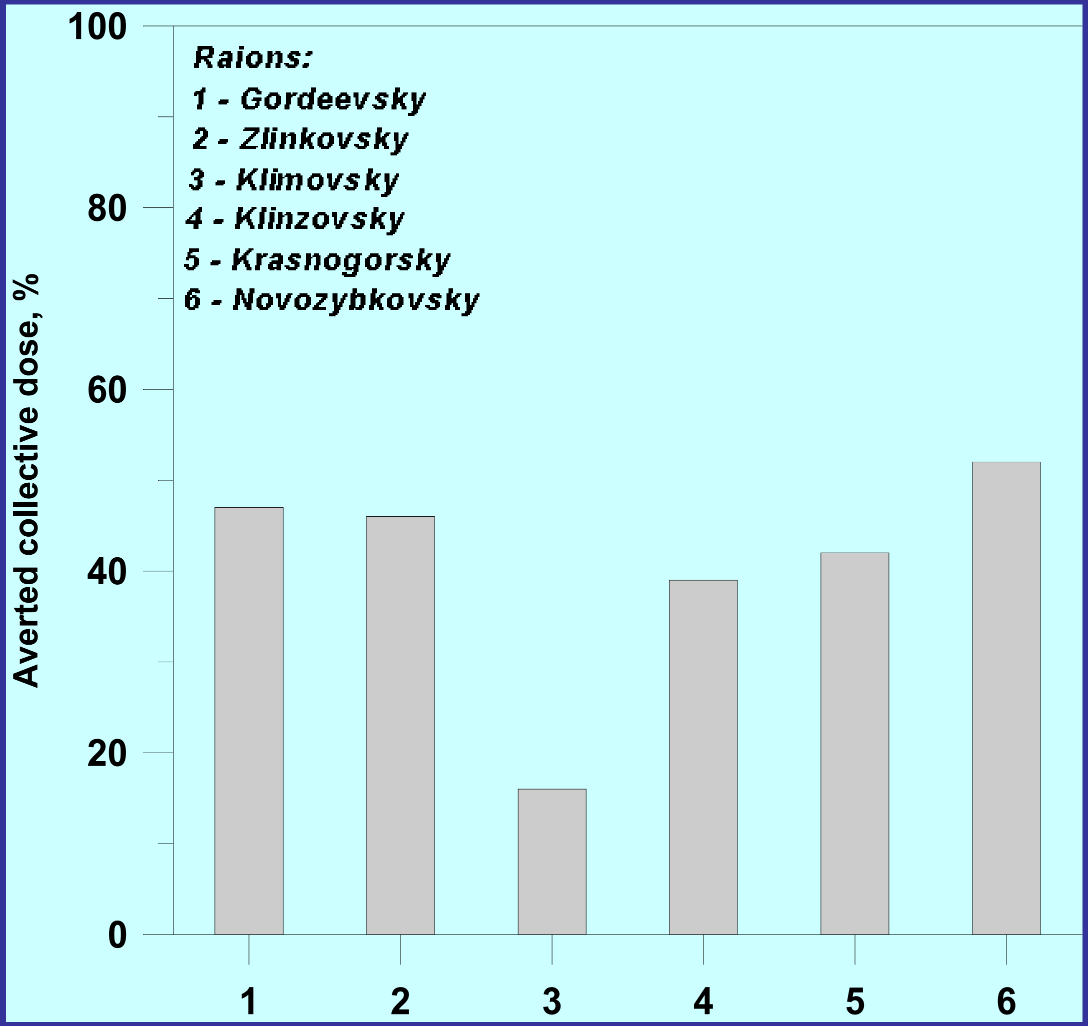
# Dynamics of $^{90}Sr$ transfer factors to perennial sown grasses on different soil types



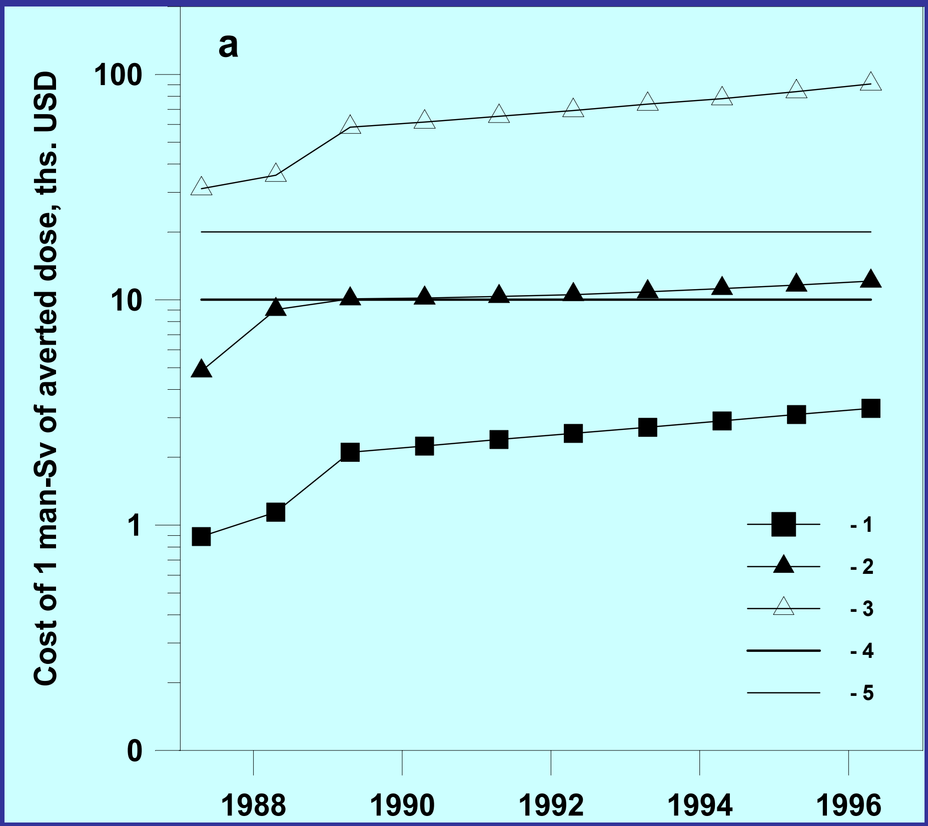
# Averted during 18 years collective doses to the population from exported agricultural products from farms of the Chernobyl contaminated regions of Russia

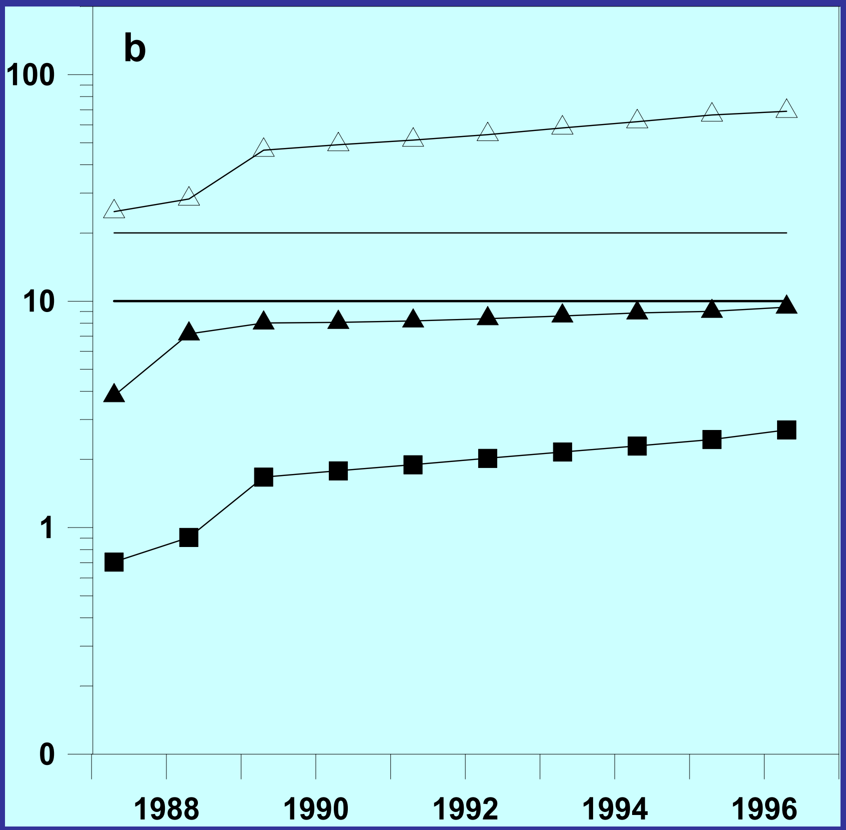


# Averted during 18 years collective doses to the population from exported agricultural products from farms of 6 districts in the Bryansk region



# Variations in the cost of dose decrease per 1 man-Sv as a result of soil radical improvement in collective (a) and private (b) sector, $^{137}Cs$ deposition density is 740 kBq m$^{-2}$

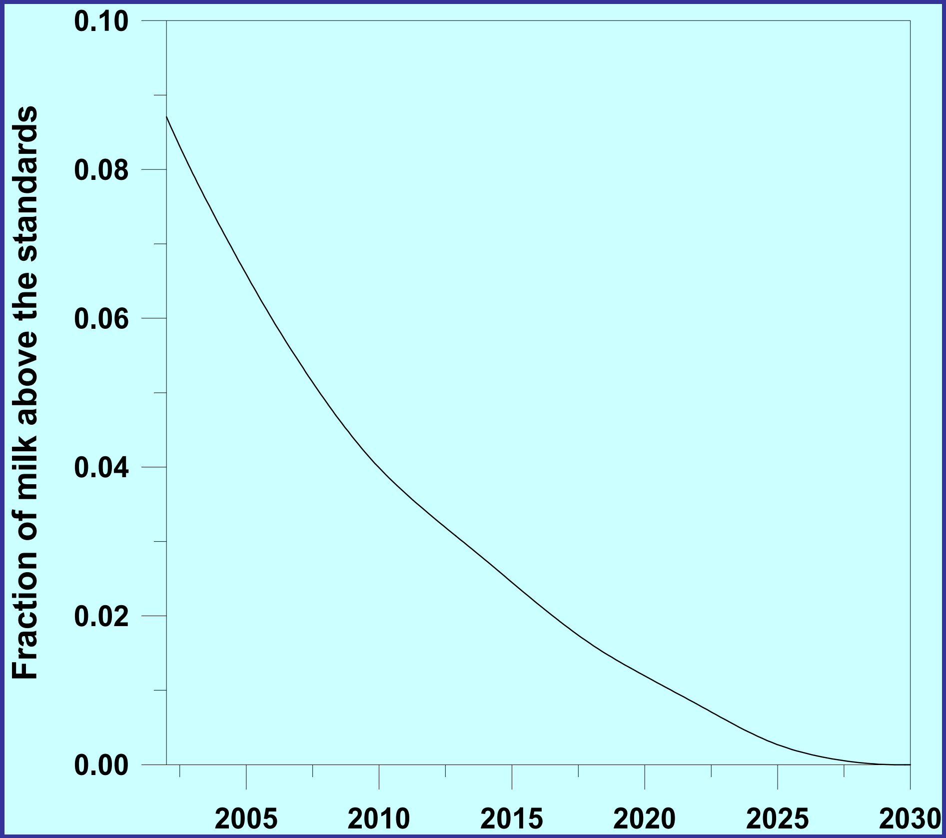


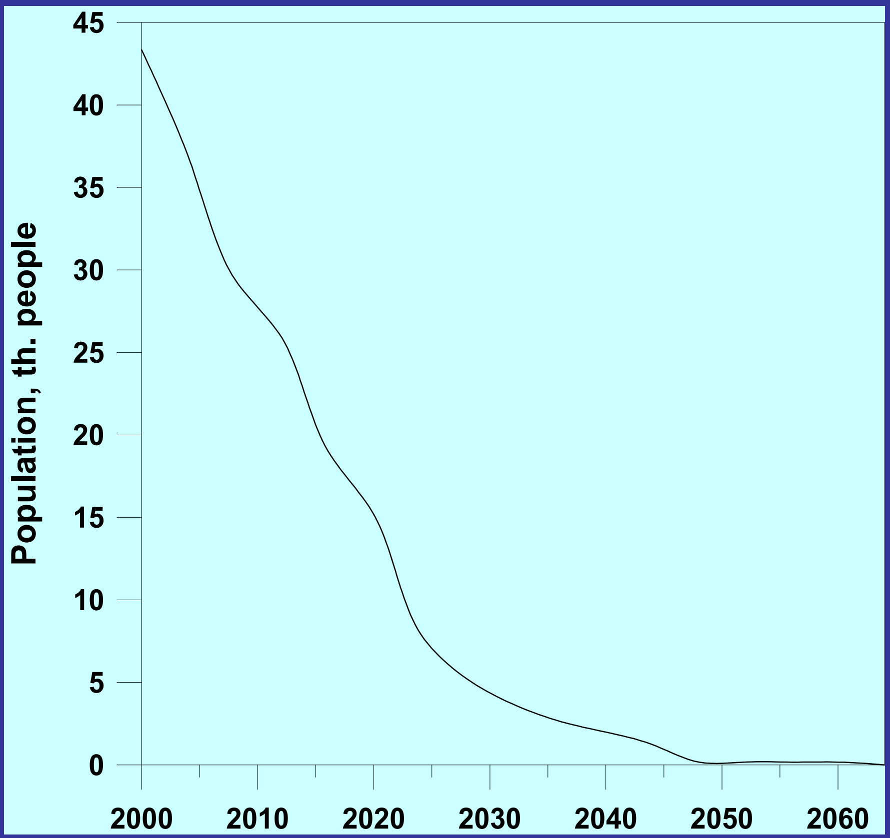




1 – peaty soils; 2 – sandy and sandy loam soils; 3 – heavy loam and clay; 4-5 – cost of dose decrease per 1 man-Sv at which countermeasure application was considered to be justified [10 (4), and 20 (5) thousand US dollars]

*Cost of averted dose of 1 man-Sv – 1000-100000 USD*

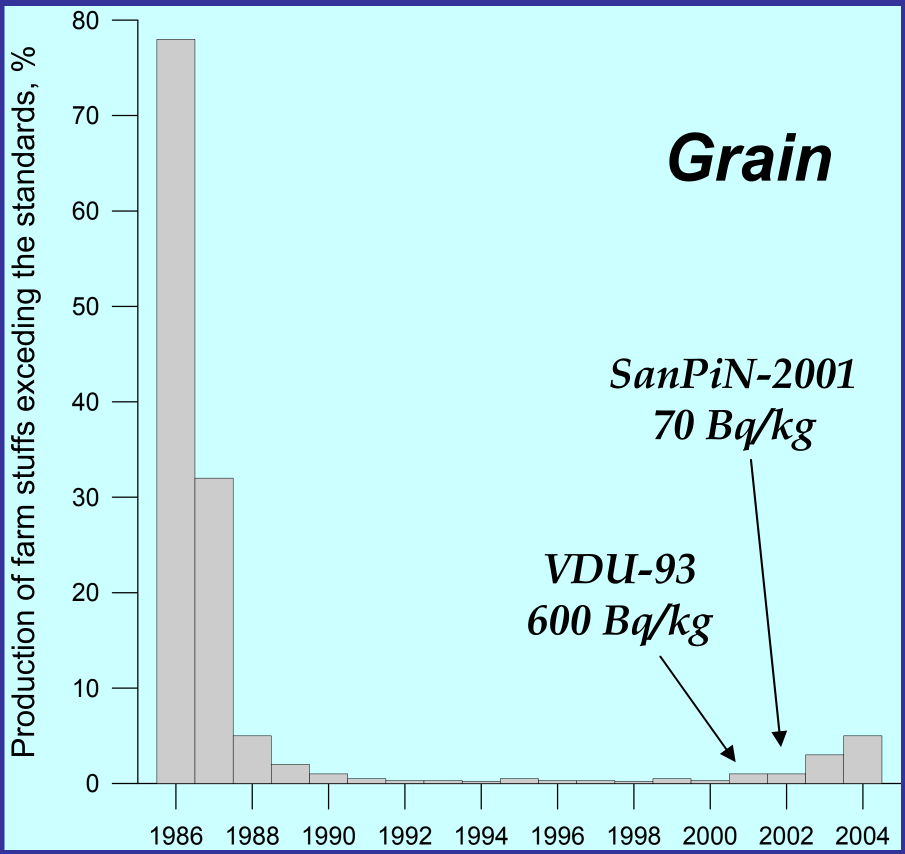
# Assessment of the need for countermeasures in the collective and private sectors up to 2060 in Russia

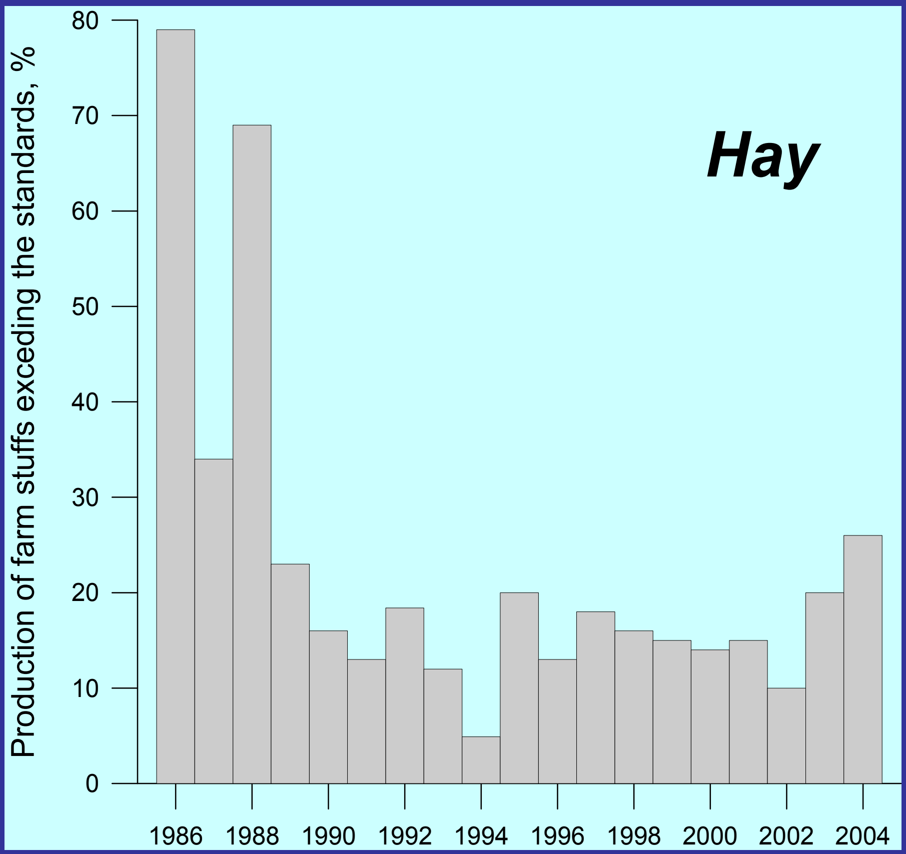


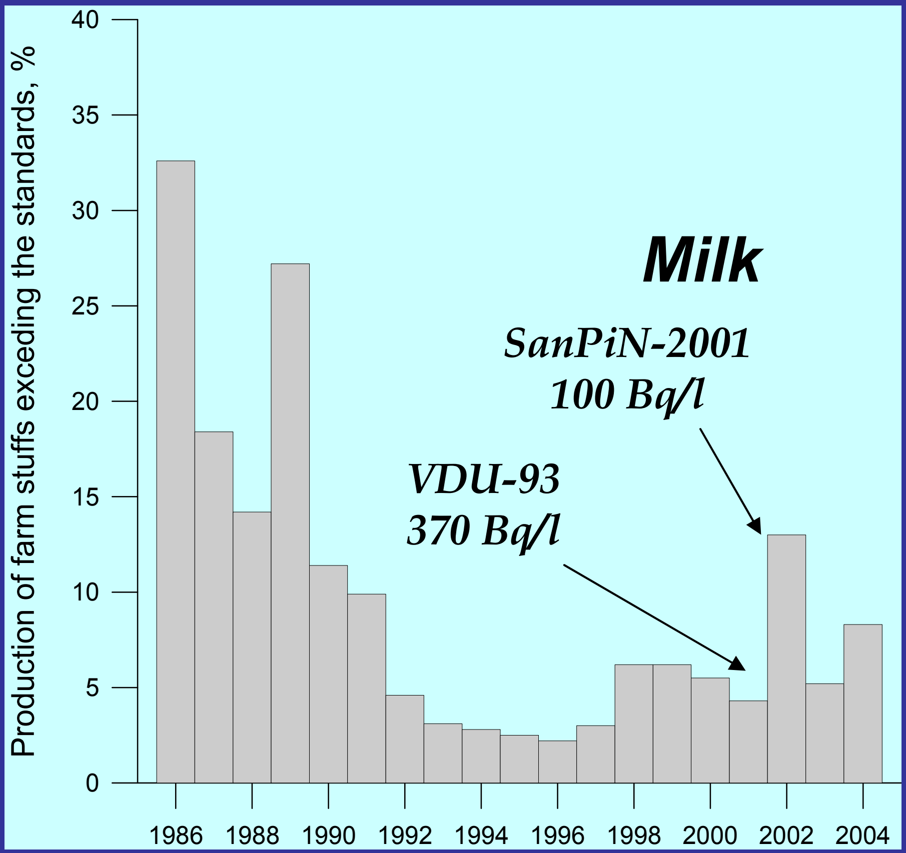

Prediction of changes: A – fraction of milk with $^{137}Cs$ content above the standard (SanPin-2001) in farms of the south-western districts in the Bryansk region; B – number of residents in rural settlements with a mean annual dose of irradiation above 1 mSv in the absence of countermeasures

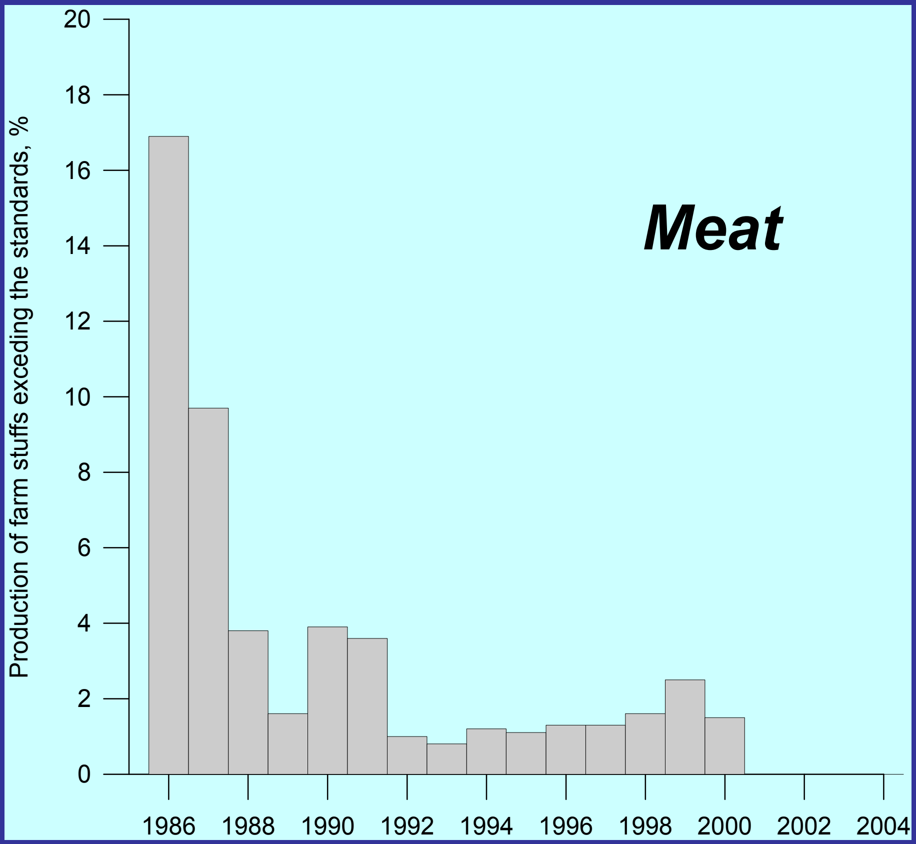
# Reduction in the volume of output of plant products exceeding the standards in the contaminated districts of the Bryansk region in 1986-2004 (Russia)



# Reduction in the volume of output of animal products exceeding the standards in the contaminated districts of the Bryansk region in 1986-2004 (Russia)



# ECOLOGICAL IMPACT

- The main paradigm has been confirmed – the area of radiation damage to biota is much less than the area where radionuclide concentrations in environmental objects are above the permissible limits.
- Despite the fact that the Chernobyl accident is termed "rural", the contribution of radionuclide containing natural products (mushrooms, berries) to the internal dose of irradiation is sometimes higher than that of agricultural products.
- Signs of radiation damage to biota at "lower" levels of biological organization (cytogenetic and cellular) are evident at large distances from the ChNPP (200-250 km), whereas ecologically important damage at the ecosystem level is reported only in the 30 km ChNPP zone.

# Threshold levels for radioecological effects in different ecosystems in the Chernobyl affected area

| Effects | Exposure dose, Gy(Sv) year$^{-1}$ (first year of exposure) | $^{137}Cs$ deposition density, Ci km$^{-2}$ (MBq m$^{-2}$) |
|---|---|---|
| Damage to ecosystems: | | |
| coniferous forests | 10 | >300 (>11) |
| deciduous forests | 30 | Not detected (except for very small plots) |
| herbaceous natural biogeocenoses | 70 | Not detected |
| agricultural crop fields | 50 | Not detected |
| Signs of radiation damage to mammals (in particular farm animals) from $^{131}I$ accumulation in the thyroid | 50 (to the thyroid) | 200 (7.4) |
| Early genetic effects | 0.1 | 50 (1.9) |
| Exceeding of derived intervention levels (DIL) of $^{137}Cs$ content: | | |
| in milk (370 Bq l$^{-1}$) | - | 15 (0.6) |
| in meat (1900 Bq kg$^{-1}$) | - | 80 (3.0) |
| in grain (370 Bq kg$^{-1}$) | - | >100 (>3.7) |

# ECOLOGICAL IMPACT Cont’d

- Difficulties in the interpretation of genetic alterations in biota in the accidental zone.
- In the long terms after the accident the thesis “if radiation standards protect man, then biota are also protected” is correct. At the early stages of the accident the radiation standards for man do not ensure protection of nature.
- Within the present conceptualization of ionizing radiation effects on man and the environment (biota), as well as considering doses of their irradiation, both potential and real detriments from all the factors of the Chernobyl accident are larger for man (direct irradiation, limitation of the economic activity including resettlement, etc.) than for biota.

# Radiation-Induced Effects on Plants and Animals: Findings of the UN Chernobyl Forum


R. Alexakhin (RIARAE, Obninsk)
M. Balonov (IAEA, Vienna)
N. Gentner (UNSCEAR, Vienna)
J. Hendry (IAEA, Vienna)
T. Hinton (University of Georgia)
B. Prister (Kiev University)
P. Strand (NRPA, Oslo)
D. Woodhead (Centre for Environment, Fishery and Aquaculture, UK)

# Pre-Chernobyl…

- wealth of data about the biological effects of radiation on plants and animals

- early data came from…
  - laboratory exposures
  - accidents (Kyshtym, 1957)
  - areas of naturally high background
  - nuclear weapons fallout
  - large-scale field irradiators

# Factors Influencing the Sensitivity of Plants to Radiation

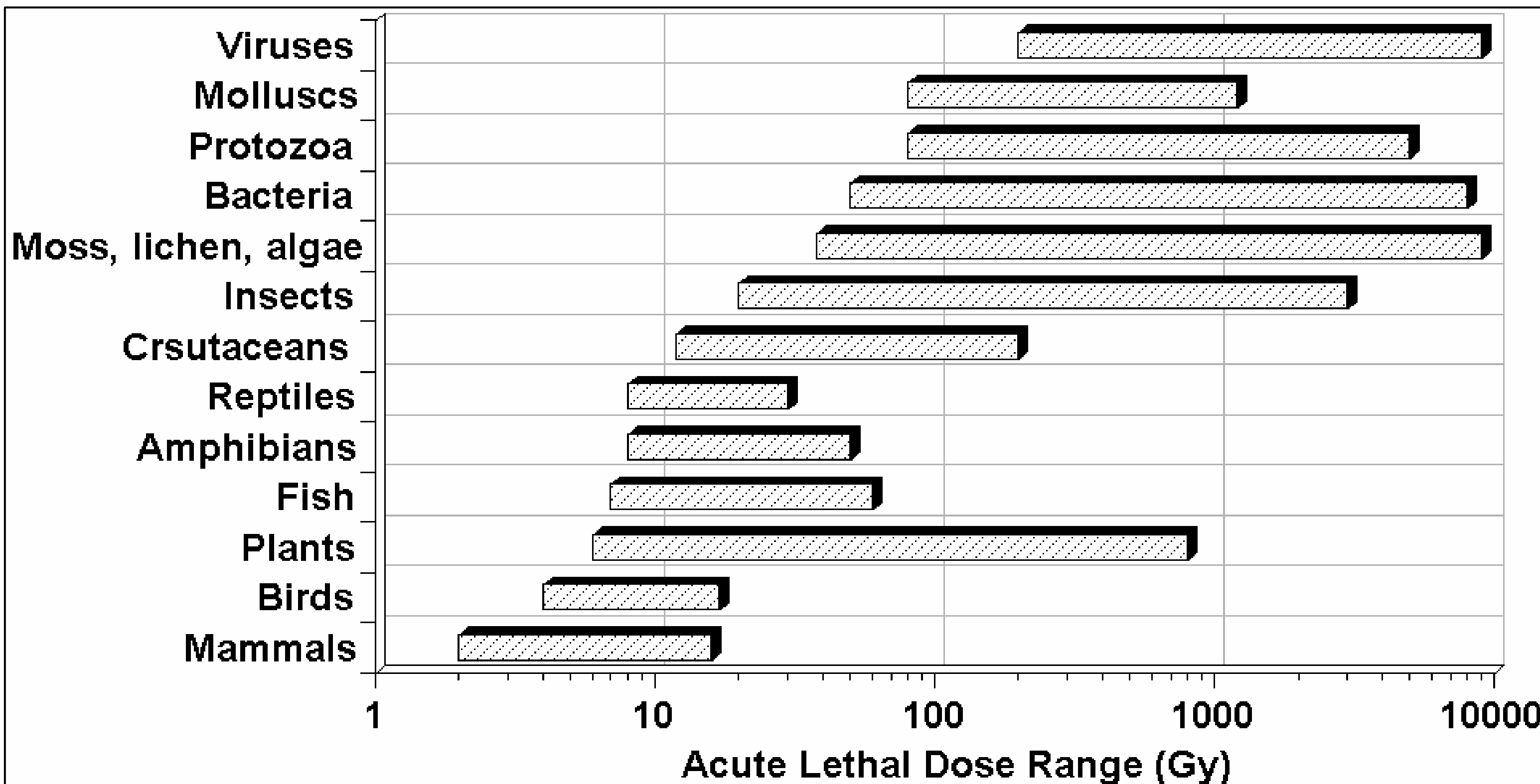
| **Increasing Sensitivity** | **Decreasing Sensitivity** |
|---|---|
| Large nucleus | Small nucleus |
| Large chromosomes | Small chromosomes |
| Acrocentric chromosomes | Metacentric chromosomes |
| Low chromosome number | High chromosome number |
| Diploid or haploid | High polypolid |
| Sexual reproduction | Asexual reproduction |
| Long intermitotic time | Short intermitotic time |
| Long dormant period | Short or no dormant period |

(Sparrow, 1961)

# Pre-Chernobyl…

## Lethal Acute Dose Ranges

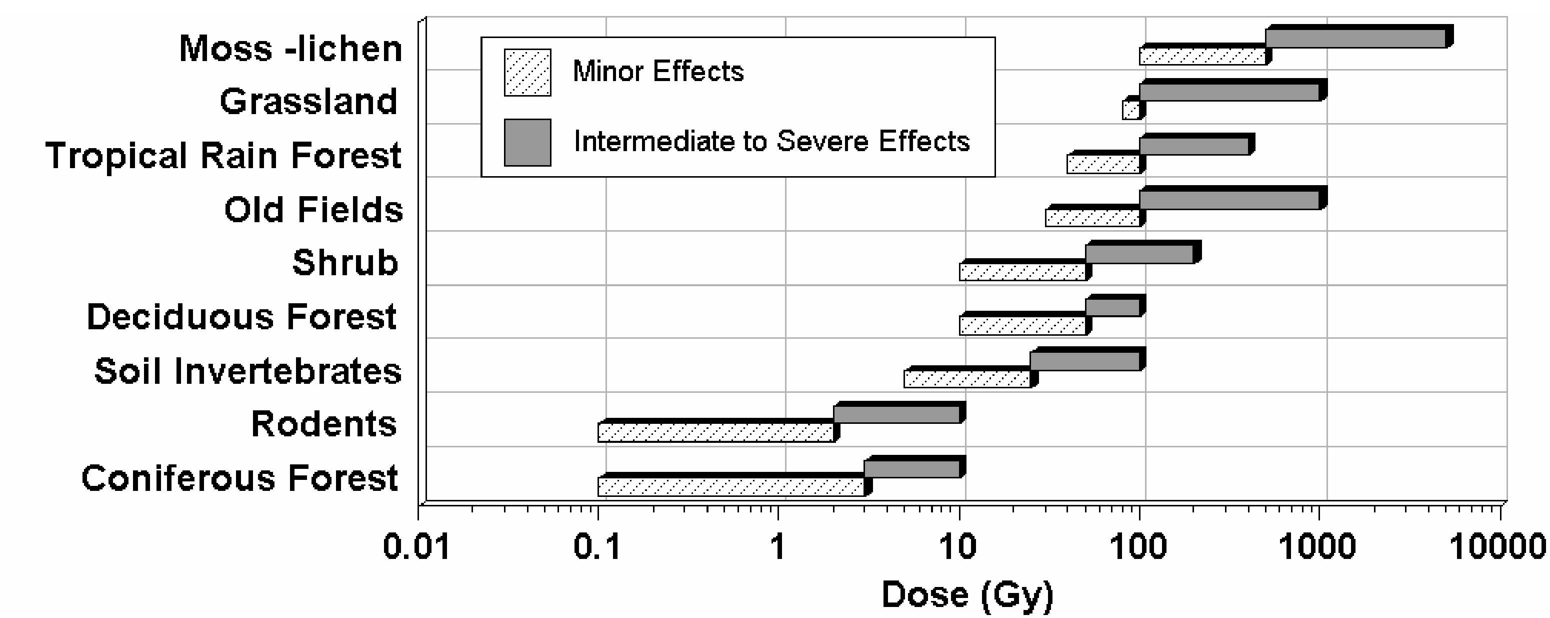
(Whicker and Schultz, 1982)



## Pre-Chernobyl…

# Effects from Short Term Exposures (5 to 60 d)

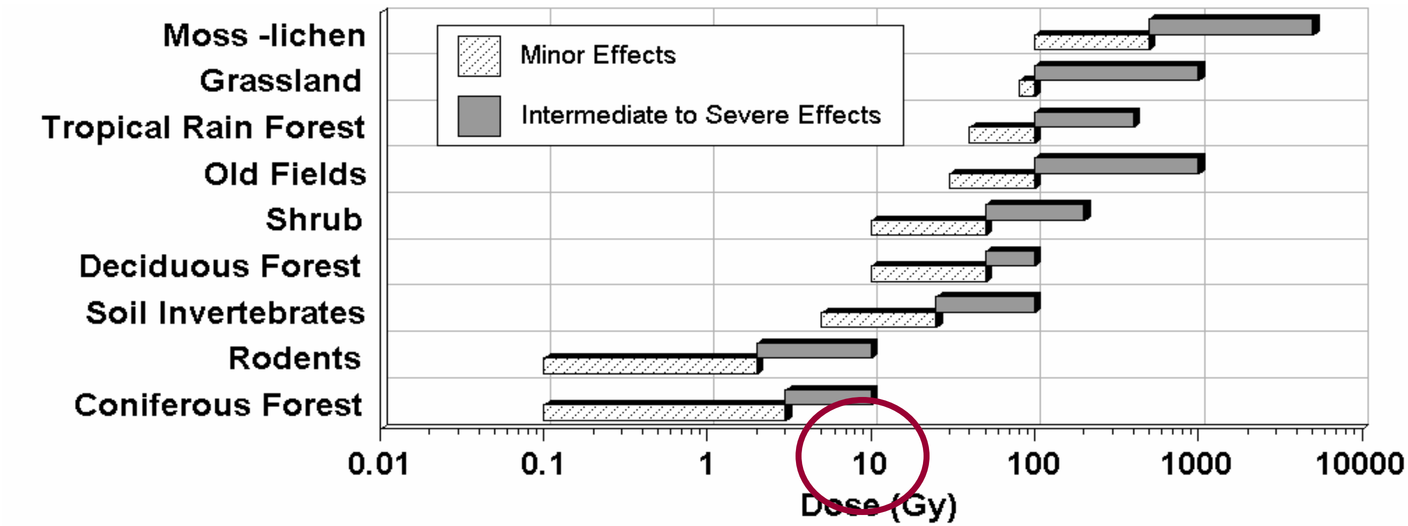
- minor effects (chromosomal damage; changes in reproduction and physiology)
- intermediate effects (selective mortality of individuals within a population)

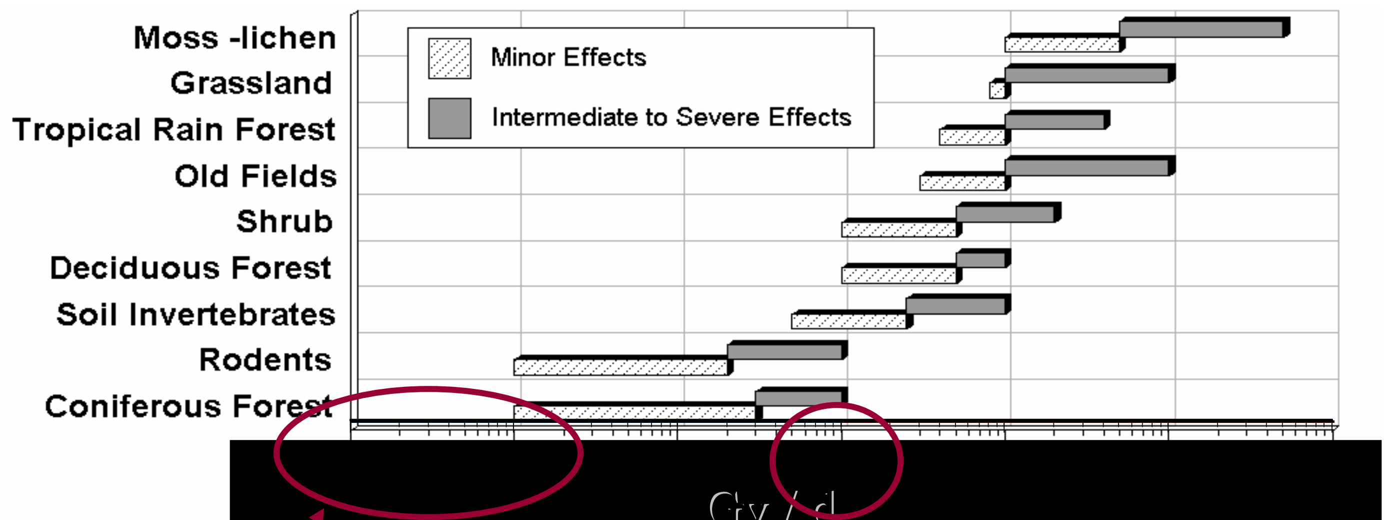


# DOSE (Gy) to DOSE RATE (Gy / d) CONVERSION

(5 to 60 d)

x/10



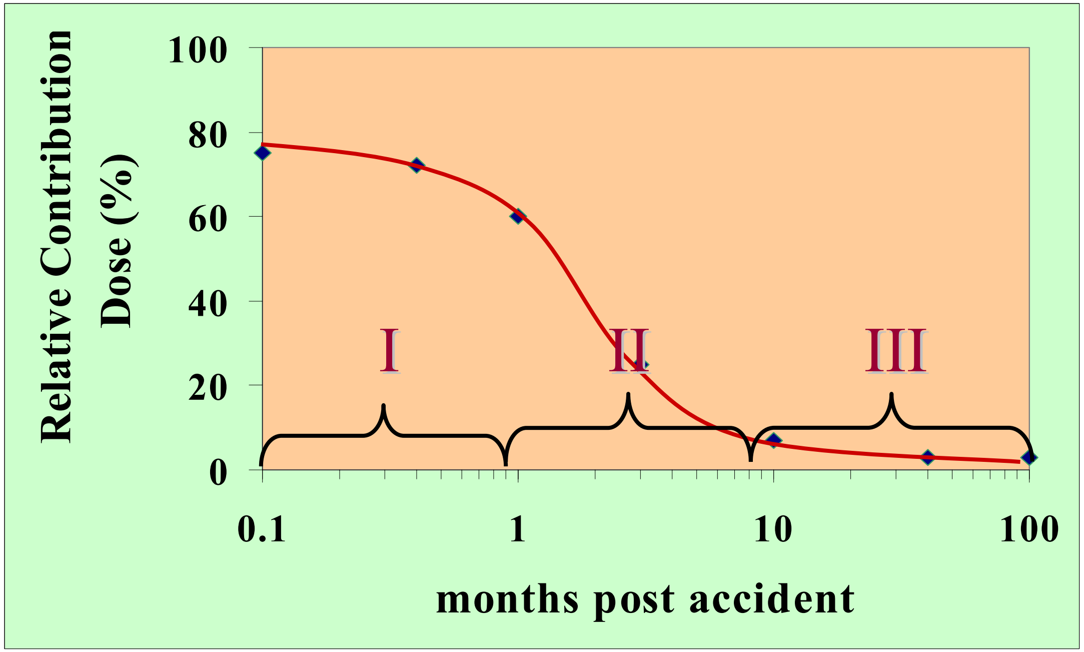




IAEA Guidelines

1 & 10 mGy / d

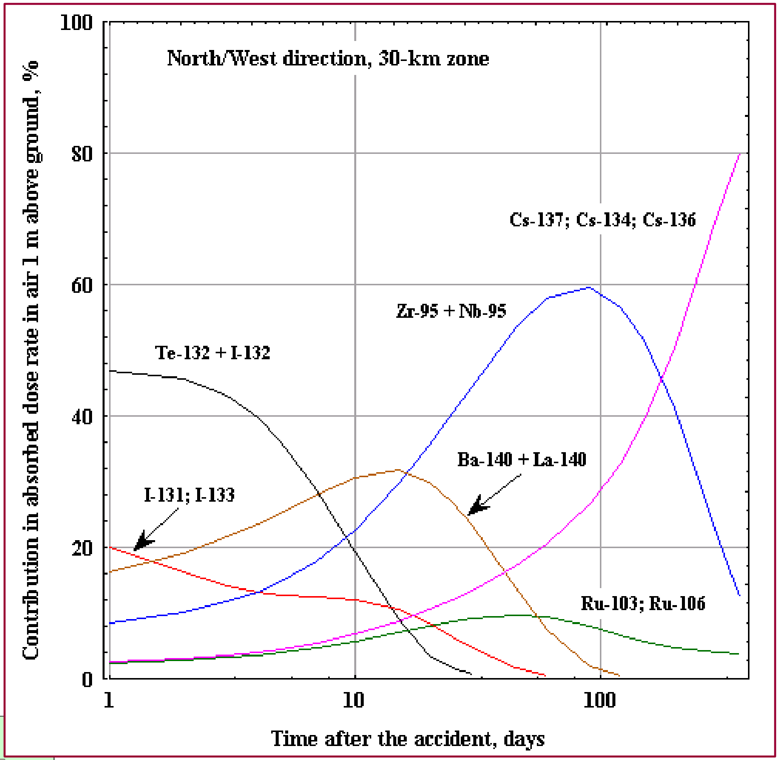
# Within Chernobyl's 30-km zone

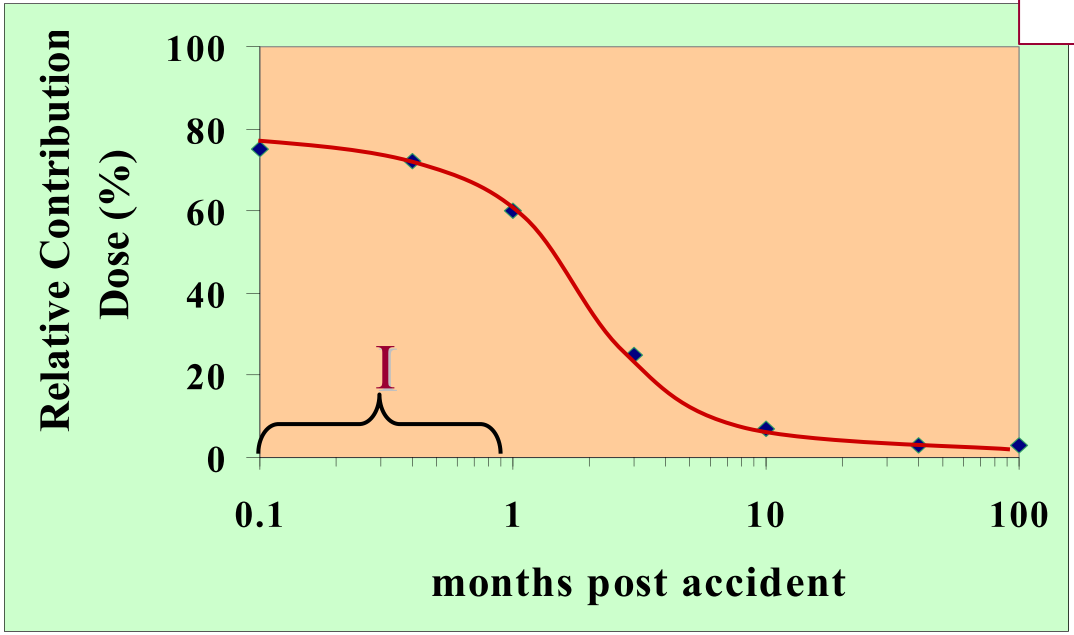
- Environmental effects were specific to 3 distinct time periods
- Biota were exposed to a diverse group of radioisotopes
- Tremendous heterogeneity and variability (in all parameters)
- Accident occurred at a period of peak sensitivity for many biota



# First 20 to 30 days

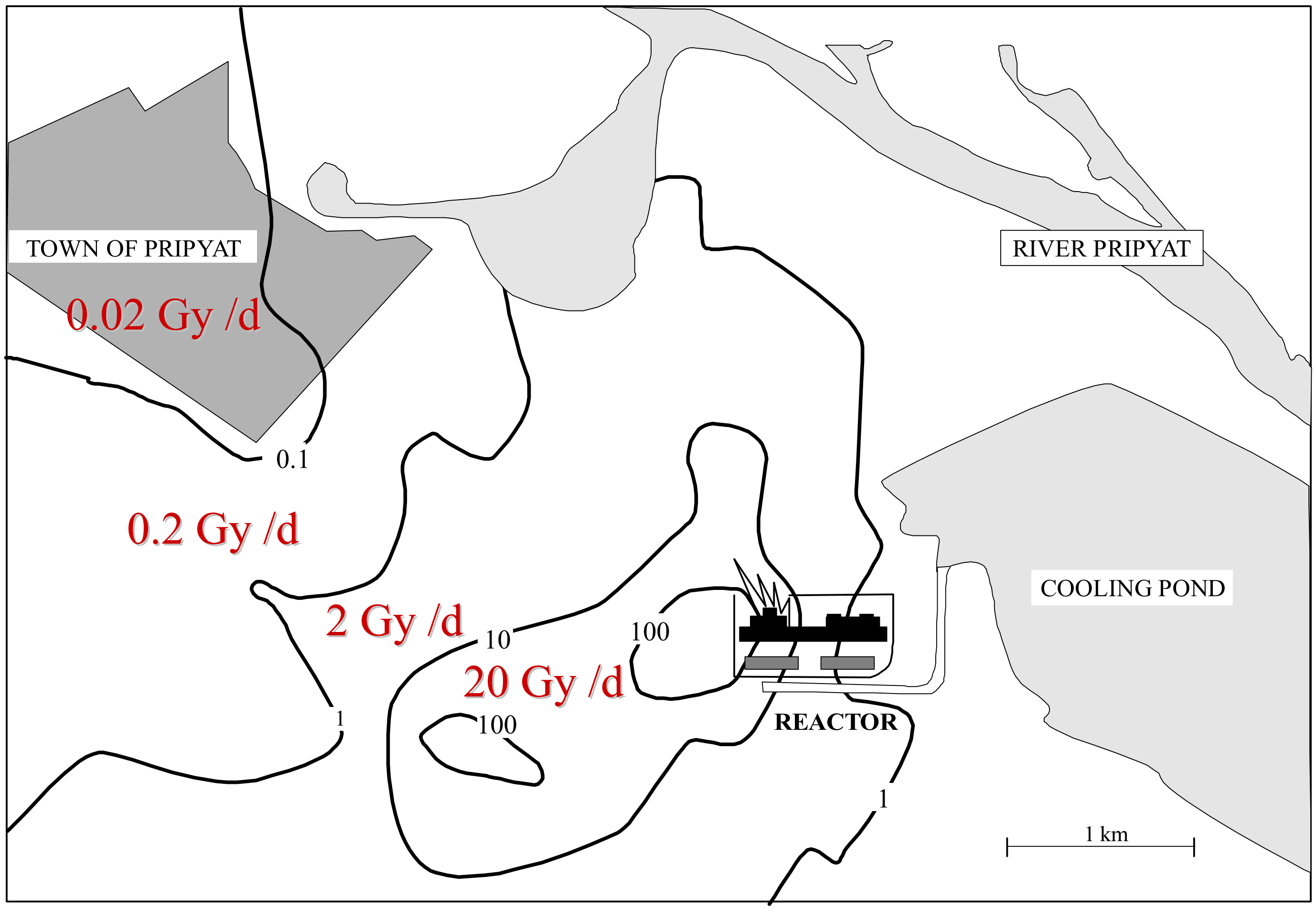
- Severe effects to biota
- Gamma exposure dose rates were > 20 Gy / d
- Dominated by short-lived isotopes $^{99}$Mo; $^{132}$Te/I; $^{133}$Xe; $^{131}$I; $^{140}$Ba/La



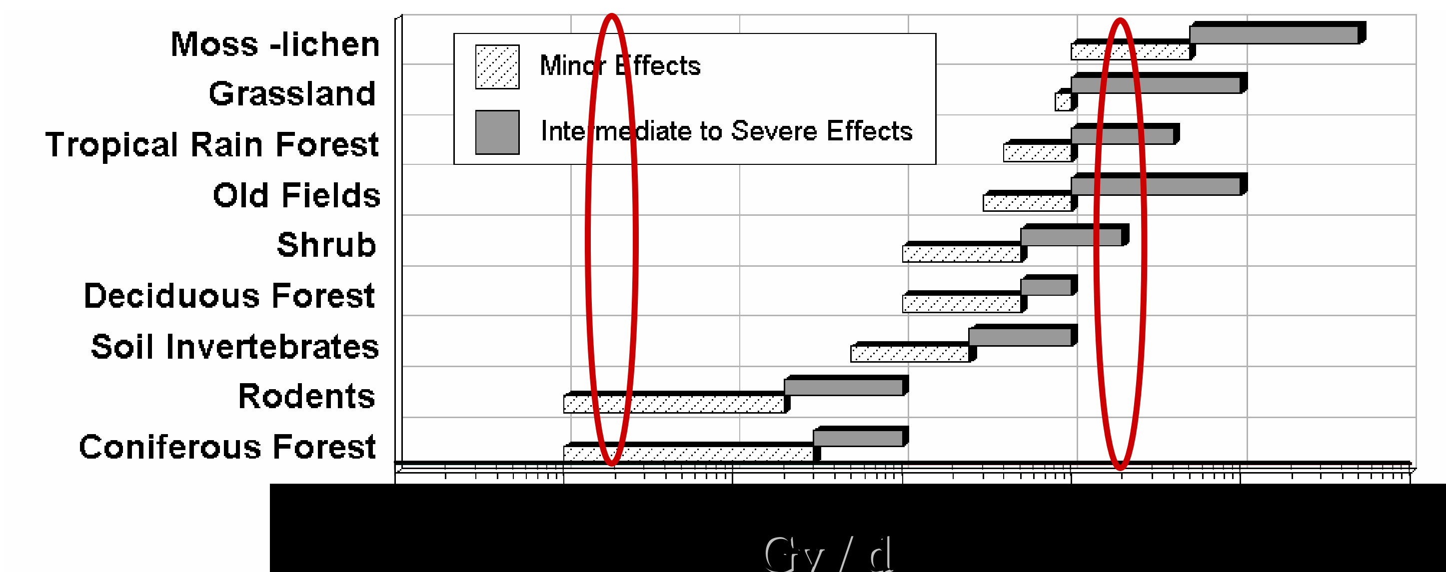

- High dose to thyroids from iodine

# Air Exposure Rates on 26 April 1986



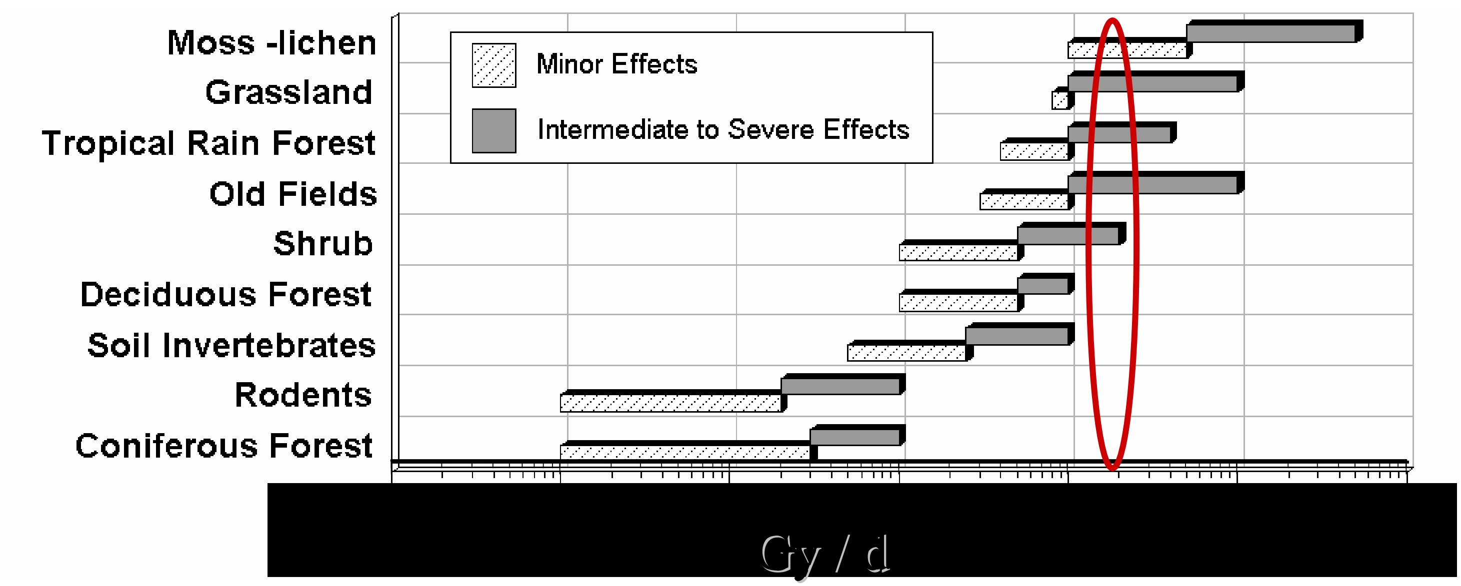

(1 R / h ~ 0.2 Gy / d; UNSCEAR 2000)

- Dose rates from gamma exposures ranged from 0.02 to 20 Gy / d



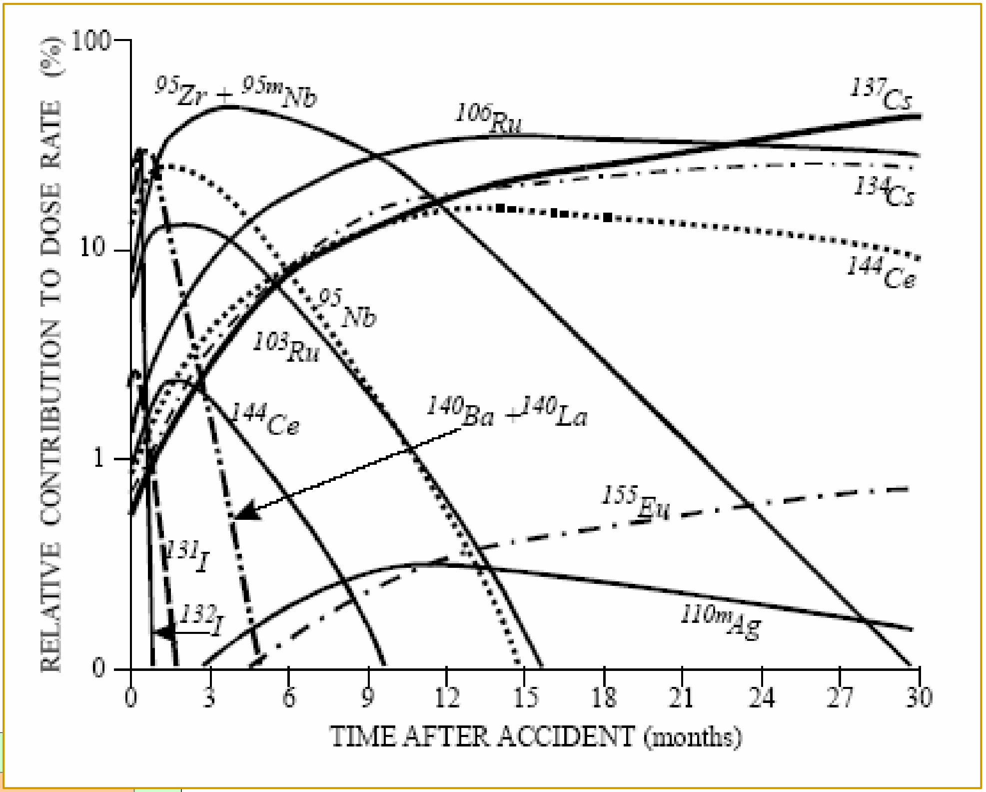
# First Phase

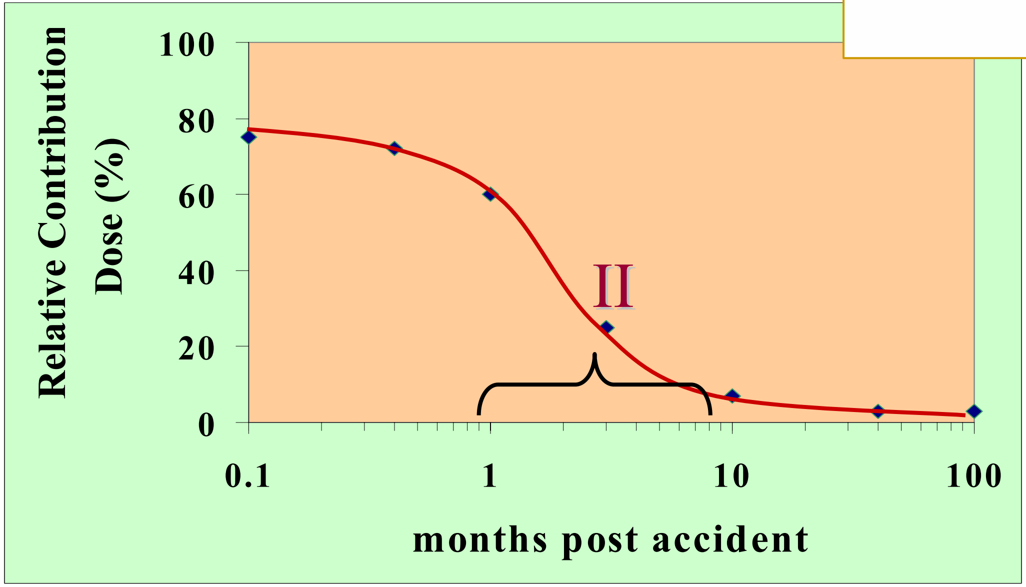
- Acute adverse effects within 10-km zone
- Mortality to most sensitive plants and animals
- Reproductive impacts to many species of biota



# Second Phase

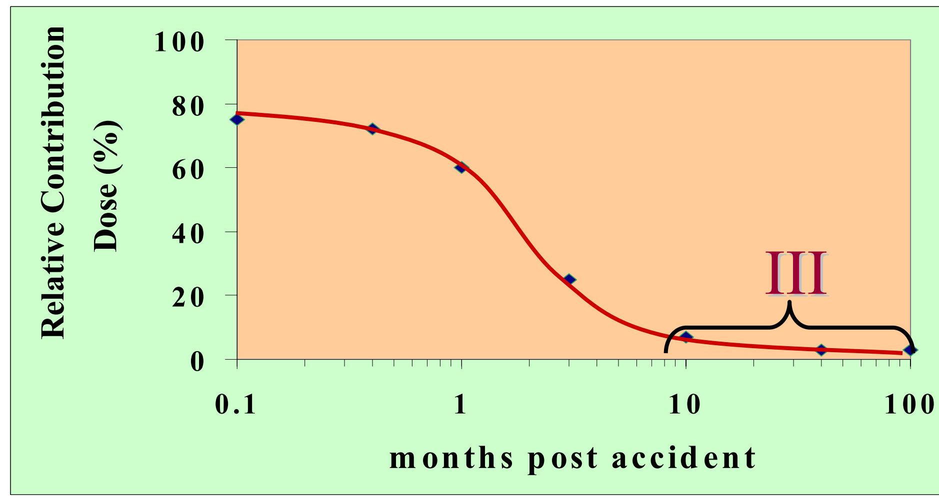
- Decay of short-lived isotopes
- β to δ ~ 6:1 to 30:1 with > 90 % of dose from β



# Third and Continuing Phase

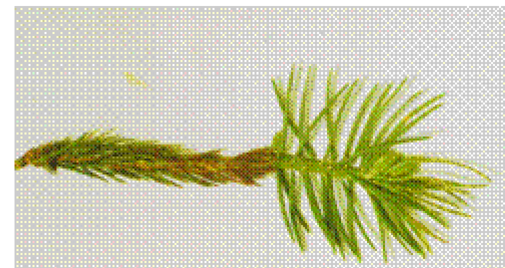
- Dose rates are chronic, < 1% of initial
- Beta to gamma contributions more comparable, depends on bioaccumulation of Cs
- $^{137}Cs$ and $^{90}Sr$ dominate dose
- Indirect effects dominate




- Genetic effects persist; although some results are controversial

# General Effects to Plants

- Morphological mutations 1 to 15 Gy (e.g. leaf gigantism)



- Shift in ecosystem structure:

  Deceased pine stands were replaced by grasses, with a slow invasion of hardwoods

- Genetic effects extended in time

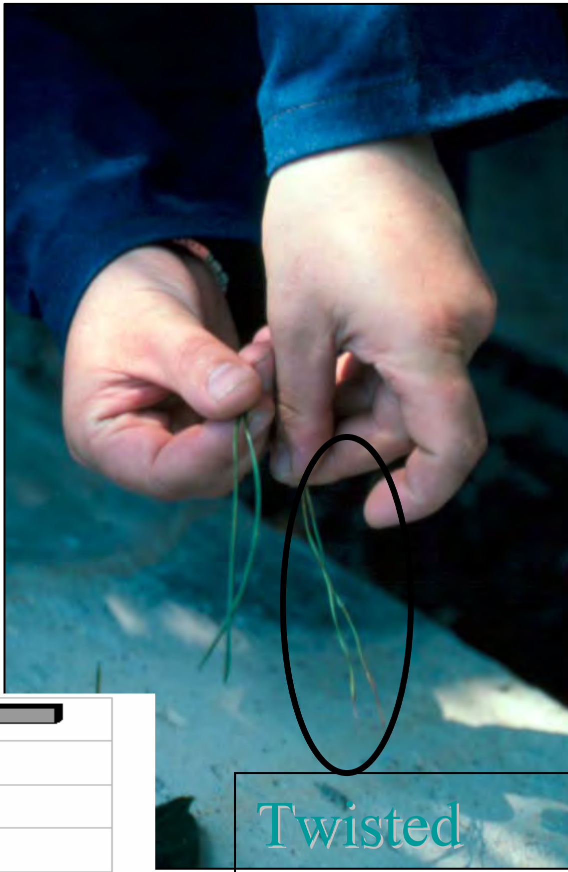
  1993, pines of 5 to 15 Gy had 8 X greater cytogentic damage than controls

- Some evidence of adaptive response

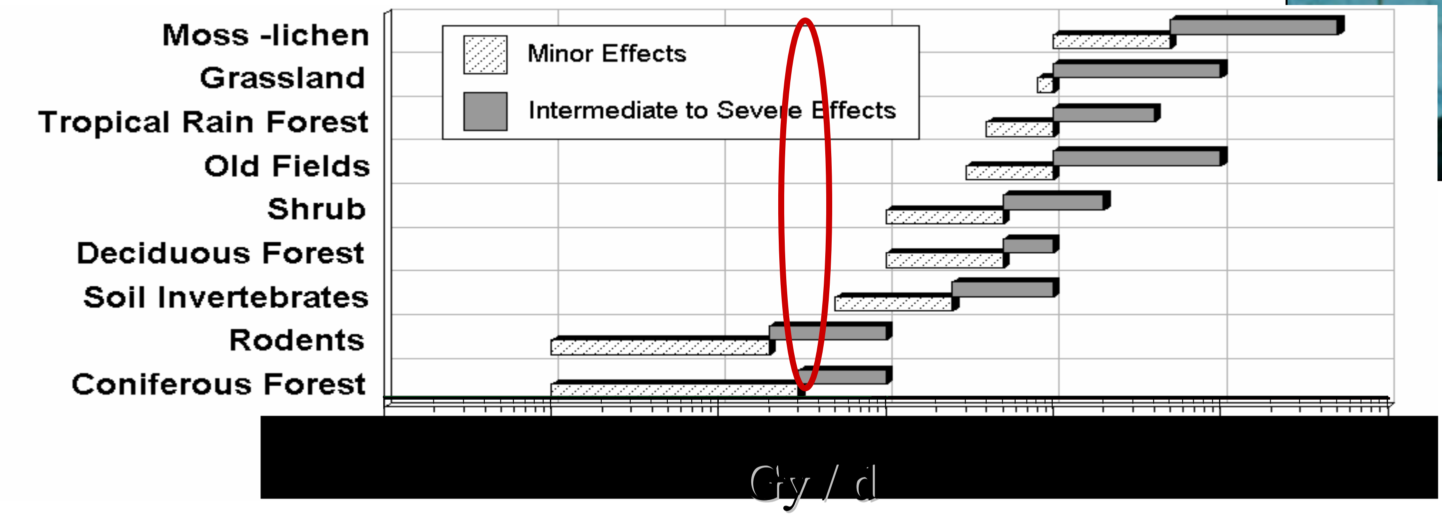
# General Effects to Plants

0.3 Gy / d

- Growth and developmental problems
- Inhibition of photosynthesis, transpiration
- Chromosome aberrations in meristem cells
- Short term sterility
- High mutation rates due to non-targeted mechanisms



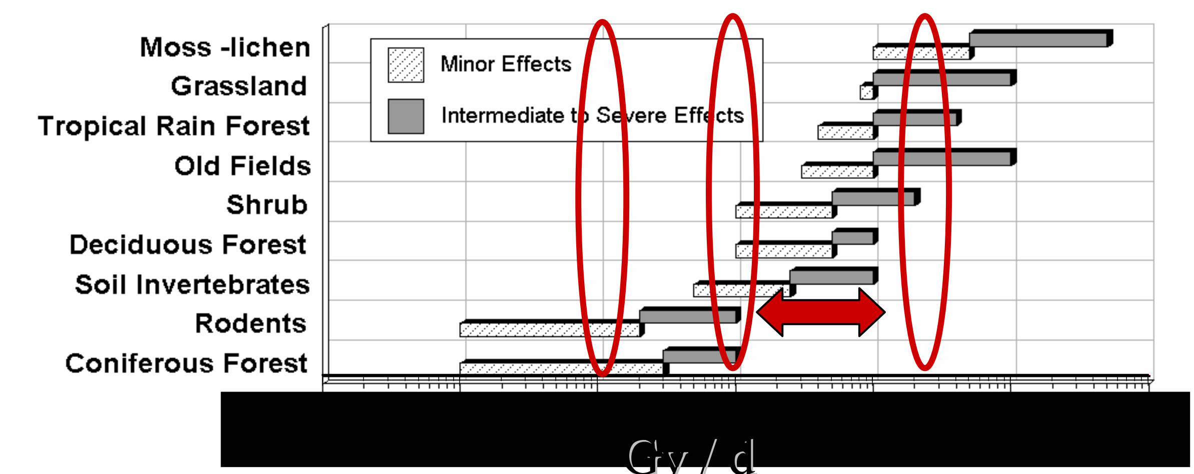
Twisted needles



- β contributed 82 to 96% of dose
- in 1992, mutations were still 4 to 8 times > than controls
- effect per unit dose was lower at high-dose rate; low dose chronic IR exerted a greater effect per unit dose

# General Effects to Rodents

- During Fall 1986, rodents population < 2- to 10-fold, dose rates 1 to 30 Gy/d (δ & β)
- At ~ 0.1 Gy/d temporary infertility, reduced testes mass
- Increased mortality of embryos
- Dose-rate dependent increase in reciprocal translocations
- Numbers of mice recovered within 3 years (immigration), but cytogenetic effects persisted



# Data from Rodents Collected in Phase III Are Ambiguous and Controversial

From virtually no effect….
… to significantly elevated mutation rates

- ~ 30 to 40 generations post-accident
- lower dose rates
- chronic exposures
- inadequate dosimetry
- sample size and technique sensitivity
- indirect effects (immigration)
- interpretation of results from new methods (microsatellites)

# Barn Swallows at Chernobyl

- partial albinism as a phenotypic marker for mutations ( ↑ 10x)
- carotenoids used for free-radical scavenging…rather than plumage coloration
- reduced levels of antioxidants in blood
- elevated mutation rates in microsats
- increase in abnormal sperm
- partial albinism correlated to reduced mating success
- clutch size, brood size and hatching success reduced

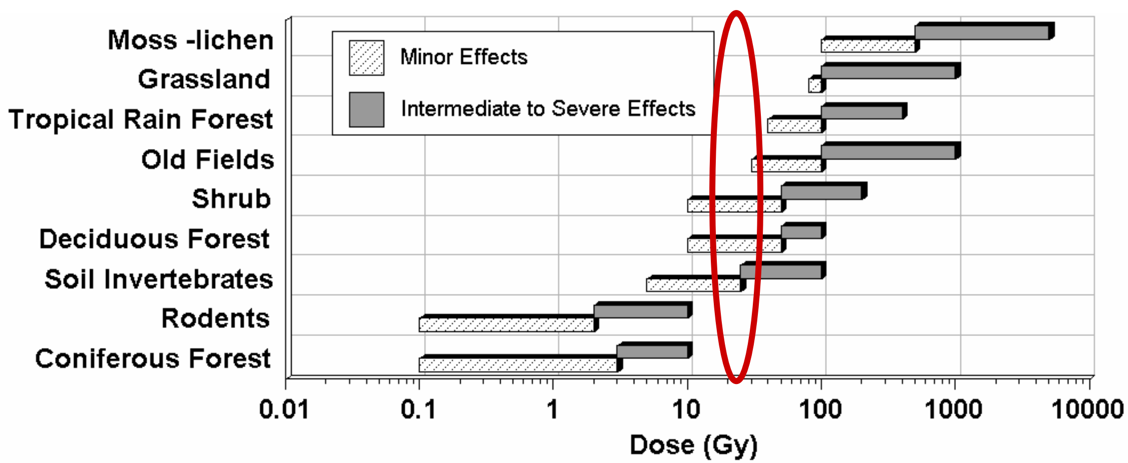
# General Effects to Soil Invertebrates

- 60 to 90% of initial contamination captured by plant canopies
- Majority washed off to soil and litter within several weeks
- Populations of soil invertebrates reduced 30-fold, reproduction strongly impacted

# General Effects to Soil Invertebrates

- Dose and effects to invertebrates in forest litter were 3- to 10-fold higher than those in agricultural soils

- 30 Gy altered community structure (species diversity) for 2.5 years



# Fluctuating Asymmetry in Morphological Characteristics

- Increased FA in Chernobyl
  - plants (4 species)
  - insects (4 species)
  - fish (2 species)
  - amphibians (1 species)
  - birds (1 species)
  - mammals (3 species)

- Male Stag Beetles
  - FA coupled to reduced mating success

# General Cytogenetic Effects

- Decline in cytogenetic damage lagged behind the decline in radiation exposure
- Some suggestions of genomic instability (increase freq. of cellular damage in offspring, while contamination decreased)
- Evidence of DNA hypermethylation in plants: such epigenetic modification is thought to be a defense strategy to reduce genome instability
- Plant data suggest that chronic low-level irradiation might alter the genetic structure of populations, increasing the karyotypic variability in the offspring

# Indirect Effects of Human Abandonment

Pripyat
Abandoned

4 km N of Reactor
50,000 people

135,000 people and 35,000 cattle evacuated

Dozens of towns and villages deserted.

# With the removal of humans, wildlife around Chernobyl are flourishing

48 endangered species listed in the international Red Book of protected animals and plants are now thriving in the Chernobyl Exclusion Zone

**Russian Boar**

**Wolves**

**Prejevalsky Horses**

The removal of humans alleviates one of the more persistent and ever-growing stressors experienced by natural ecosystems

As has been shown many times before, when humans are removed----nature flourishes, even in the aftermath of the world's worst nuclear accident

What will be the long-term population effects?

# BROAD SUMMARY

## Period 1 (first month)

Acute adverse effects within 30-km zone
Mortality of conifers; reproductive impacts to plants & animals

## Period 2 (1 to 12 months)

Lowered dose rates
Morphological effects
Soil invertebrates impacted

## Period 3 (> 1 year)

Ongoing recovery
Secondary effects due to human abandonment
Noticeable positive impacts
Long term genetic consequences are unknown

# Questions remaining to be answered…

- What is the extent of inherited, transgenerational effects from chronic, low-level irradiation?

- What is the significance of molecular effects to individuals and populations?

We ACKNOWLEDGE the many, many scientists whose works have been incorporated within this general review

Please accept our apologies for not having the space to cite each and everyone of you within this brief presentation

# Cleanup, Containment, and Disposal of Radionuclides Released by the Chernobyl Accident

Bruce Napier

2006 NCRP Annual Meeting

- Emergency remediation of the reactor site in 1986-1987 resulted in large amounts of radioactive waste
  - In the reactor buildings
  - In the immediate vicinity
  - Throughout the 30-km evacuated zone
- More waste will be generated by future activities

# Sources of Waste

- Radioactive waste in temporary radioactive waste facilities located throughout the Exclusion Zone as a result of the clean up of contaminated areas to avoid dust spread, reduce the radiation levels, and enable better working conditions
- Radioactive waste in existing radioactive waste-disposal facilities
- Accident-generated transuranic waste, which has been mingled with radioactive waste from operations at ChNPP Units 1, 2 and 3
- Construction of infrastructure and future remediation activities

# Temporary Low- and Intermediate Level Solid Wastes

- Established without proper design documentation, engineered barriers, or hydrogeological investigations
- A large number of poorly-documented sites; documentation of the wastes disposed was not a matter of priority at the time

# Temporary Waste Facilities

| Location | Size (ha) | Volume ($m^3$) | Contents | Inventory (Bq) |
|---|---|---|---|---|
| ***Reasonably well characterized*** | | | | |
| Neftebaza | 53 | 104,000 | soil, plants, metal, concrete, bricks | $4 \times 10^{13}$ |
| Peschannoe Plato | 78 | 57,000 | soil, rubble, concrete | $7 \times 10^{12}$ |
| ***Uncharacterized Sites*** | | | | |
| Stantzia Yanov | 128 | 30,000 | soil, plants, metal, concrete, bricks | $>4 \times 10^{13}$ |
| Ryzhy Les | 227 | 500,000 | Mainly soil, some construction and domestic material | $4 \times 10^{14}$ |
| Staraya Stroybaza | 130 | 171,000 | soil, metal, concrete, wood | $1 \times 10^{15}$ |
| Novaya Stroybaza | 122 | 150,000 | soil, plants, metal, concrete, bricks | $2 \times 10^{14}$ |
| Pripyat | 70 | 16,000 | vehicles, machinery, wood and construction waste | $3 \times 10^{13}$ |
| Christogalovka | 6 | 160,000 | buildings, soil, wood, work clothes | $4 \times 10^{12}$ |
| Kopachi | 125 | 110,000 | Demolition wastes | $3 \times 10^{13}$ |

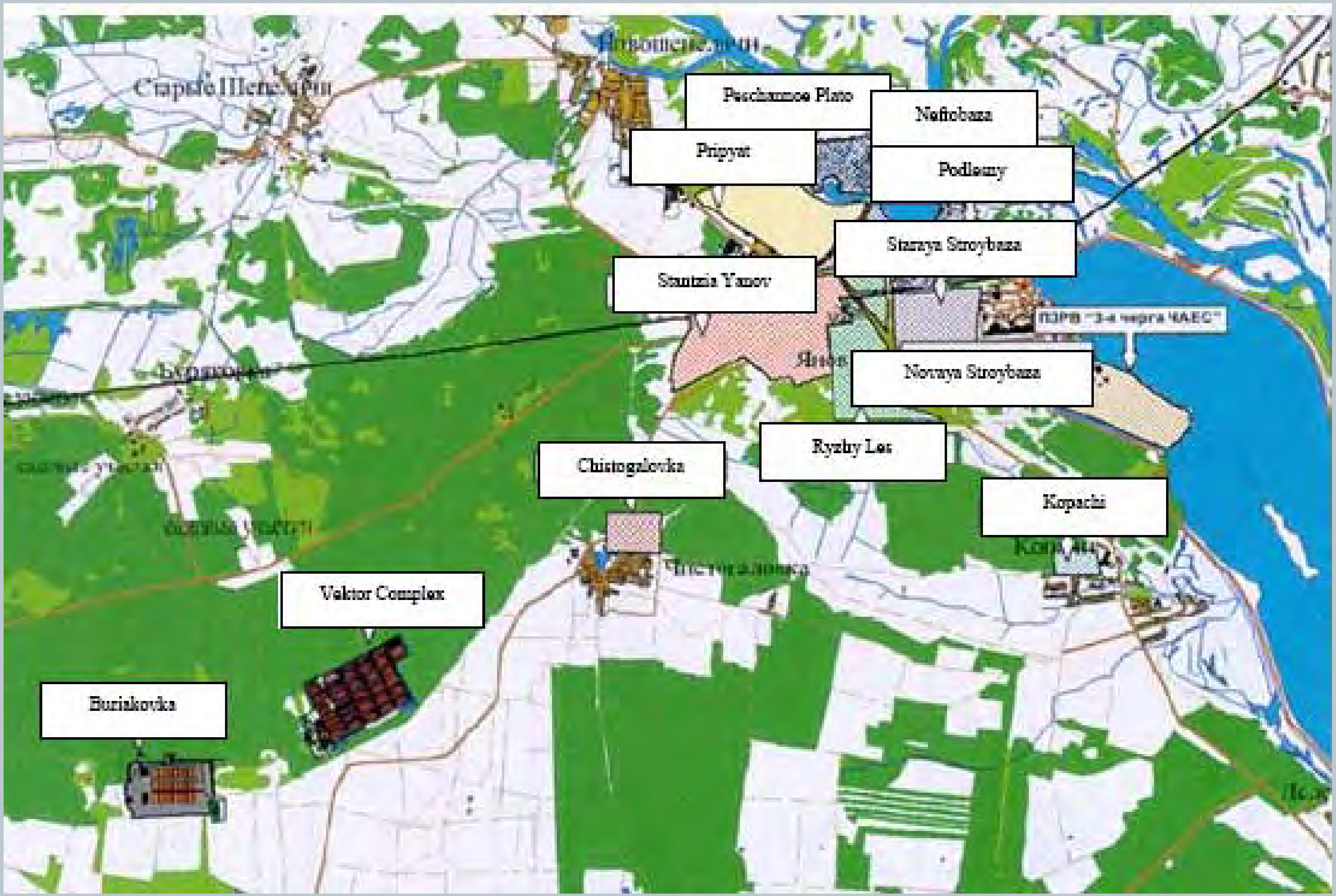
# Permanent Disposal Facilities

| **Location** | **Size (ha)** | **Volume ($m^3$)** | **Contents** | *Inventory (Bq)* |
|---|---|---|---|---|
| Buriakovka | 24 | 653,000 | metal, soil, sand, concrete, wood | $2.5 \times 10^{15}$ |
| Podlesney | Vaults | 11,000 | building material, metal debris, sand, soil, concrete, wood | >2600 TBq |
| Kompleksny | Vaults | 26,200 | sand, concrete, metal, construction material, bricks | $4 \times 10^{14}$ |

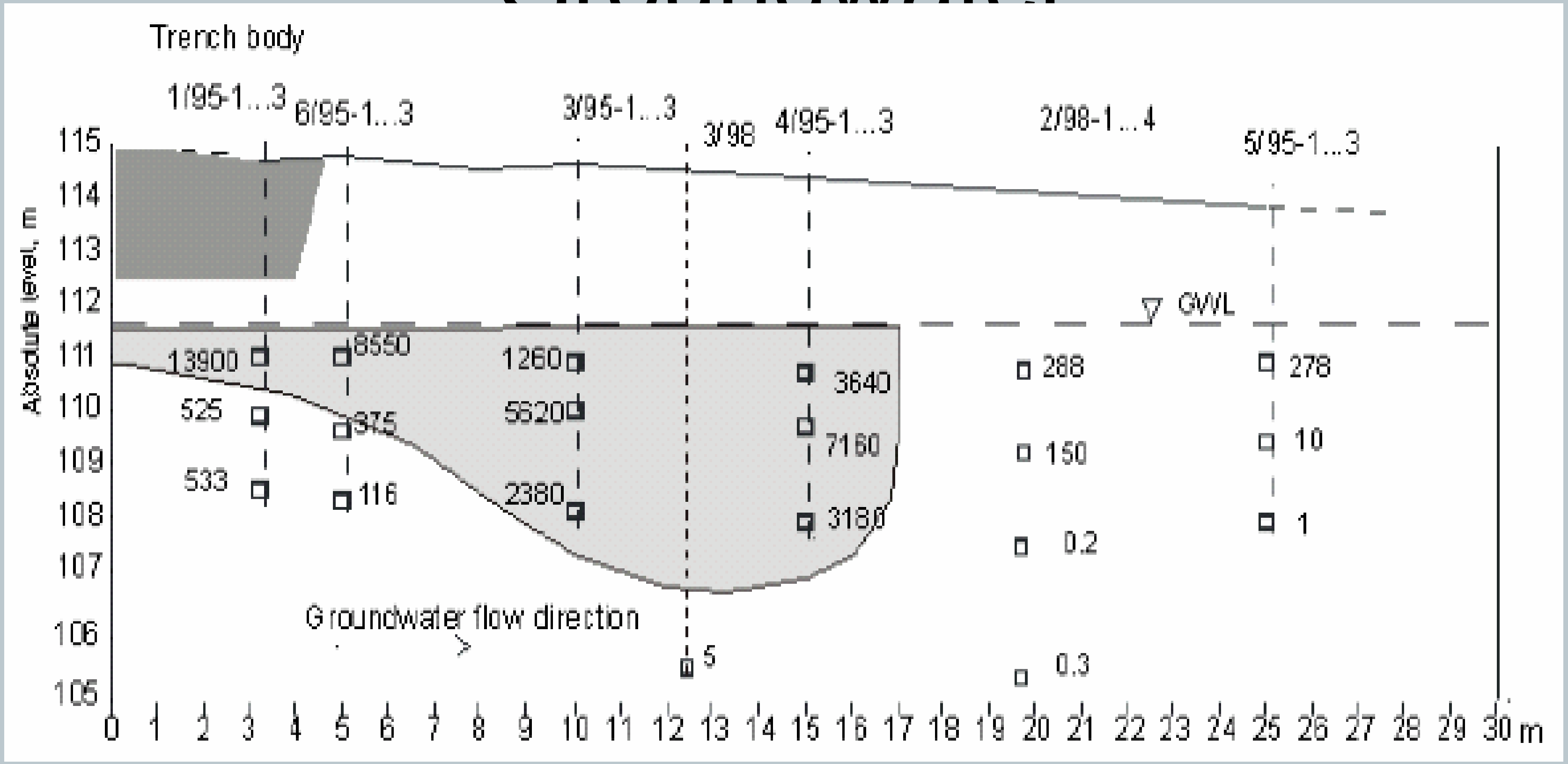
Podlesney and Kompleksny are closed

Buriakovka is the only open site in the zone; it has >30 clay-lined trenches

# LLW and ILW Waste Sites



# Many Sites are Leaching to Groundwater




This example is Ryzhy Les; most contaminants will decay before traveling any great distance

# Current conditions are not urgent from a public exposure view.

- Some sites are flooded and represent a minor source of contamination of ground and surface water in the nearby areas.
- Current calculations do not indicate any meaningful exposure pathway for the public.
- Institutional controls are currently adequate, but may not be over the long term.

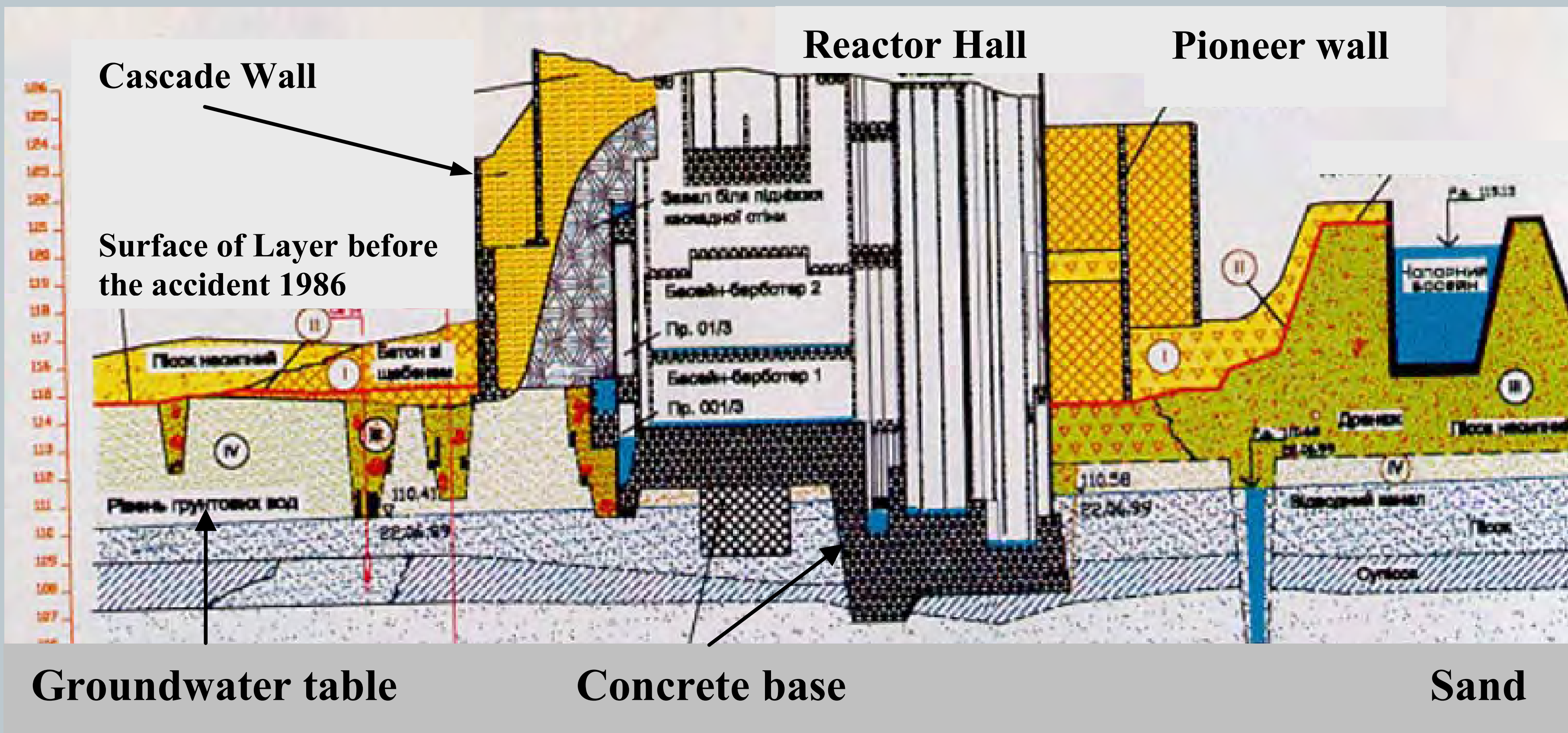
# The “Shelter”

- Was erected in a short time period between May and November 1986 under conditions of severe radiation exposure to the workers.
- Rests on portions of the original reactor of uncertain stability.
- Has 1000 $m^2$ of openings through which about 2000 $m^3\ y^{-1}$ of precipitation enters.
- Further flooding might lead to criticality, but this is considered unlikely.

# Shelter Foundations

- Debris of the destroyed reactor building was collected along with fragments of reactor core, etc., and the soil surface layer. Thousands cubic meters of radioactive waste generated by this work was disposed in the Pioneer Wall and the Cascade Wall

# Cross Section



# Wastes in the Shelter

| | Waste Type | Waste Category | Amount |
|---|---|---|---|
| **Fuel Containing Material** | Fresh fuel assemblies,<br>Spent fuel assemblies,<br>Lava type material, fuel fragments, radioactive dust | High level waste | About 190-200 t |
| **Solid Radioactive Waste with less than 1% nuclear fuel** | Fragment of the core with dose rate at 10 cm of more than 10 mSv/h | | 700 tonnes of graphite |
| **Liquid radioactive waste** | Changing inventory based on precipitation (e.g. pulp, oils, suspensions, with soluble U salts) | Low level (< $3.7 \times 10^5$ Bq/l)<br><br>Intermediate (> $3.7 \times 10^5$ Bq/l) | 2 500 - 5 000 $m^3$<br><br>500 - 1 000 $m^3$ |
| **Solid radioactive waste** | Metal equipment and building material e.g. concrete, dust, non-metal material (organic, plastic material) | High level waste | 38 000 $m^3$ (building material) 22 240 t (metal constructions) |
| | | Low and intermediate level waste | 300 000 $m^3$ (building material and dust)<br>5 000 $m^3$ (non-metal) |

# Major Shelter Elements to be Dismantled

| Name | Number | Weight (ton) |
|---|---|---|
| Light roof panels (A) | 6 | 126 |
| Pipe roofing (B) | 27 | 540 |
| Southern panels (C) | 12 | 282 |
| South hockey sticks (D) | 12 | 456 |
| B1 & B2 beams (E & F) | 4 | 247 |
| Mammoth beam (G) | 1 | 127 |
| Octopus beam (H) | 1 | 44 |
| Debris | | 2200 |

# Radiological Conditions of the Shelter

- Core fragments—fuel assemblies or small fragments, 95% remains in the Shelter.
- Fuel dust or dust—particulate fuel material mixed with other materials.
- Lava—fuel containing material fused with other materials.
- Cs-137 is the principal isotope.
- Dose rates—up to 200 R/hr.
- Debris—destroyed parts of the reactor.
- Helicopter drops—up to 10 m in the Central Hall.

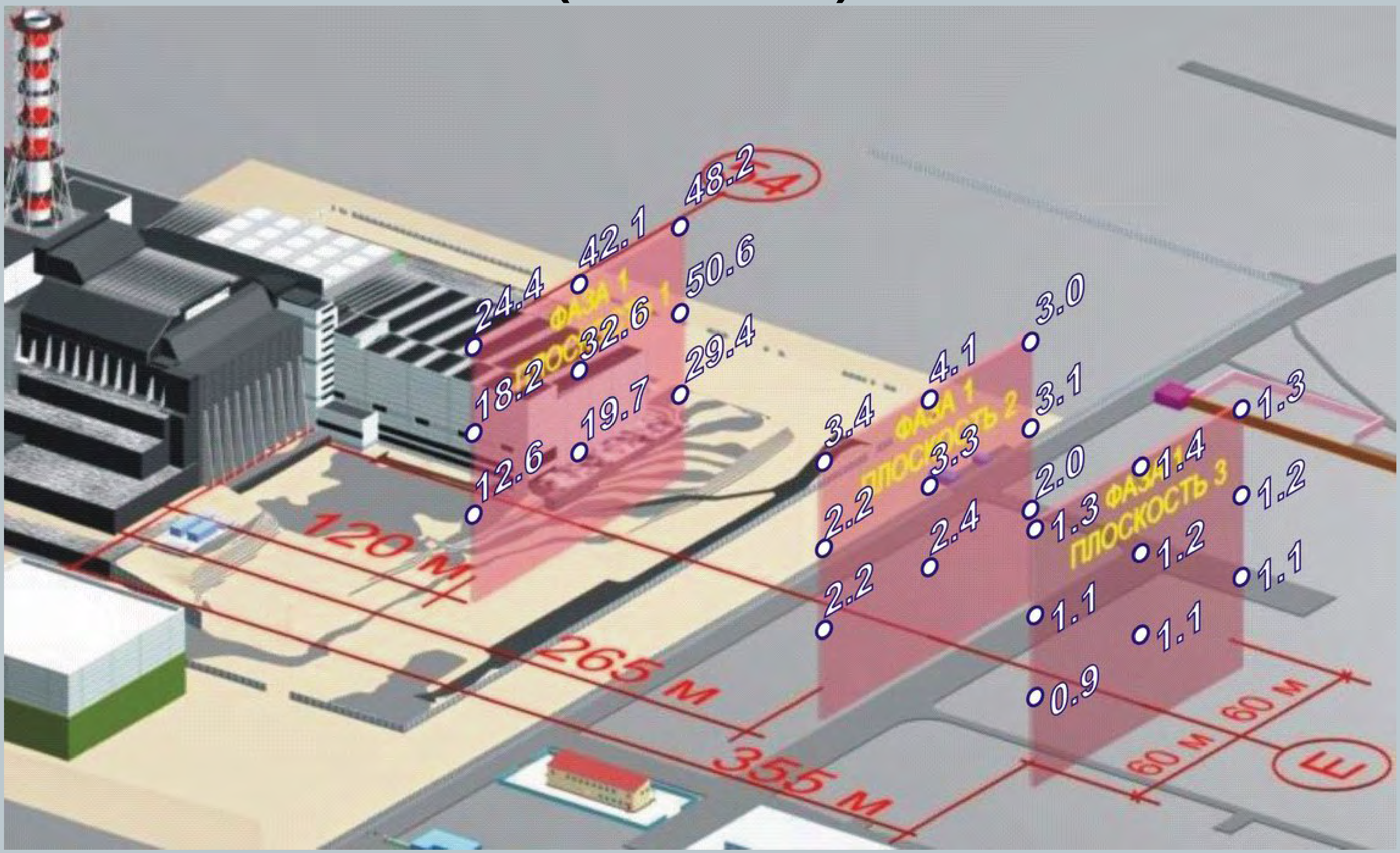
# Radionuclides in Dust

| Nuclide | Bq/kg (U) |
|---|---|
| Cs134 | 2.8E+09 |
| Cs137/Ba137m | 1.3E+12 |
| Sb125 | 2.3E+09 |
| Sr90/Y90 | 6.3E+11 |
| Pu238 | 8.7E+09 |
| Pu239/40 | 2.2E+10 |
| Pu241 | 6.1E+11 |
| Am241 | 2.8E+10 |

# Dose Rates in Work Areas

| Shelter structures | Structural members | Dose Rate (mrem/h) |
|---|---|---|
| Southern part of the roofing | Flat panels, hockey sticks | 300-2500 |
| "Mammoth" beam | - | 300-2500 |
| Southern Beam B1 | Beam B1 | 1500-5000 |
| Octopus beam | - | 300-4000 |
| Northern Beam B1 | Supporting points | 2500-8000 |
| Eastern part of the roofing | Hockey stick panels | 2500-8000 |
| Northern part of the roofing | Northern hockey sticks | 700-2500 |
| Internal structures | Debris | 1000-5000 |

# Dose Rates Outside the Shelter (mR/hr)



# There are concerns that the Shelter might collapse.

- This would complicate further recovery efforts.
- Collapse might lead to the release of 500 to 2000 kg of dust containing 8 to 50 kg of dispersed nuclear fuel.
- This material, if released, would be deposited within the 30-km zone.

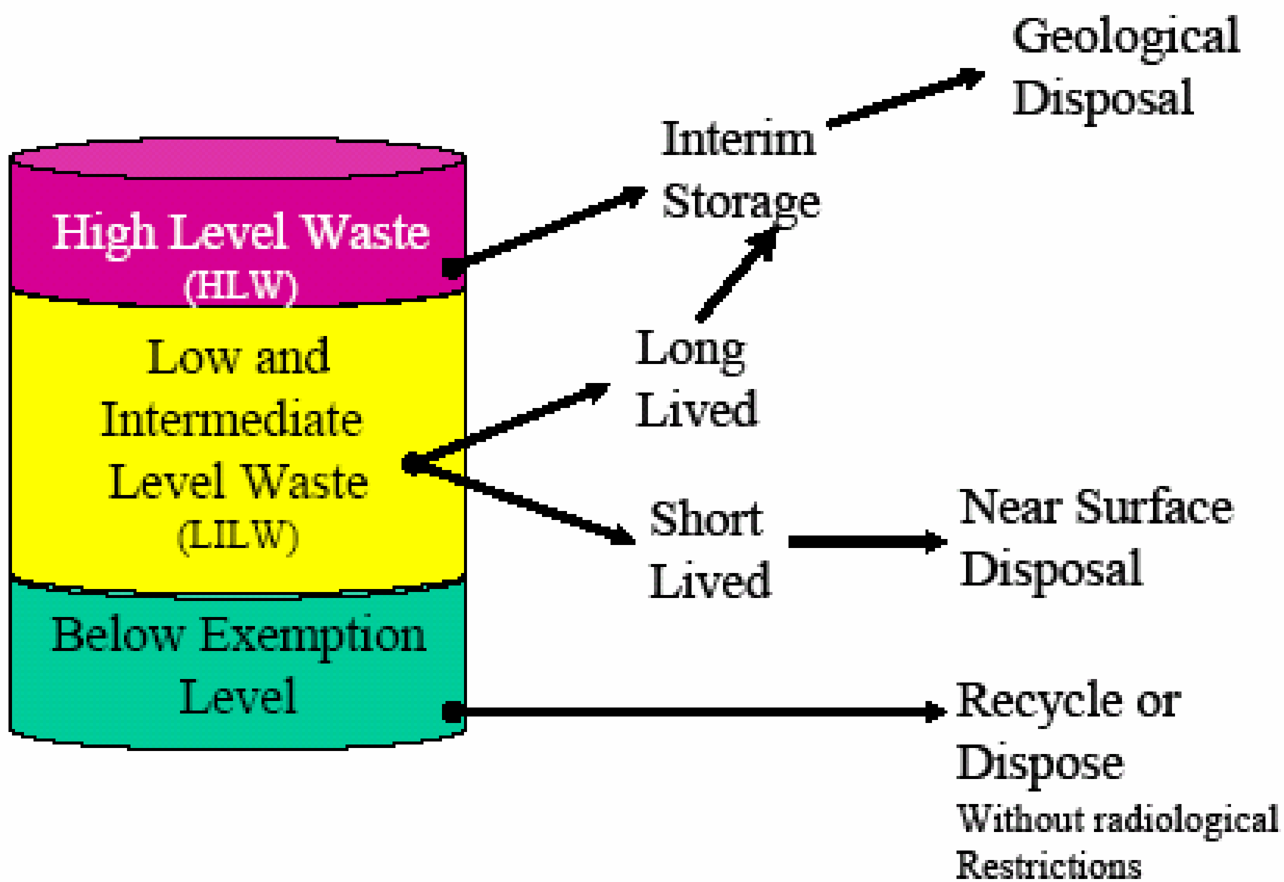
# The NSC should allow for

- Dismantlement of the old Shelter,
- Removal of fuel-containing material (FCM) from the reactor,
- Eventual decommissioning of the reactor, and
- Decrease of environmental impacts.
- Removal of the FCM depends upon the establishment of a geologic disposal facility.

# A comprehensive strategy for waste-management is needed.

- Some material from dismantlement should be placed in a geologic repository.
- Should existing sites be remediated? This would be costly in terms of money and exposure to workers.

# The plan



High Level Waste
(HLW)
Low and
Intermediate
Level Waste
(LILW)
Below Exemption
Level
Interim
Storage
Geological
Disposal
Long
Lived
Short
Lived
Near Surface
Disposal
Recycle or
Dispose
Without radiological
Restrictions

# Physical Dosimetry and Biodosimetry of Highly Exposed Emergency Respondents and Cleanup Workers

Vadim Chumak

Scientific Center for Radiation Medicine AMS Ukraine

# Structure of the presentation

- Liquidators - overview
- Dosimetric practices at time of clean-up
- Existing dosimetric data
- Dose reconstruction and dosimetric support of Chernobyl follow-up studies
- Outlook

# Total number of liquidators
## (UNSCEAR, 2000)

| Country and period | Number of clean-up workers | Percentage for whom dose is known |
|---|---|---|
| Belarus | | |
| 1986-1987 | 31 000 | 28 |
| 1986-1989 | 63 000 | 14 |
| Russian Federation | | |
| 1986 | 69 000 | 51 |
| 1987 | 53 000 | 71 |
| 1988 | 20 500 | 83 |
| 1989 | 6 000 | 73 |
| 1986-1989 | 148 000 | 63 |
| Ukraine | | |
| 1986 | 98 000 | 41 |
| 1987 | 43 000 | 72 |
| 1988 | 18 000 | 79 |
| 1989 | 11 000 | 86 |
| 1986-1989 | 170 000 | 56 |

# Liquidators are extremely heterogeneous cohort:

- Duration of work – from hours to years.
- Locations of work – ruins of the reactor 4 to remote places at the border of the 30-km zone
- Tasks – from manual removal of reactor debris to support activities (cooks, secretaries etc).
- Doses – from a fraction of mSv to lethal.
- Radiation safety and dosimetric monitoring – from perfect organization to complete absence

# Main keys for categorization of clean-up workers with respect to the quality of dosimetry

- Time
- Affiliation (ministry)
- Dosimetry service
- Category (type of work, tasks, position)

# Categories of liquidators

- Witnesses of the accident (NPP staff, firemen, guards)
- Early liquidators (April – May 1986)
- ChNPP staff / personnel temporally assigned to ChNPP
- AC-605 personnel
- Military liquidators
- Sent on mission to the 30-km zone
- Personnel of PA “Combinat” / SPA “Pripjat”

# Causes of dosimetric monitoring failure at initial phase of the accident

- The accident had caught radiation safety structures by surprise
- Dose and contamination levels far exceeded the ranges of available instrumentation and techniques
- The scale of the accident and number of engaged emergency workers was above the capacity of existing dosimetry services

# Periods of dosimetry of clean-up workers

| Period | Time interval | Characteristics |
|---|---|---|
| Pre-accidental | 1978-26.04.1986 | Normal operation of ChNPP, radiation safety in compliance with NRB-76 |
| Initial | 26.04-ca.10.05.1986 | Failure of routine dosimetry service, use of wartime approaches for troops |
| Interim | Ca.10.05-01.06.1986 | Development of unity in radiation safety, establishing dosimetric facilities |
| Main | June-October 1986 | Operation of three dosimetry services (ChNPP, AC-605, military) using different approaches |
| Routine | Since November 1986 | Gradual return to normality, reduction of dose limits (1987-1988) |

# Dosimetry services in Chernobyl

| Service | Responsibility domain | Period of operation | Quality of results |
|---|---|---|---|
| ChNPP | •ChNPP personnel<br>•Temporary assigned to ChNPP<br>•Sent on mission to the 30-km zone | May 1986-present | reasonable |
| AC-605 | Personnel of AC-605 (civil and military) | June 1986 – 1987 | high |
| Military | Troops | April 1986 - 1990 | low |
| PA “Combinat” and successors | Workers in the 30-km zone | November 1986 - present | reasonable |

# Radiation safety legislation

## Dose limits:

- Initial phase: 250 mSv (NRB-76) for emergency workers, 500 (250) mSv for troops
- Since 21.05.1986 – 250 mSv for all liquidators
- Since February 1987 – differential: 50, 100 and 250 mSv
- Since February 1988 – 50 mSv

## Harmonization of dosimetry:

- Dosimetric monitoring of civilians was regulated by the Statute of 31.05.1986 – full coordination and harmonization never achieved
- Military had stand-alone regulation and dosimetry

# Dosimetry methods

- TLD monitoring with a personal dosimeter
- “group-dosimetry” – one dosimeter per group of workers
- “group-estimation” – one pre-calculated dose to a whole group of workers

# Main problems and gaps in dosimetry of liquidators

## Main gaps in data:

- Doses of all early liquidators (26 April – end of May 1986)
- Lost data on doses of ChNPP staff for the period May-June 1986
- Insufficient coverage by dosimetric monitoring by ChNPP
- Doses of Sent on Mission

## Main problems:

- Inaccurate data for military
- Incomplete (fragmented) monitoring data (ChNPP, PA “Combinat”)
- Limited access to dosimetric data retained in Russia
- Lack of data on beta exposure

# Lessons of dosimetric support of clean-up activities

## Positive experience:

- Successful radiation safety program for multi-thousand contingents
- Efficient dosimetric monitoring program at AC-605

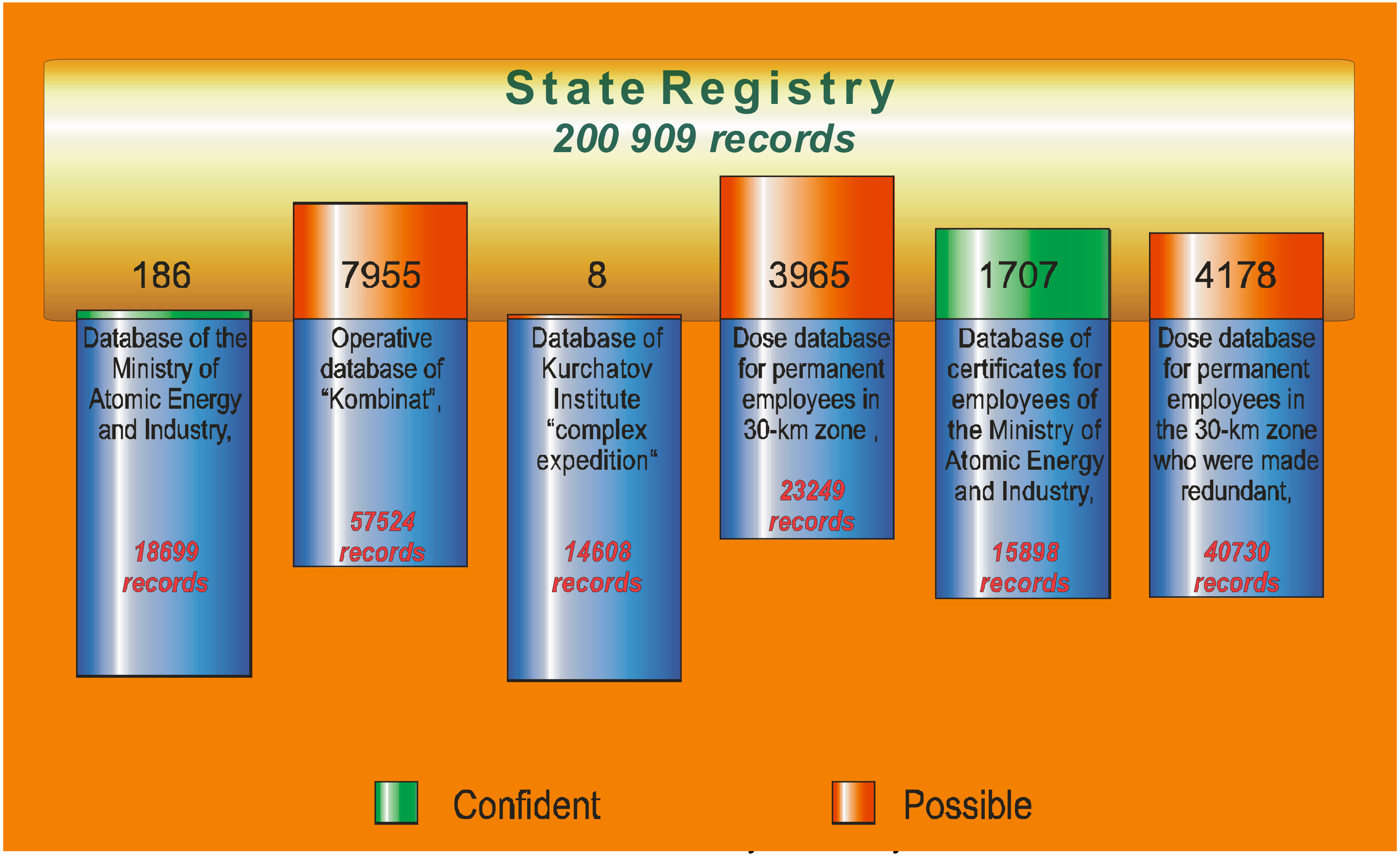
## Negative experience:

- Lack of preparedness for operation under conditions of large scale radiation emergency
- Lack of harmonization and coordination between dosimetry services
- Deficiencies in instrumentation and methods
- Insufficient attention to retention of dosimetric information

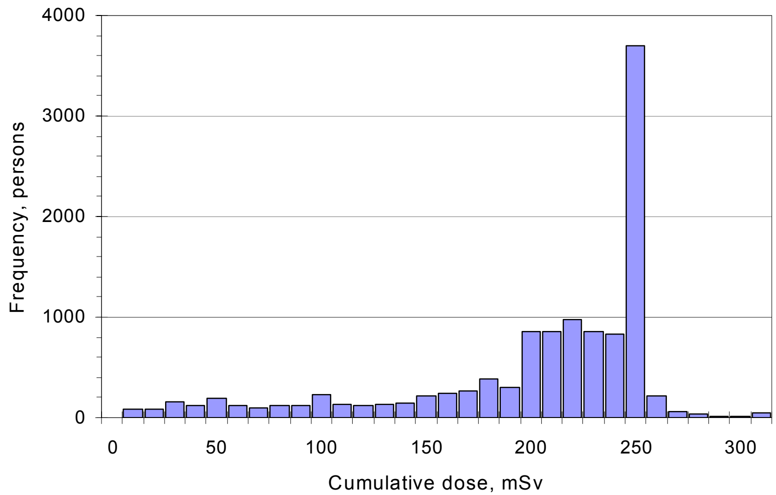
# Inventory of dosimetric databases

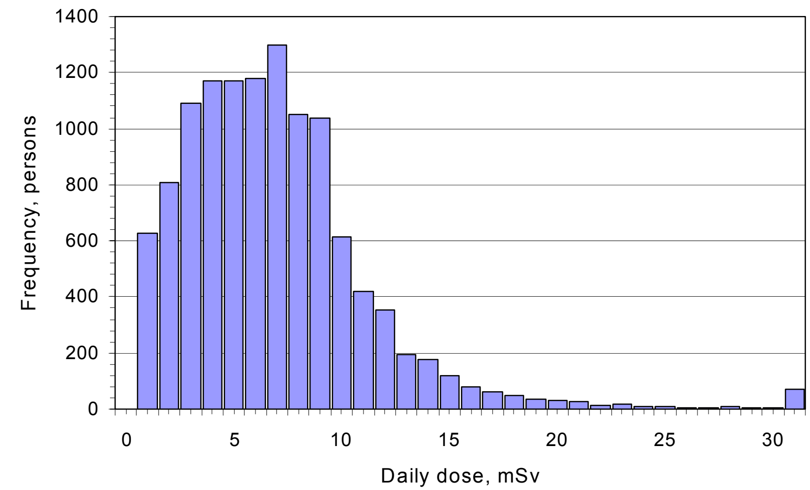
- Only about 47% records in SRU, which are related to liquidators of 1986-1990, contain individual doses (51% for 1986-1987)
- 95% of ODR in SRU belong to military liquidators
- Six IDM databases related to civilian liquidators (ChNPP, AC-605, PA “Combinat”) – 168,394 dose records
- Paper archives of the Ministry of Defense were converted into electronic databases (ca.50,000 records) – good overlap and coincidence with SRU data

# Results of IDM linkage with SRU

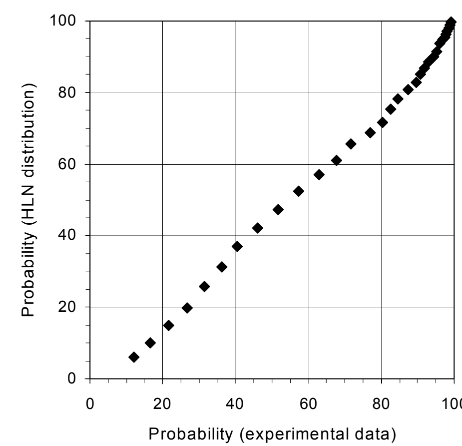


# Dose distributions for military liquidators (reservists, 1986)




- Distribution of total doses
- Distribution of daily doses
- Normalized probability plot of daily doses – HLN hypothesis



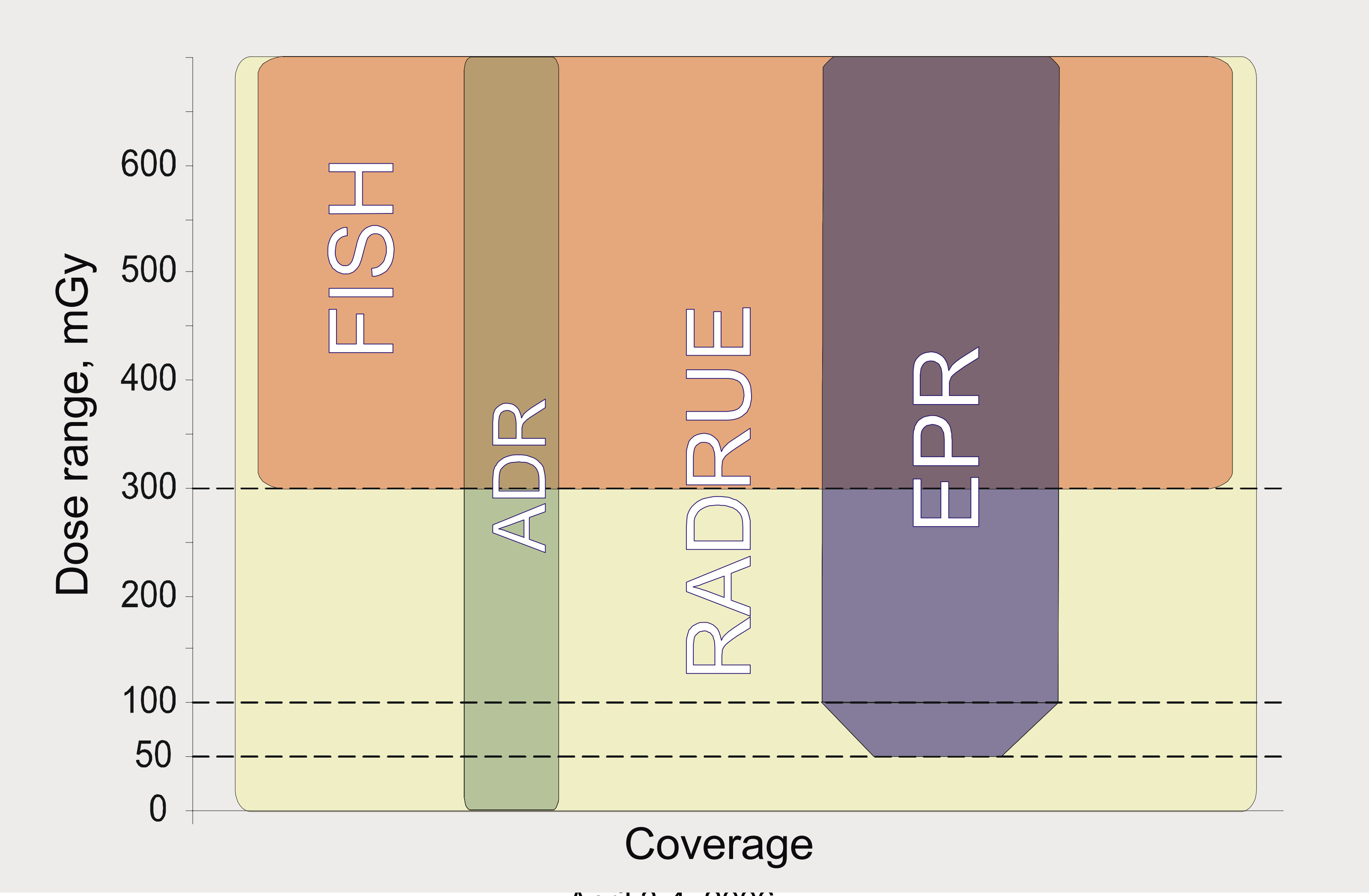
# The need for retrospective dose assessment is determined by:

- Insufficient coverage of liquidator population with Official Dose Records (ODR)
- Low accuracy of the majority of ODR
- The need to estimate both dose value and uncertainty

# Plausible methods of dose assessment

- Analytical Dose Reconstruction (ADR) and its derivatives
- Electron Paramagnetic Resonance (EPR)
- Fluorescence In Situ Hybridization (FISH)

# Application areas of plausible methods of dose assessment



# EPR dosimetry: metrological parameters of SCRM protocol

- Sensitivity threshold – 50 mGy

**Simplified error propagation model:**

- $\pm$ 25 mGy for dose $\leq$250 mGy
- $\pm$ 10% for dose >250 mGy

# SRCM results in the intercomparisons

for nominal dose: <300 mGy – absolute deviation
>300 mGy – percentage

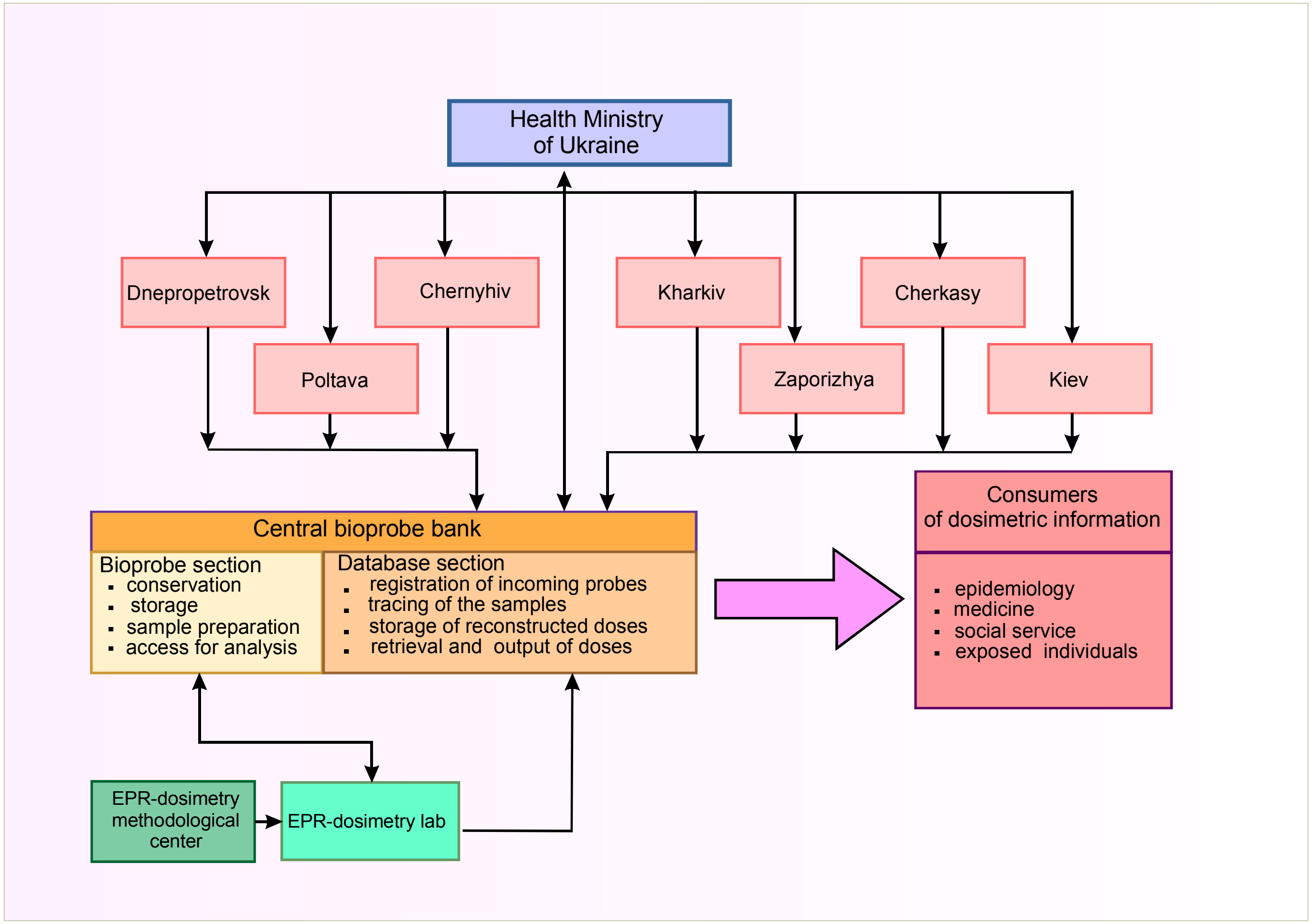
| Title of the intercomparison | Year | Dose range, mGy | Deviation from nominal dose | $r^2$ |
|---|---|---|---|---|
| 1st International | 1994 | 0-1000 | 29 mGy<br>5% | 0.951 |
| 2nd International | 1998-1999 | 99-815 | 2 mGy<br>26% | 0.988 |
| Bilateral with Utah University (USA) | 2000-2001 | 74-810 | 21 mGy<br>9% | 0.998 |
| Bilateral with NIST (USA) | 2001-2002 | 0-269 | 15 mGy | 0.975 |
| 3rd International | 2003 | 79-704 | 18 mGy<br>10% | 0.995 |

# Application of EPR dosimetry with teeth as a "gold standard"

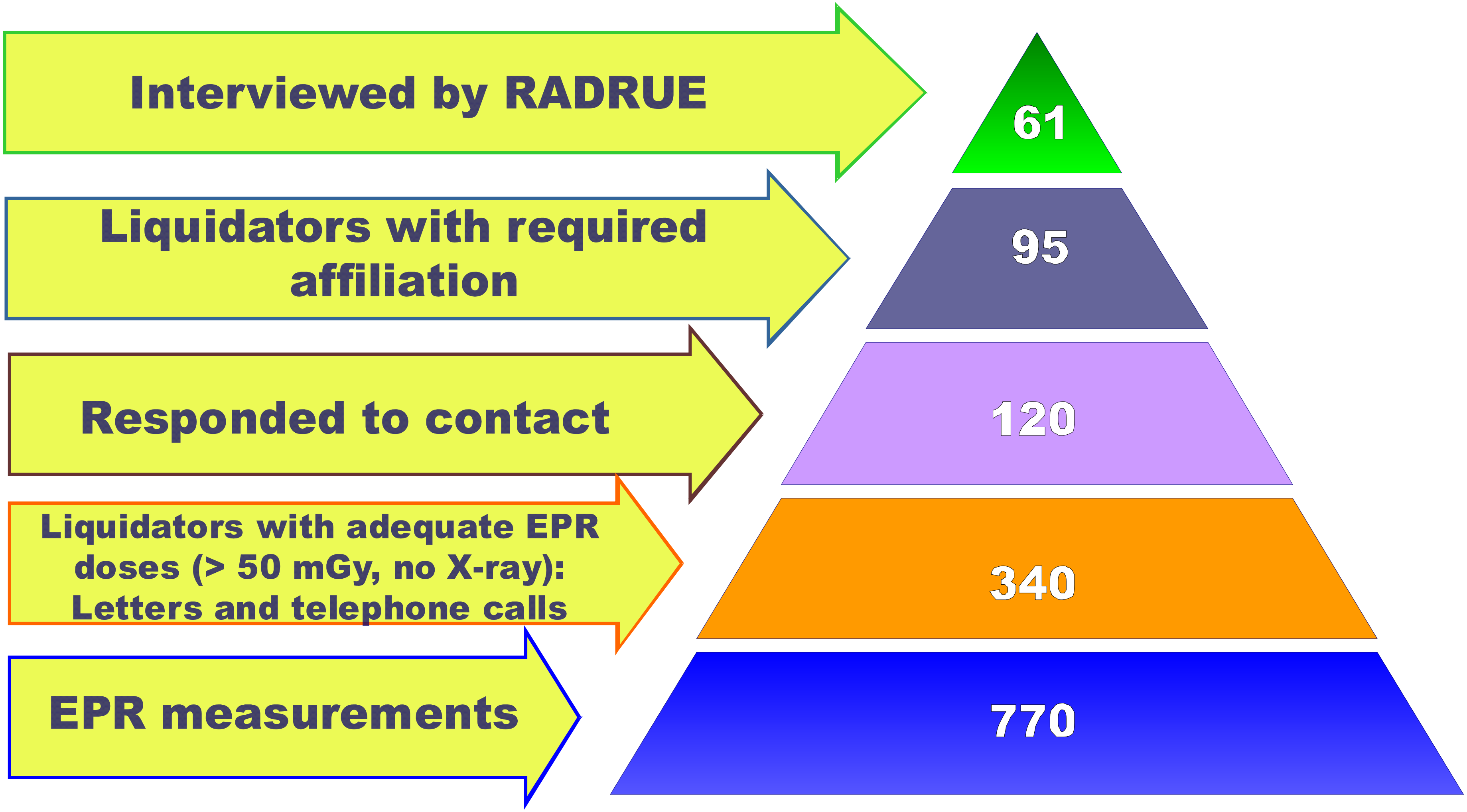
- Validation of other dose assessment methods
- Verification of existing dose estimates
- Routine individual dose reconstruction

Typical useful dose range: < 300 mGy

# Samples for analysis: Tooth acquisition network in Ukraine



# Use of EPR dosimetry as a reference: Effect of application criteria

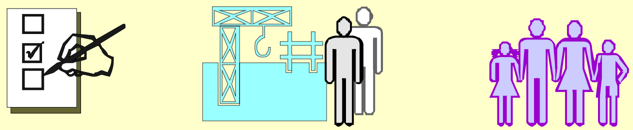


# Analytical dose reconstruction techniques

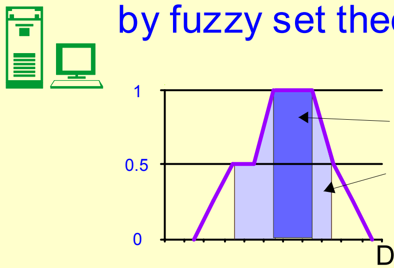
- ADR - Analytical Dose Reconstruction
- RADRUE – Realistic Analytical Dose Reconstruction with Uncertainty Estimation)
- SEAD - Soft Expert Assessment of Dose

# Four easy steps to calculate dose by SEAD

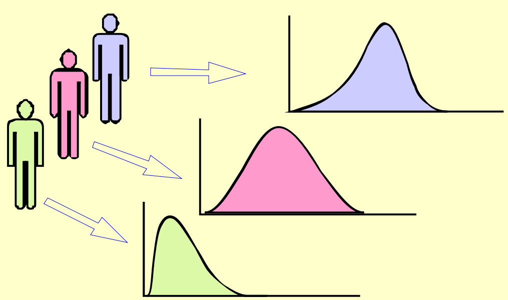
**1.** Interviewing a liquidator or his proxy



**4.** Calculation of dose intervals by fuzzy set theory



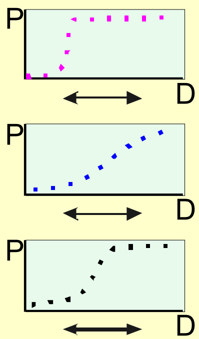

**2.** Assigning the category (dose distribution)



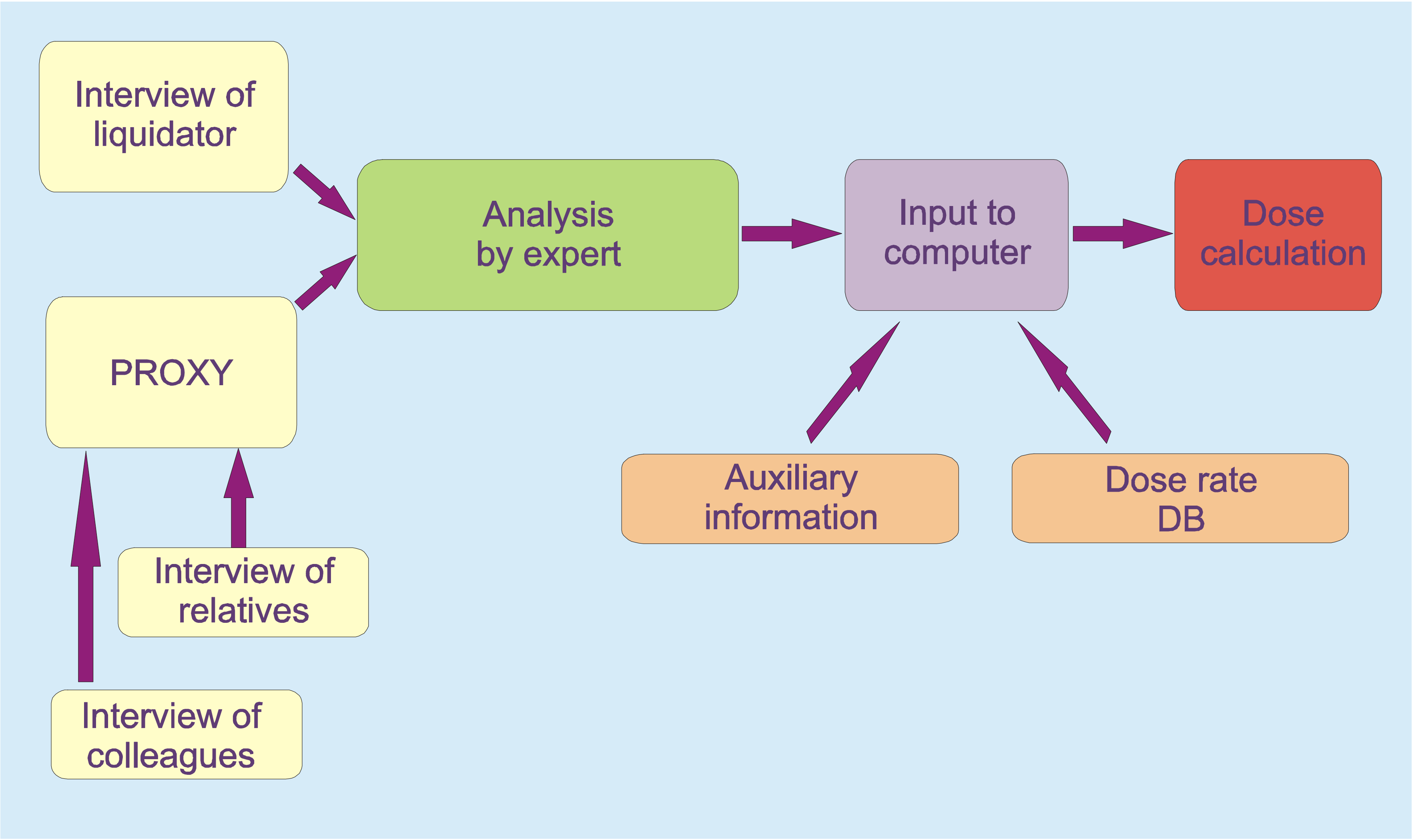
**3.** Expert assessment of modifying factors

- date when participation began
- duration of participation
- affiliation at time of clean-up
- occupation at time of clean-up
- typical place of work
- hazardous place of work
- type of personnel

0 0.25 1 0.5



# RADRUE basic flow-chart



# Examples of routine dose reconstruction

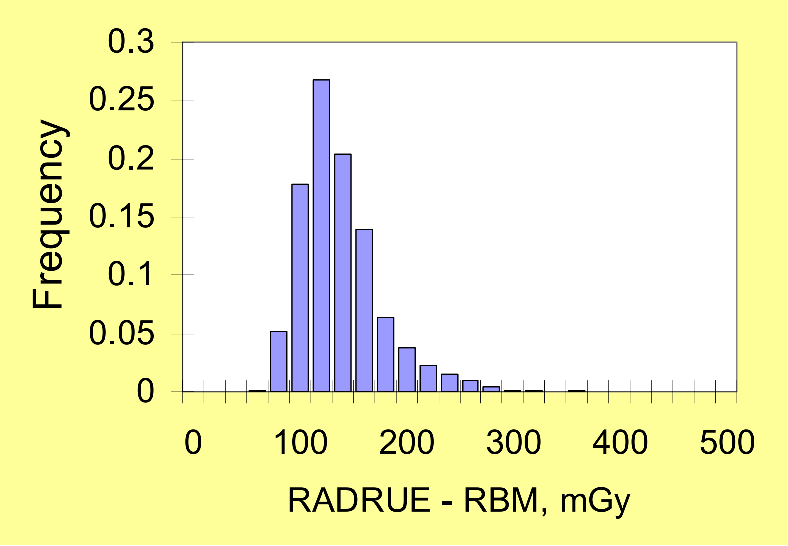
- Estimation of red bone marrow doses in the framework of Ukrainian-American Study of Leukemia among Chernobyl Liquidators
- Estimation of eye lens doses in the framework of Ukrainian-American Chernobyl Ocular Study (UACOS)

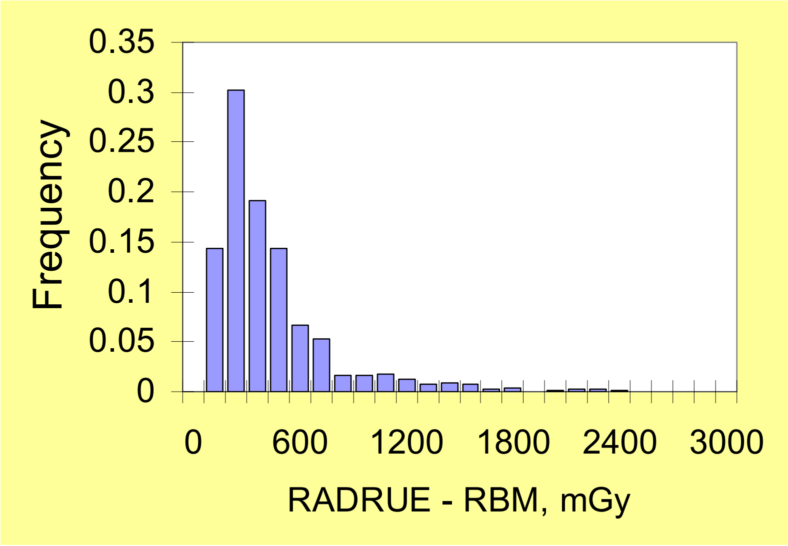
# Dosimetry plan for leukemia study

- Problem:
  - RBM doses are needed for 614 subjects of a case-control study
  - Dose reconstruction with universal method to all cases and controls (without exception!)
  - 79 diseased cases
- Solution:
  - Application of interview based RADRUE method
  - Interview of proxy (colleagues) to reconstruct doses to diseased cases

# Examples of RADRUE simulator output:

uncertainty distributions of RBM dose

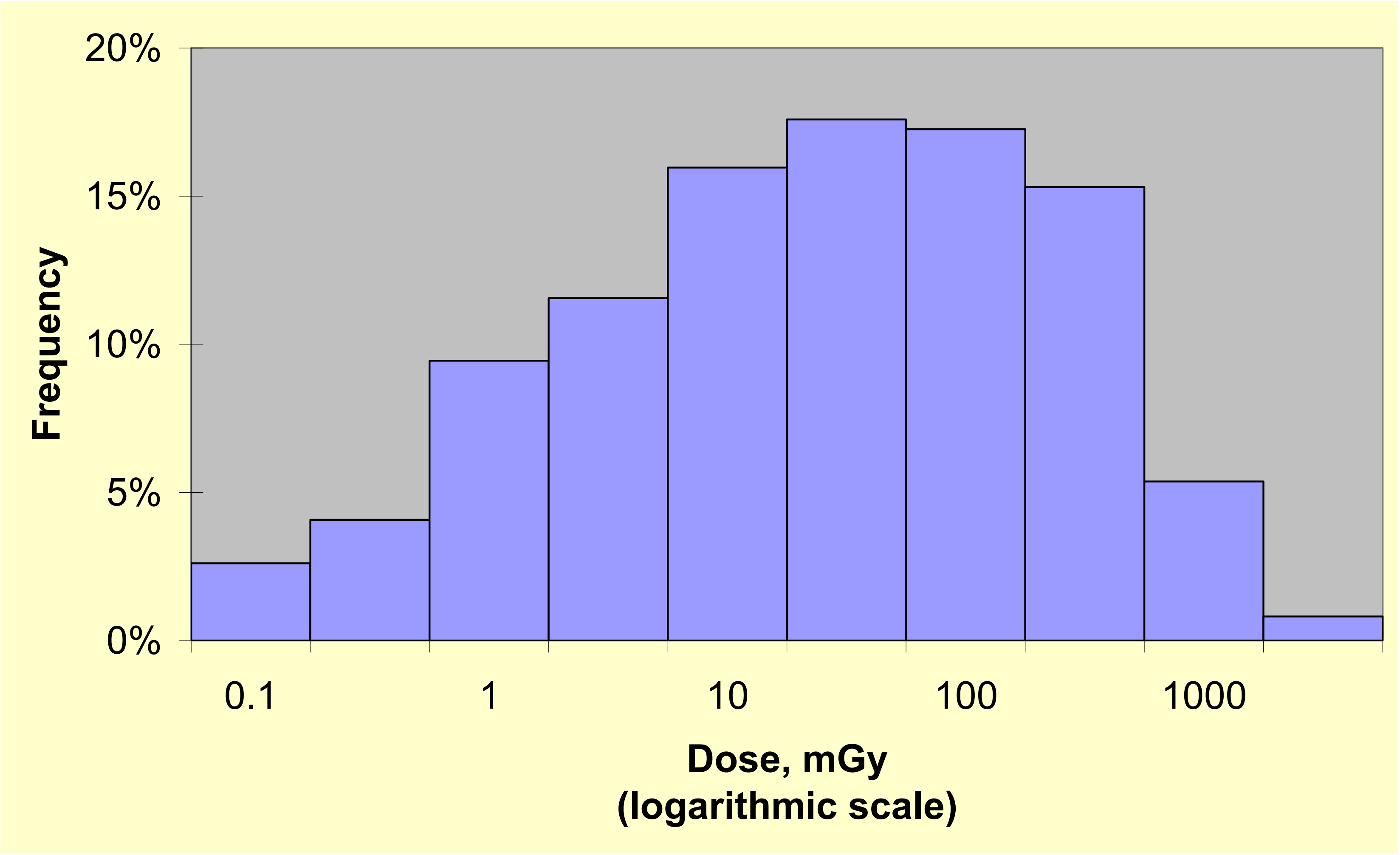



Subject Q0072790
(driver, evacuation,
4 trips in 1 week in Sept. '86)
Mean = 0.74 mGy
SD = 1.26 mGy
Median = 0.41mGy
GSD = 2.42

Subject Q0593432 - proxy
(bulldozer, road construction,
10 days in May '86)
Mean = 382 mGy
SD = 406 mGy
Median = 267 mGy
GSD = 2.18

# RADRUE dose estimates
## (mean of 10 k simulations)
### Mean: 90 mGy, SD: 270 mGy, GM: 12 mGy, GSD: 11, min: 0, max: 3.2 Gy



# Parameters of dose distributions by category

| Category | Number | Mean (mGy) | Median (mGy) | GSD (mGy) |
|---|---|---|---|---|
| Military | 218 | 76 | 54 | 2.1 |
| Atomic workers | 35 | 381 | 277 | 1.78 |
| Ministry of interior | 27 | 203 | 173 | 1.86 |
| SOM | 340 | 70 | 48 | 1.95 |
| Drivers | 213 | 64 | 41 | 1.99 |

# Parameters of dose distributions for military (by year)

| Year | Number | Mean (mGy) | Median (mGy) | GSD (mGy) |
|---|---|---|---|---|
| 1986 | 99 | 105 | 82 | 1.89 |
| 1987 | 52 | 78 | 46 | 2.32 |
| 1988 | 44 | 29 | 17 | 2.41 |
| 1989 | 20 | 31 | 17 | 2.22 |
| 1990 | 3 | 60 | 24 | 2.89 |

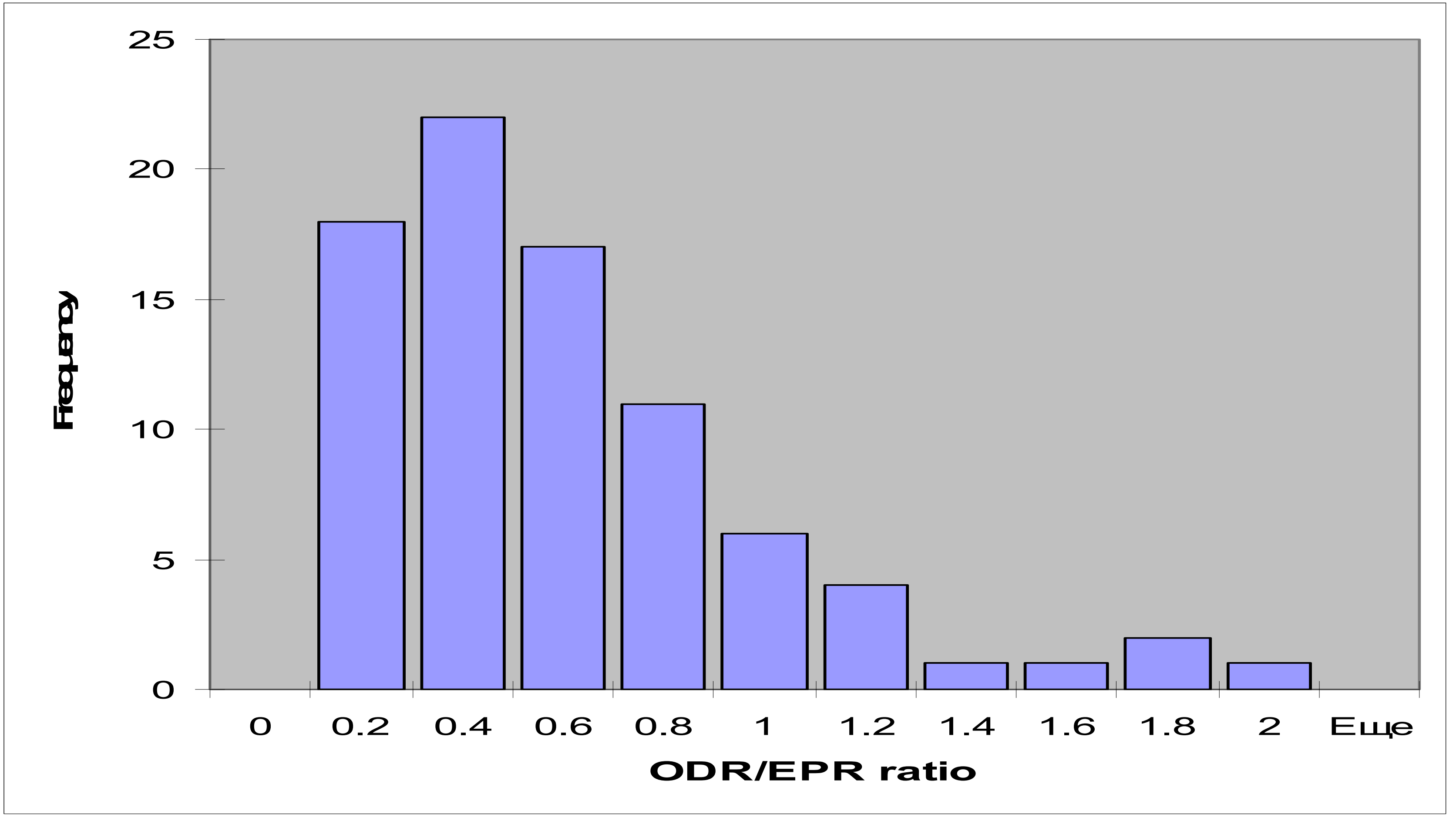
# UACOS dosimetry plan

- Problem:
  - Total (beta+gamma) doses are needed for about 12,000 subjects of a cohort study
  - Formation of the cohort can be based on the availability of dosimetric data
- Solution:
  - Dose data from different sources (ODR, IDM, ADR, EPR) were reviewed and incorporated into the study
  - Subjects with available dose information were enlisted into the study
  - Calibration of all dosimetric data against EPR dosimetry (“gold standard”)
  - Estimation of individual beta doses by conversion from gamma doses

# Doses of the main groups of UACOS subjects

| Liquidator Group | Number in the Study | Distribution of Imputed Doses (Gamma + Beta) (mGy): Median (5th, 95th Percentiles) |
|---|---|---|
| AC-605 workers (personal dosimeters) | 410 | 16 (2, 235) |
| EPR measurements | 104 | 94 (19, 426) |
| Analytical Dose Reconstruction (ADR) - ChNPP | 712 | 502 (142, 1143) |
| ADR - RADEC | 126 | 16 (1, 242) |
| Military | 7,255 | 121 (30, 287) |
| Total | 8,607 | 123 (15, 480) |

# Distribution of ODR/EPR ratio

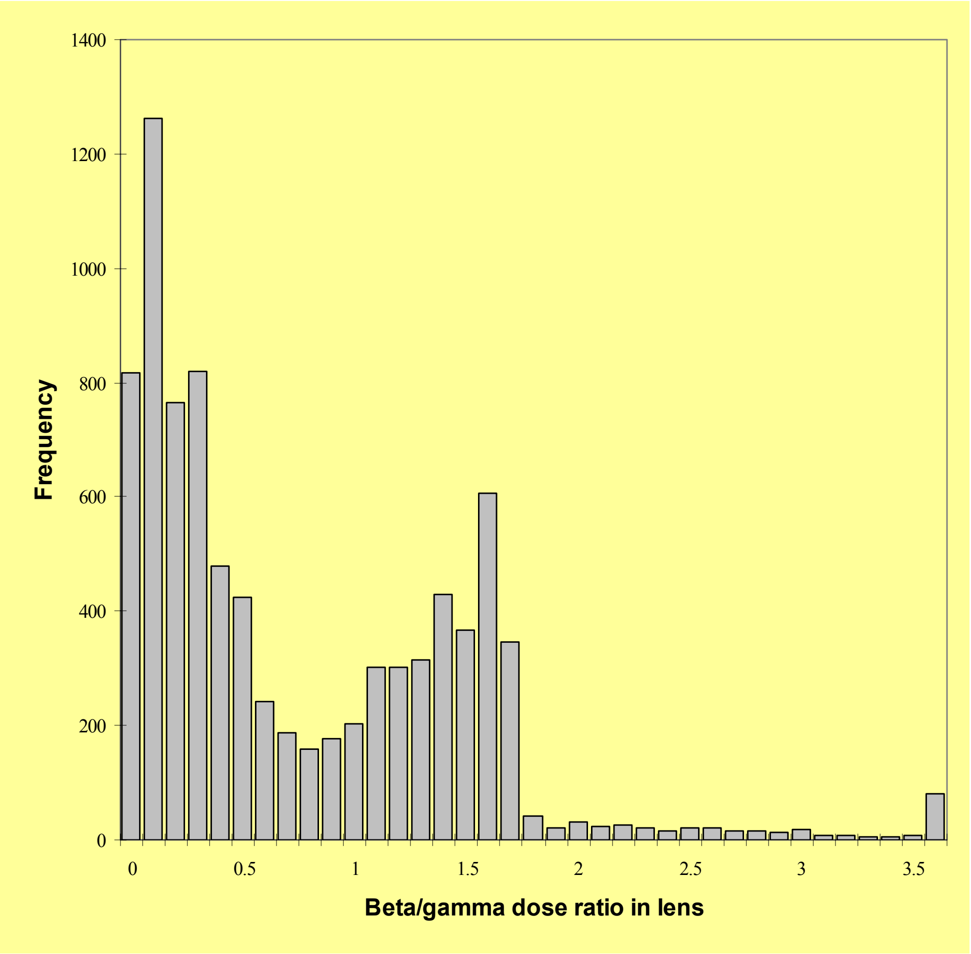


# Retrospective assessment of bias and uncertainty of ODR (2002)

- 92 subjects with group assessment ODR (military liquidators of 1986-1987)
- EPR used as a reference (point dose estimate)
- Ratio ODR/EPR is considered as model uncertainty distribution
- Parameters of distribution (2003 data for 119 subjects):

| | | | |
|---|---|---|---|
| GM | – | 0.39 | (0.43) |
| GSD | – | 2.14 | (2.05) |

# Estimated beta/gamma ratios for UACOS subjects



# Conclusions

Dosimetry of Chernobyl liquidators is unique and challenging experience in many respects.

- At time of clean-up:
    - Radiation protection of multi-thousand masses of liquidators
    - Application of unique dose monitoring and dose management practices
    - Lessons learnt from dosimetric support of large scale activities
- In course of dosimetric support of Chernobyl follow-up studies
    - Individual dose reconstruction
    - Retrospective re-evaluation and verification of existing dose records
    - Development of new techniques to fit the demands of epidemiological studies
    - Use of combination of different methods to address practical needs

# The Chernobyl ARS Cases

- 134 ARS cases finally documented
- ~400 ARS cases recorded worldwide
- Chernobyl represents ~ 30% of total ARS experience

# Whole body radiation dose/effect

- 10mGy (1 rad) 1/1000 chance of cancer
- 100 mGy (10 rads) Chromosomal aberrations

---

- 1 Gy (100 rads) Prodromal symptoms
- 3.5 Gy (350 rads) LD50 (without treatment)
- 6.5 Gy (650 rads) LD50 (with treatment)

---

- >12 Gy (>1200 rads) Not survivable

# Comparison of acute radiation "syndrome" vs. "sickness"

| Acute radiation syndrome | Dose (Gy) | Acute radiation sickness | Dose (Gy) |
|---|---|---|---|
| Subclinical | < 1 | | |
| Hematopoietic | > 1 (0.7-4.0) | Mild | 1-2 |
| | | Moderate | 2-4 |
| Gastrointestinal | > 5 | Severe | 4-6 |
| | (6-8) | Very severe | 6-8 |
| | | Lethal | >8 |
| CV/CNS | >30 (20-40) | | |

## Radiosensitivity is related to cell turnover rate

- White blood cells/lymphocytes
- Bone marrow stem cells
- Skin/epithelium

- GI tract
- Connective tissue/blood vessels

- Muscle
- Nerve/brain

Most sensitive

Most resistant

# Acute radiation "sickness"
## Prodromal phase

| | Vomiting | Diarrhea | Headache | Body temperature |
|---|---|---|---|---|
| Mild (1-2 Gy) | > 2 hr 10-50% | None | Slight | Normal |
| Moderate 2-4 Gy | 1-2 hr 70-90% | None | Mild | Increased 1-3h |
| Severe 4-6 Gy | < 1 hr 100% | Mild | Moderate 4-24h 50% | Fever 1-2 h |
| Very Severe 6-8 Gy | < 30 min 100% | Heavy | Severe 3-4h 80% | High fever < 1h |
| Lethal > 8 Gy | < 10 min 100% | Heavy | Severe 1-2h 80-90% | High fever < 1 hr |

# Acute radiation "sickness"

## Latent phase

| | Lymphocytes G/L 3-6 days | Granulocytes G/L | Diarrhea | Hair loss |
|---|---|---|---|---|
| Mild (1-2 Gy) | 0.8-1.5 | > 2.0 | None | None |
| Moderate 2-4 Gy | 0.5-0.8 | 1.5 - 2.0 | None | Moderate > 15 days |
| Severe 4-6 Gy | 0.3-0.5 | 1.0 - 1.5 | Rare | Moderate > 11 days |
| Very Severe 6-8 Gy | 0.1-0.3 | < 0.5 | Days 6-9 | Complete < 11 days |
| Lethal > 8 Gy | 0.0-0.1 | < 0.1 | Days 4-5 | Complete < day 10 |

# Which is the most accurate dose method ?

| | Patient A | Patient B |
|---|---|---|
| Symptoms | 4 Gy | 6 Gy |
| Blood response | 5 Gy | 4 Gy |
| Cytogenetics | 6 Gy | 5 Gy |

Complicated by beta burns

Complicated by non-uniform gamma radiation

Regardless: we treat the patient not the estimated dose

# Dose range, number and outcome of 134 patients with varying degrees of ARS

| ARS Degree | Dose Range (Gy) | Number of patients | Short term deaths | Number of survivors |
|---|---|---|---|---|
| Mild (I) | 0.8-2.1 | 41 | 0 (0%) | 41 |
| Moderate (II) | 2.2-4.1 | 50 | 1 (2%) | 49 |
| Severe (III) | 4.2-6.4 | 22 | 7 (32%) | 15 |
| Very severe (IV) | 6.5-16 | 21 | 20 (95%) | 1 |
| Total | | 134 | 28 | 106 |

# Doses, number and outcome of 134 patients with Acute Radiation Sickness

| ARS Degree | Dose Range (Gy) | Number of patients | Short term deaths | Number of survivors |
|---|---|---|---|---|
| Mild (I) | 0.8-2.1 | | 0% | |
| Moderate (II) | 2.2-4.1 | | 2% | |
| Severe (III) | 4.2-6.4 | | 32% | |
| Very severe (IV) | 6.5-16 | | 95% | |
| Total | | | | |

50% lethality about 6.5 Gy

# Time and cause of short term ARS fatalities

| Time (days) | Number | Cause |
|---|---|---|
| 14-23 | 15 | Skin or intestinal injury |
| | 2 | Pneumonitis |
| 24-48 | 6 | Skin or lung injury |
| | 2 | Marrow transplant complications |
| 86-96 | 2 | Skin and kidney injury |
| 112 | 1 | Brain hemorrhage |

# General treatments

- Prophylactic and therapeutic antibiotics
- Gamma globulin
- Antiviral agents
- Parenteral nutrition and electrolytes
- Transfusions (platelets and red cells)
- Topical skin therapy
- Detoxification (plasmapheresis and absorption)
- Reverse isolation
- Anticoagulation
- Allogenic transplants (13), fetal liver cells (6)

# Were bone marrow transplants useful in the Chernobyl experience ?

- 1 survived 8.7 Gy (recovered native marrow) = survival about 5%
- 3 Chernobyl patients died as a result of complications
- 4 Chernobyl patients (6-8 Gy) survived without transplant
- Transplantation at doses below 9 Gy only worsened the ARS therapy results
- 1/34 worldwide (survival < 3%)

# Skin Changes with acute radiation exposure

| | |
|---|---|
| 2-6 Gy | Transient erythema 2-24 h |
| 3-5 Gy | Dry desquamation 3-6 wks |
| 3-4 Gy | Temporary epilation 3 wk |
| 10-15 Gy | Erythema 18-20 days |
| 15-20 Gy | Moist desquamation |
| 25 Gy | Ulceration/ slow healing |
| 30-50 Gy | Blistering, necrosis at 3 wk |
| 100 Gy | Blistering, necrosis at 1-3 wk |

- Skin doses exceeded bone marrow doses by a factor of 10-30
- Some patients had doses in the range of 400-500 Gy ( 40,000-50,000 rads)

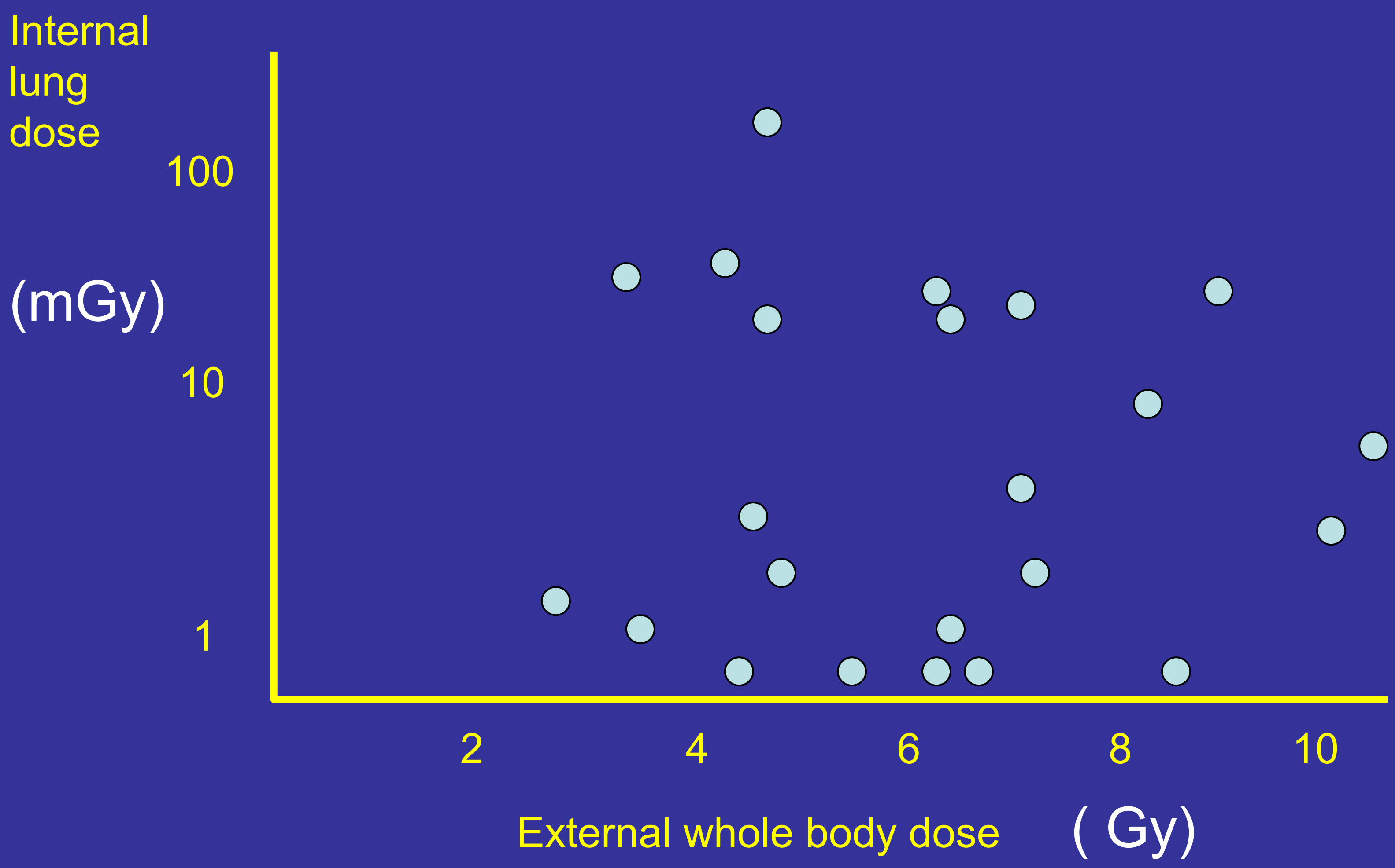
# Relationship of ARS grade to percent of total body radiation skin burns

| ARS grade | Number of patients | 1-10 % burn | 10-50% burn | 50-100% burn | Skin dose (Gy) |
|---|---|---|---|---|---|
| I | 31/41 | 2 | 1 | 0 | 8-12 |
| II | 43/50 | 2 | 9 | 1 | 12-20 |
| III | 21/22 | 3 | 15 | 3 | 20-25 |
| IV | 20/21 | 1 | 10 | 9 | > 20 |
| Total | 115/134 | 8 | 35 | 13 | |

6.5 Gy LD/50 includes these burns

# Relationship of external dose to internal lung dose

(about a factor of 1000 difference or 0.1%)



# Cataracts (as of 2000)

- At least ARS 17 survivors have developed cataracts
- The majority with doses WB external doses > 2 Gy
- Dose to lens complicated by ? beta dose
- Most occurred 3-8 years post exposure
- Surgery was effective and non-complicated

| ARS degree | Cataracts by 10 years |
|---|---|
| Mild | 5 % |
| Moderate | 15% |
| Severe | 85% |

# Late lethality of 14 ARS survivors 1987-2001

| Year | ARS grade | Cause |
|---|---|---|
| 1987 | II | Lung gangrene |
| 1990 | II | Ischemic cardiac disease |
| 1992 | III | Ischemic cardiac disease |
| 1993 | I | Ischemic cardiac disease |
| 1993 | III | Myelodysplastic syndrome |
| 1995 | I | Lung tuberculosis |
| 1995 | II | Liver cirrhosis |
| 1995 | I | Fatty embolism |
| 1995 | | Coronary heart disease |
| 1996 | II | Myleodysplastic syndrome |
| 1998 | II | Myelomonoblastic acute leukemia |
| 1998 | II | Liver cirrhosis |
| 1998 | II | Coronary heart disease |
| 2001 | III | Coronary heart disease |

# Acute health effects lessons from Chernobyl

- Triage by symptoms and blood count
- Possibly hundreds or more persons needing reverse isolation, bone marrow stimulation, antibiotics, antivirals etc
- Combined injuries adversely affect outcome
- LD/50 with good medical treatment is about 6.5 Gy with skin injuries
- Without skin injuries LD/50 is possibly 6-8 Gy but not higher

**Medical Radiological Research Center**
**National Radiation and Epidemiological Registry**

# LATE HEALTH EFFECTS, INCLUDING CANCER AND NON-CANCER EFFECTS

***V.K. IVANOV, Correspondent Member of RAMS, Vice-Chairman, Russian Scientific Commission on Radiation Protection***

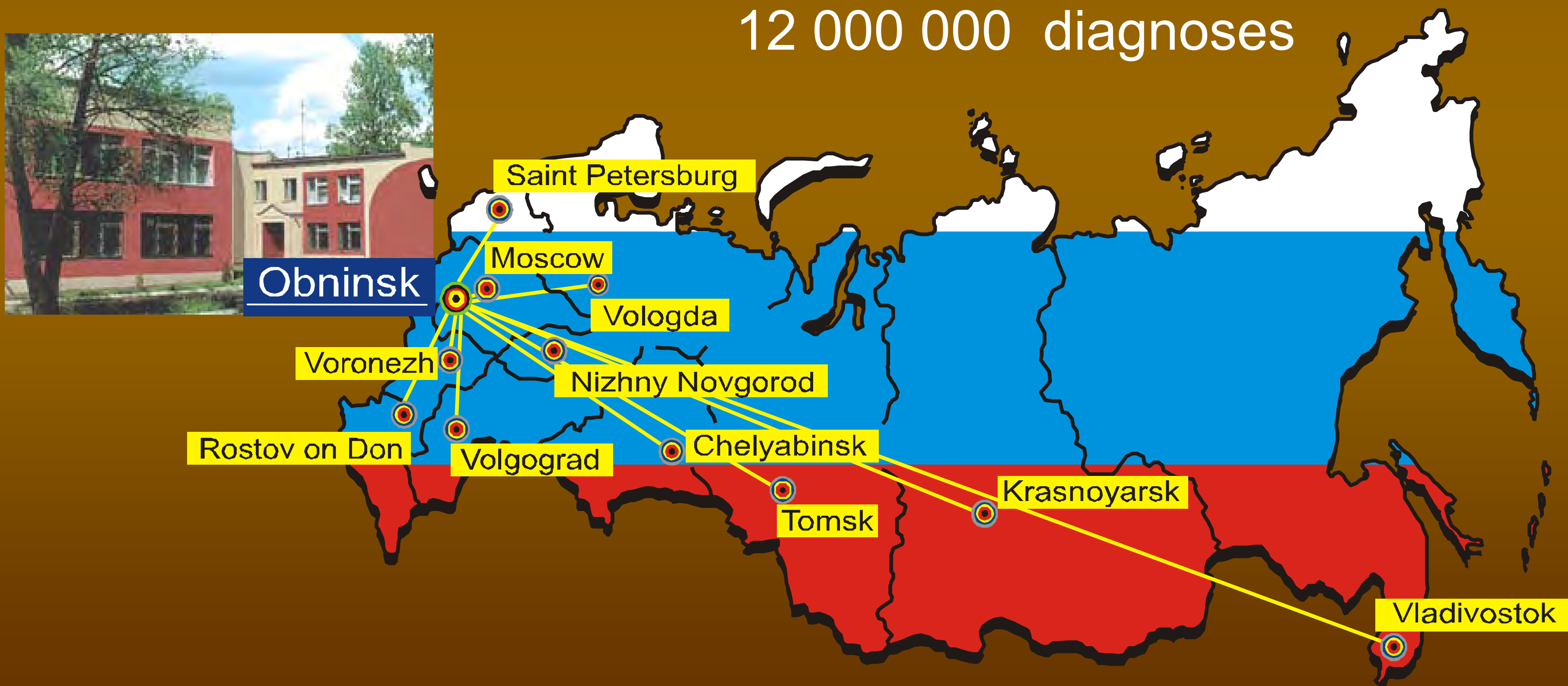
NCRP 2006 Annual Meeting
Virginia, USA

## PRESENTATION CONTENTS

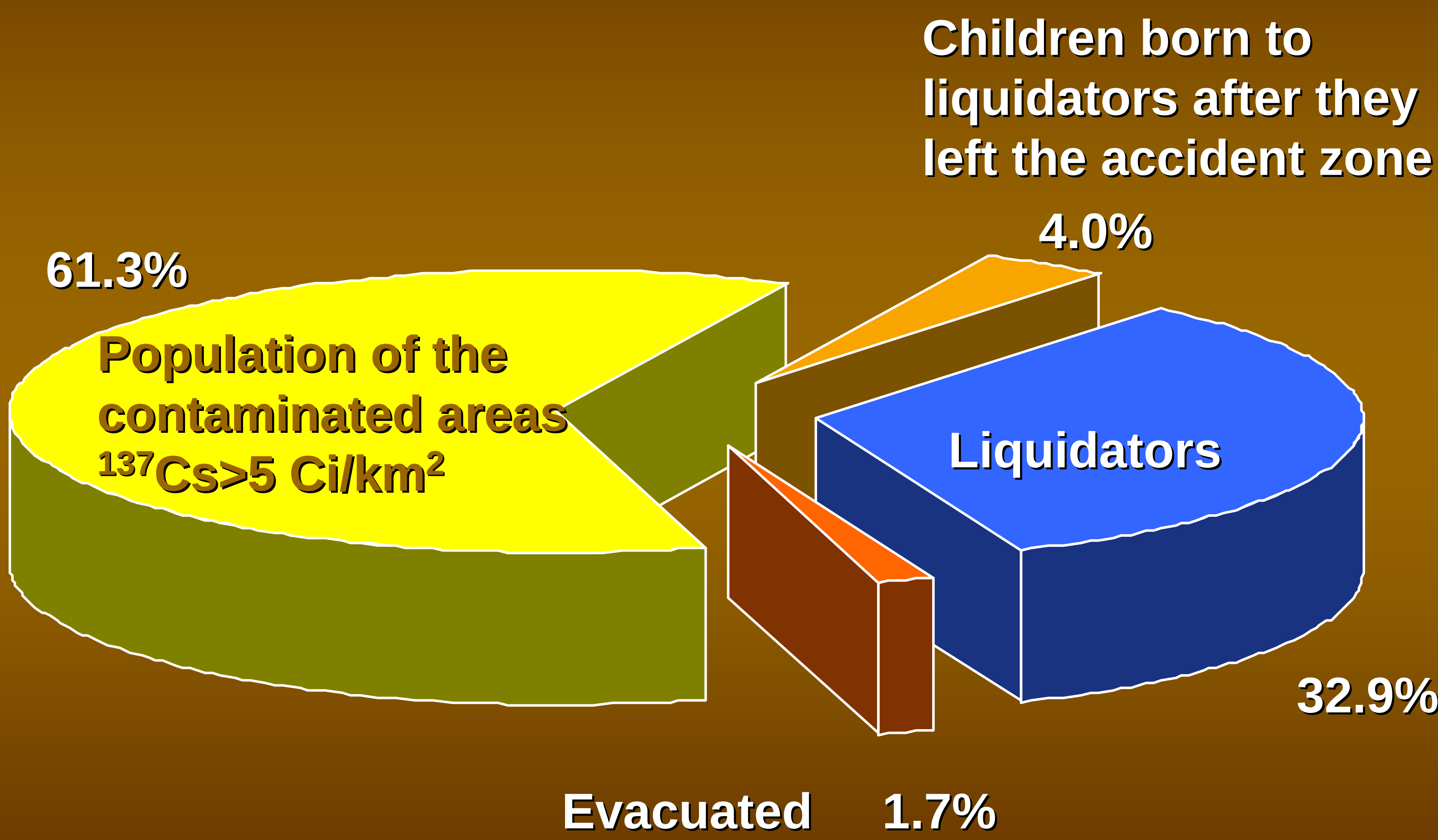
- *National Registry*.
- Solid cancers.
- Leukemias.
- Non-cancer diseases.

# NATIONAL RADIATION AND EPIDEMIOLOGICAL REGISTRY

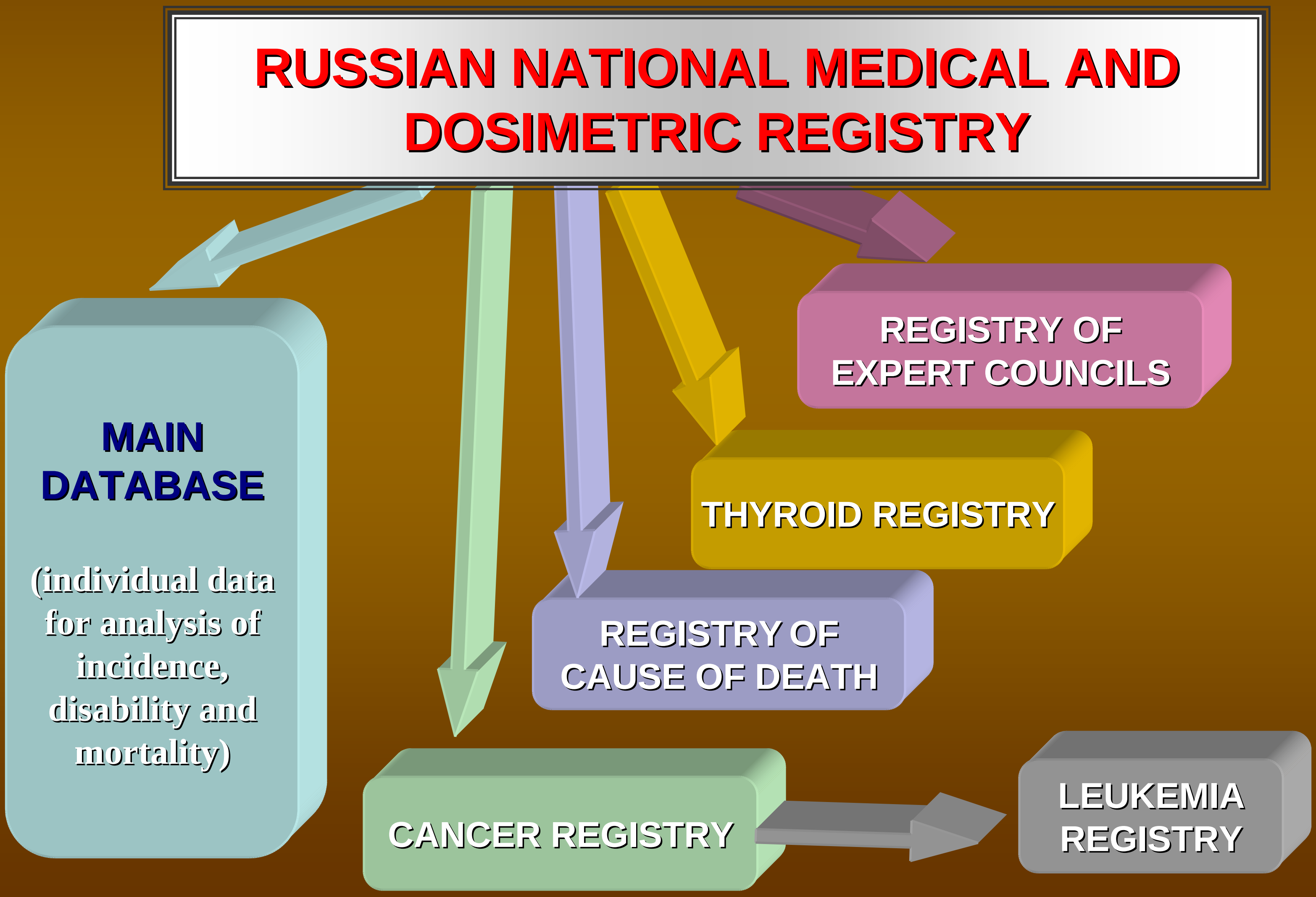
20 regional centers
4 000 hospitals and clinics
615 000 registered persons
12 000 000 diagnoses



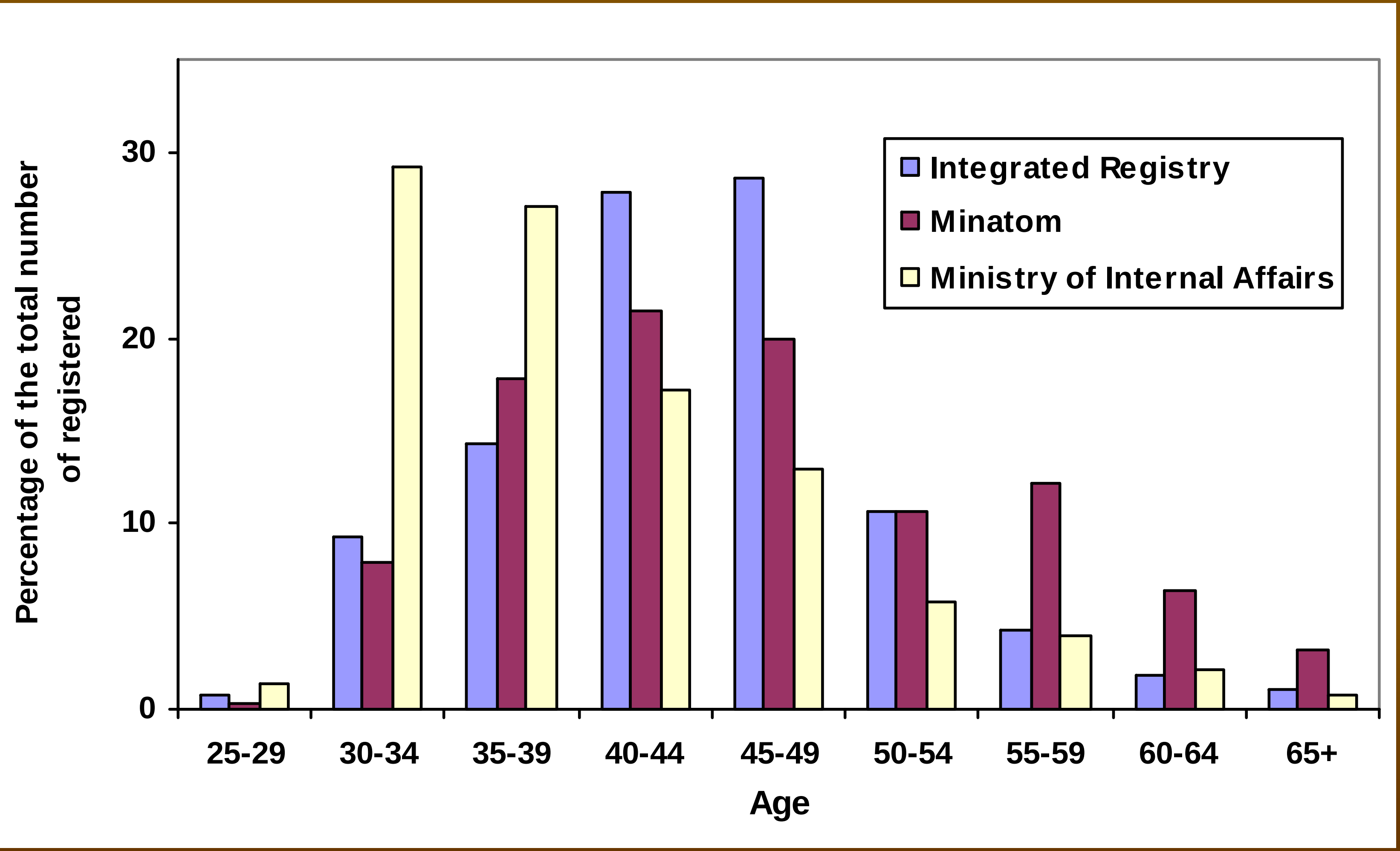
# STRUCTURE OF THE REGISTERED GROUPS



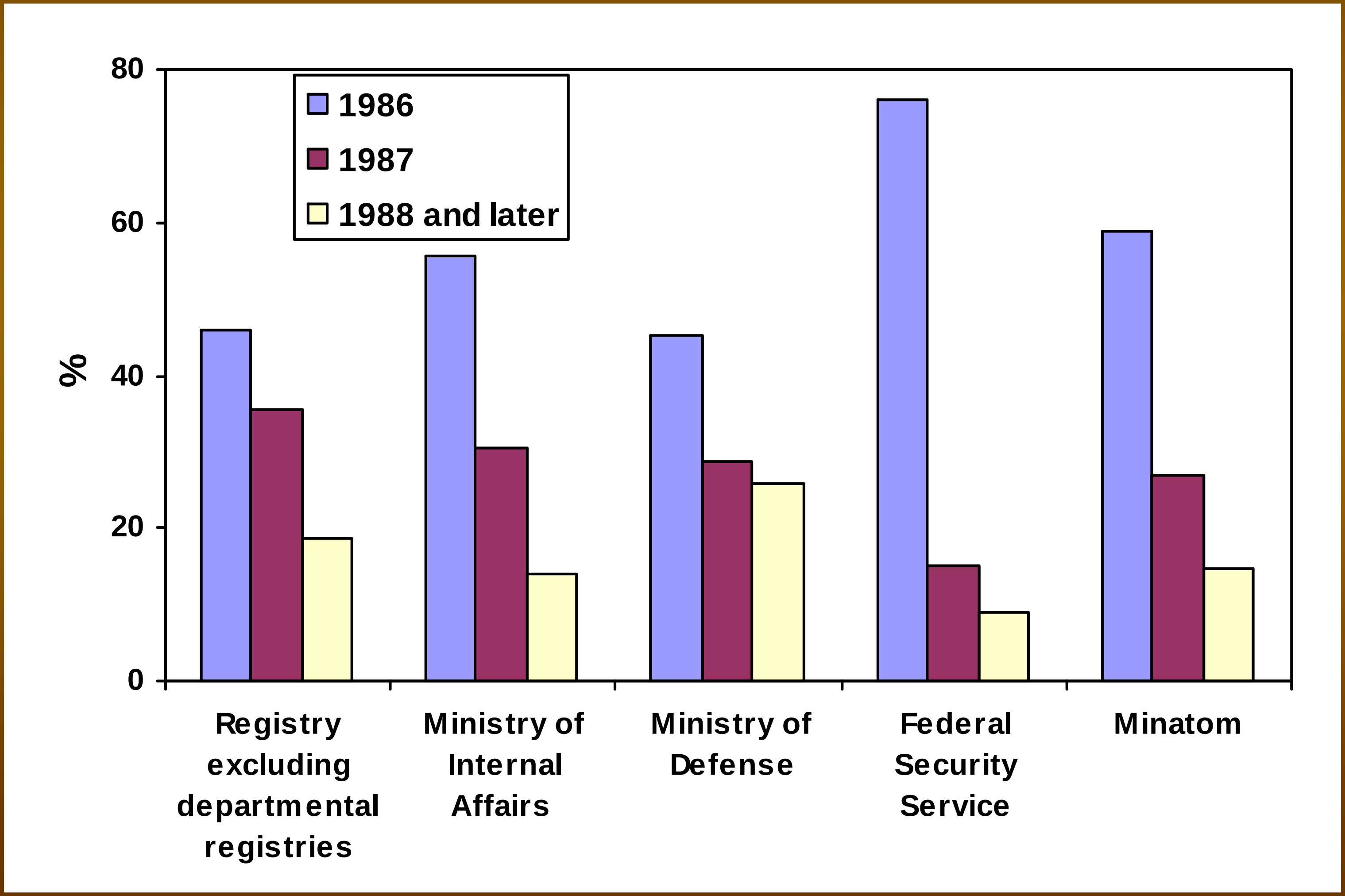
# OPERATIONS OF THE MAIN DATABASE OF THE REGISTRY AND SPECIALIZED SUB-REGISTRIES



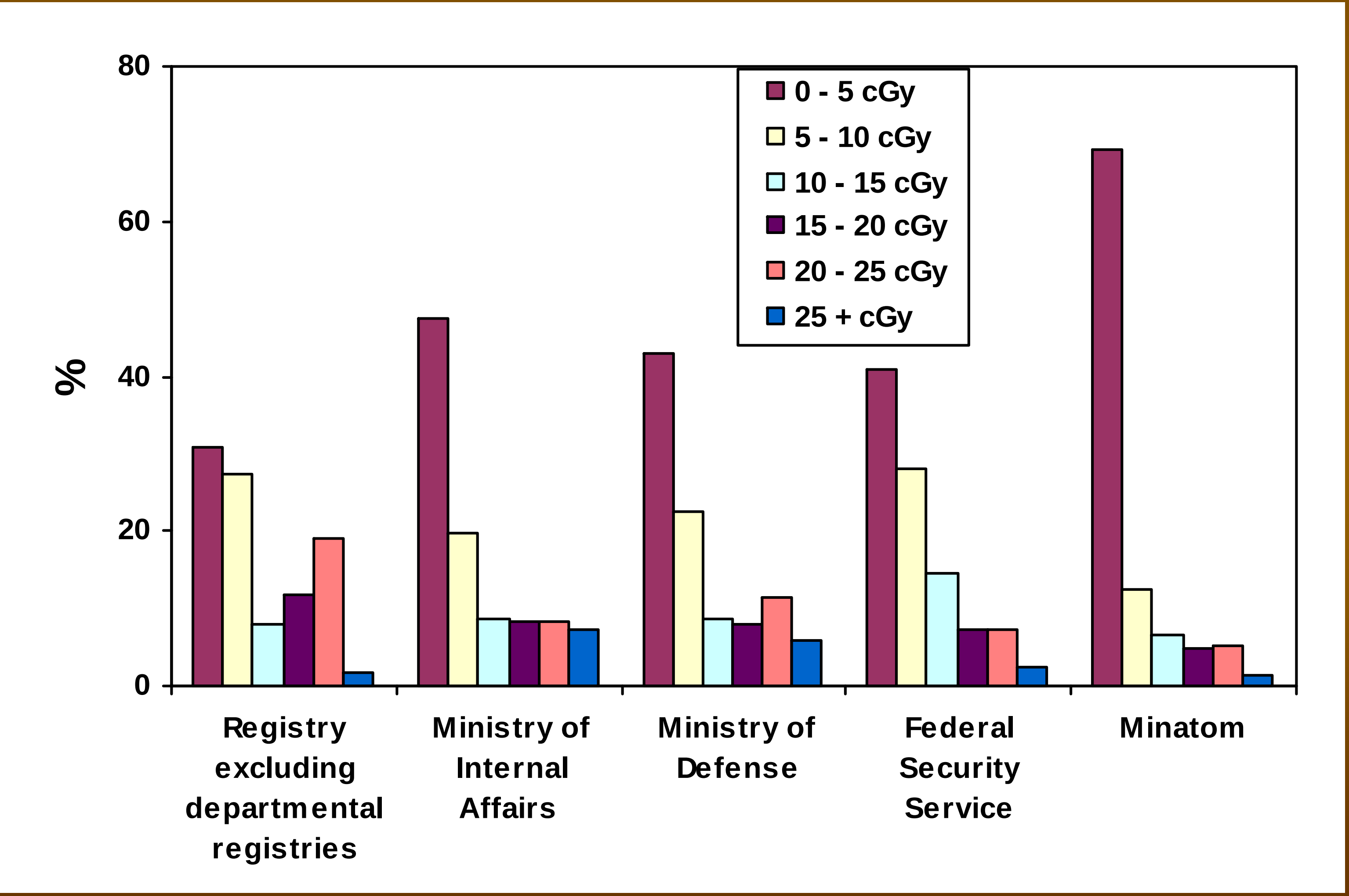
# AGE DISTRIBUTION OF EMERGENCY WORKERS REGISTERED IN THE RNMDR



# DISTRIBUTION OF EMERGENCY WORKERS REGISTERED IN THE RNMDR BY YEARS OF ARRIVAL TO THE ZONE



# DISTRIBUTION OF EMERGENCY WORKERS BY DOSE GROUPS



# PRESENTATION CONTENTS

A. National Registry.

B. *Solid cancers*.

C. Leukemias.

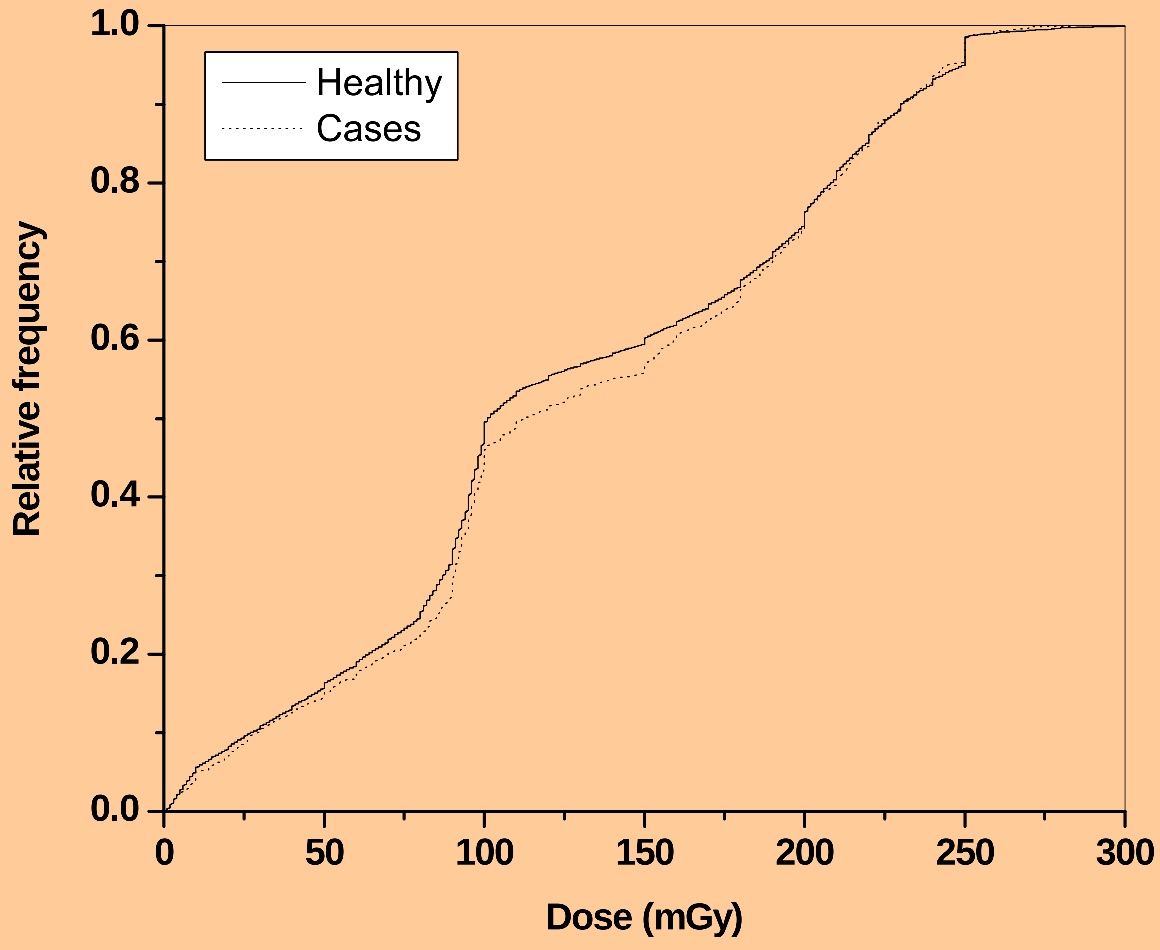
D. Non-cancer diseases.

# KEY CHARACTERISTICS FOR EMERGENCY WORKERS AS A FUNCTION OF WORKING TIME IN THE 30-KM ZONE

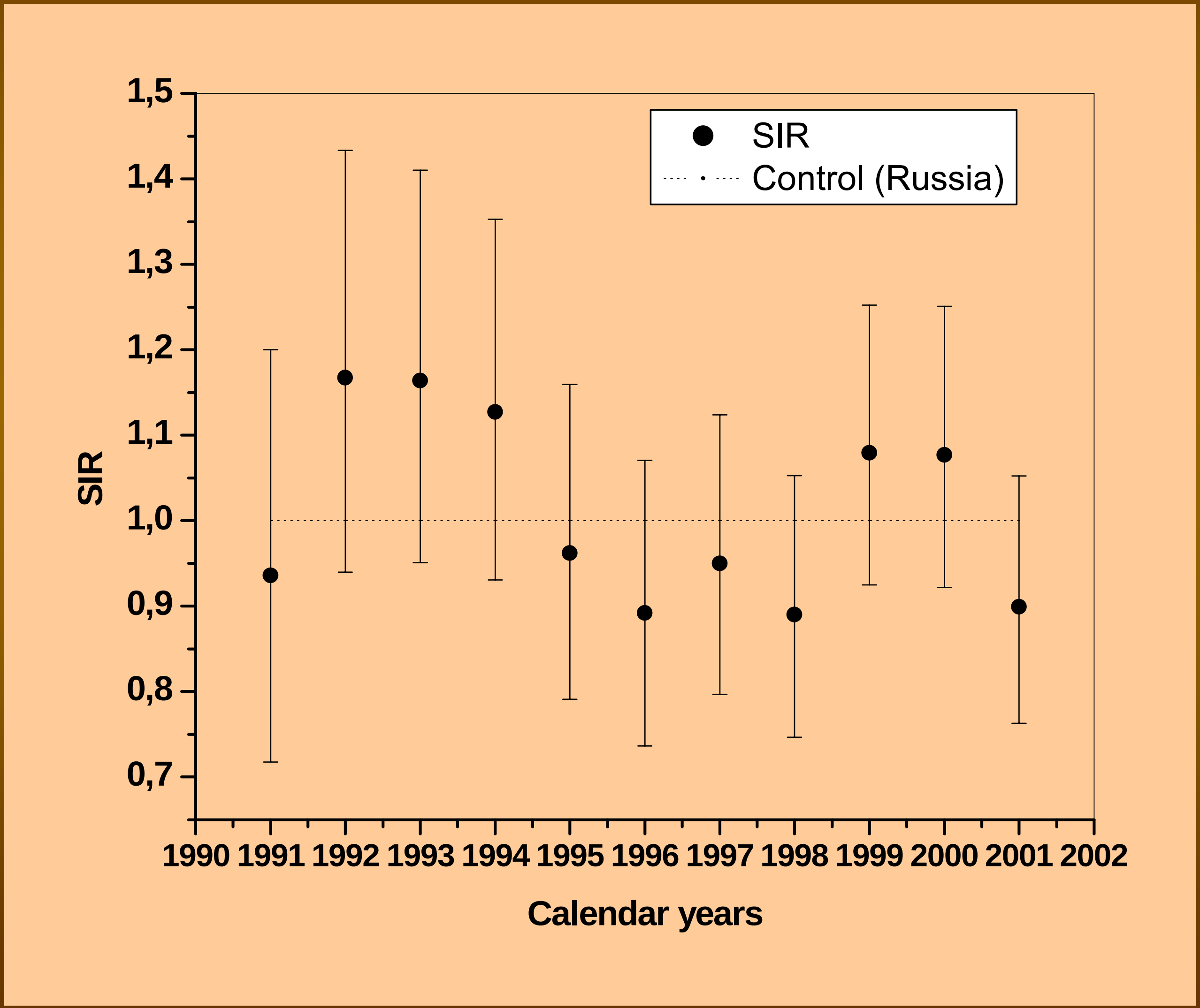
| Working time | Population (cases) | Mean attained age (years) | Mean dose (mGy)[a] | Mean duration of stay (days)[a] | Mean dose rate (mGy/day)[a] |
|---|---|---|---|---|---|
| 1986 | 27 236 (721) | 48.5 | 164.3 | 76.6 | 3.49 |
| 1987 | 28 484 (649) | 48.5 | 93.6 | 85.0 | 1.65 |
| 1986-1987 | 55 720 (1370) | 48.5 | 130.1 | 80.6 | 2.54 |

[a] Person-year weighted averages

# DISTRIBUTION OF EMERGENCY WORKERS BY DOSE



# DEPENDENCE OF SIR ON TIME (1991-2001)



# KEY CHARACTERISTICS OF THE COHORT UNDER STUDY BY DOSE GROUPS

**Follow-up period 1991-1995**

| Mean dose (mGy) | Observed | Person-years | Expected | SIR (95% CI) | RR (95% CI) |
|---|---|---|---|---|---|
| 21.2 | 80 | 43 142 | 82 | 0.98 (0.78, 1.21) | 1.0 |
| 79.0 | 105 | 65 719 | 123 | 0.86 (0.70, 1.03) | 0.87 (0.65, 1.15) |
| 102.1 | 111 | 51 131 | 97 | 1.15 (0.95, 1.38) | 1.17 (0.88, 1.56) |
| 152.5 | 64 | 26 699 | 62 | 1.04 (0.80, 1.31) | 1.30 (0.93, 1.79) |
| 193.7 | 124 | 43 972 | 98 | 1.27 (1.05, 1.50) | 1.52 (1.15, 2.02) |

SIR value for the follow-up period 1991-1995 is 1.03 (0.95, 1.12 95% CI, control, Russia
SIR value for unexposed emergency workers 0.94 (0.78, 1.12 95% CI)
$ERR_{1Gy}$=0.76 (-0.42, 2.41 95% CI) internal control (stratification by time and attained age)
$ERR_{1Gy}$=0.69 (-0.47, 2.28 95% CI) external control

# KEY CHARACTERISTICS OF THE COHORT UNDER STUDY BY DOSE GROUPS

**Follow-up period 1996-2001**

| Mean dose (mGy) | Observed | Person-years | Expected | SIR (95% CI) | RR (95% CI) |
|---|---|---|---|---|---|
| 21.1 | 120 | 42 105 | 135 | 0.94 (0.79, 1.12) | 1.0 |
| 78.9 | 191 | 61 234 | 203 | 0.94 (0.81, 1.08) | 1.03 (0.82, 1.28) |
| 102.1 | 143 | 48 384 | 161 | 0.88 (0.75, 1.04) | 0.98 (0.77, 1.24) |
| 152.4 | 103 | 25 111 | 96 | 1.07 (0.88, 1.29) | 1.35 (1.04, 1.75) |
| 193.7 | 142 | 40 570 | 152 | 0.94 (0.79, 1.10) | 1.15 (0.91, 1.46) |

SIR value for the follow-up period 1996-2001 is 0.95 (0.89, 1.01 95% CI, control, Russia
SIR value for unexposed emergency workers 0.92 (0.80, 1.06 95% CI)
$ERR_{1Gy}$=0.20 (-0.66, 1.30 95% CI) internal control (stratification by time and attained age)
$ERR_{1Gy}$=0.19 (-0.66, 1.27 95% CI) external control

# KEY CHARACTERISTICS OF THE COHORT UNDER STUDY BY DOSE GROUPS

Follow-up period 1991-2001

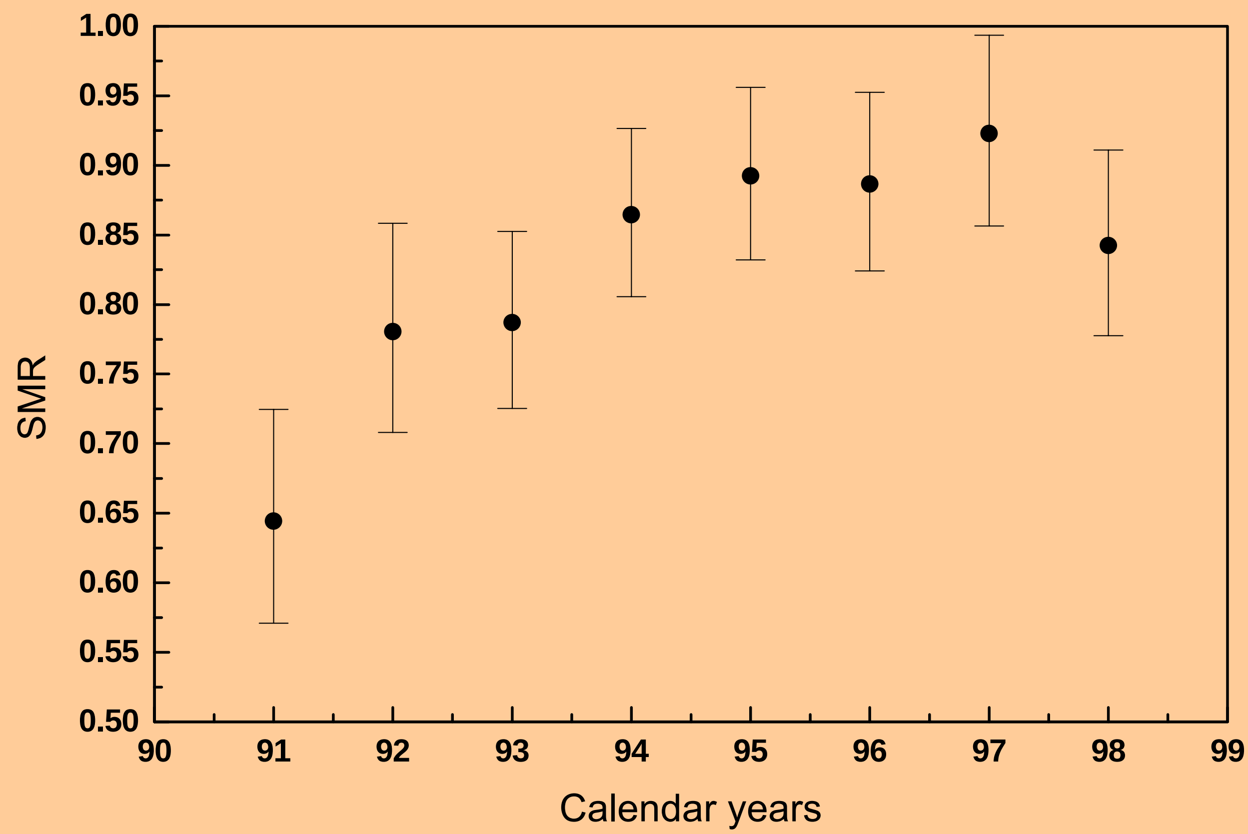
| Mean dose (mGy) | Observed | Person-years | Expected | SIR (95% CI) | RR (95% CI) |
|---|---|---|---|---|---|
| 21.1 | 195 | 77 781 | 196 | 0.99 (0.86, 1.14) | 1.0 |
| 78.9 | 274 | 115 984 | 294 | 0.93 (0.83, 1.04) | 0.94 (0.78, 1.13) |
| 102.1 | 234 | 90 924 | 233 | 1.00 (0.82, 1.13) | 1.03 (0.85, 1.24) |
| 152.5 | 151 | 47 311 | 142 | 1.06 (0.90, 1.24) | 1.27 (1.03, 1.57) |
| 193.7 | 243 | 77 230 | 225 | 1.08 (0.95, 1.22) | 1.25 (1.04, 1.52) |

SIR value for the follow-up period 1991-2001 is 1.00 (0.95, 1.06 95% CI, control, Russia
SIR value for unexposed emergency workers 0.96 (0.85, 1.07 95% CI)
$ERR_{1Gy}$=0.34 (-0.39, 1.22 95% CI) internal control (stratification by time and attained age)
$ERR_{1Gy}$=0.34 (-0.39, 1.24 95% CI) external control

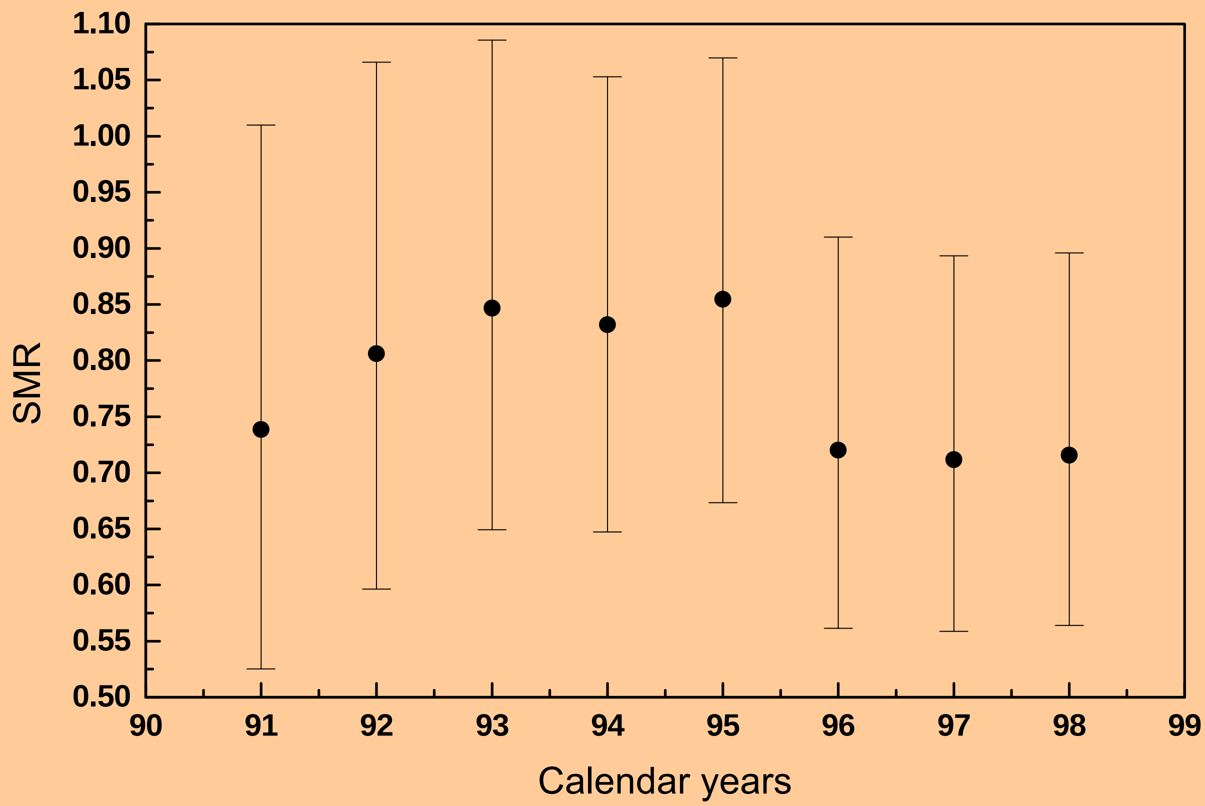
# NUMBER OF DEATHS FOR MAIN MORTALITY CLASSES

| All causes | Malignant neoplasms | Non-cancer causes of death | | | |
|---|---|---|---|---|---|
| | | Circulatory system diseases | Injuries and poisoning | Other | Total number of non-cancer death |
| 4 995 | 515 | 1 728 | 1 858 | 894 | 4 480 |

# SMR TIME TREND FROM ALL CAUSES



# SMR TIME TREND FROM MALIGNANT NEOPLASMS



# ESTIMATES OF RISK COEFFICIENT FOR MORTALITY FROM MALIGNANT NEOPLASMS AMONG EMERGENCY WORKERS

| Risk coefficient | Value (95% confidence interval) |
|---|---|
| ERR/Sv | 2.11 (1.31, 2.92) |
| Coefficient *f* | 0.70 (0.64, 0.76) |
| Number of deaths | 515 |

# PRESENTATION CONTENTS

A. National Registry.

B. Solid cancers.

C. *Leukemias*.

D. Non-cancer diseases.

# RADIATION RISKS OF LEUKEMIAS IN EMERGENCY WORKERS

| Follow-up period | 1986-1996 | | | | 1997-2003 | | | |
|---|---|---|---|---|---|---|---|---|
| Dose groups, mGy | 0- | 45- | 90- | 150-300 | 0- | 45- | 90- | 150-300 |
| Mean doses, mGy | 17 | 66 | 106 | 215 | 17 | 65 | 106 | 215 |
| Number of leukemia cases | 11 | 3 | 5 | 22 | 9 | 7 | 5 | 9 |
| Relative risk (90% CI) | 1.0<br>- | 0.4<br>(0.1, 1.0) | 0.4<br>(0.1, 1.0) | 1.4<br>(0.8, 2.6) | 1.0<br>- | 1.1<br>(0.5, 2.6) | 0.6<br>(0.2, 1.5) | 0.9<br>(0.3, 1.8) |
| Comparison of two groups (90% CI) | 1<br>- | | | 2.2<br>(1.3, 3.8) | 1<br>- | | | 0.9<br>(0.5, 1.5) |
| Excess relative risk per 1 Gy (90% CI) | 4.4 (0.0, 16.4) | | | | -1.0 (-3.0, 3.6) | | | |

## PRESENTATION CONTENTS

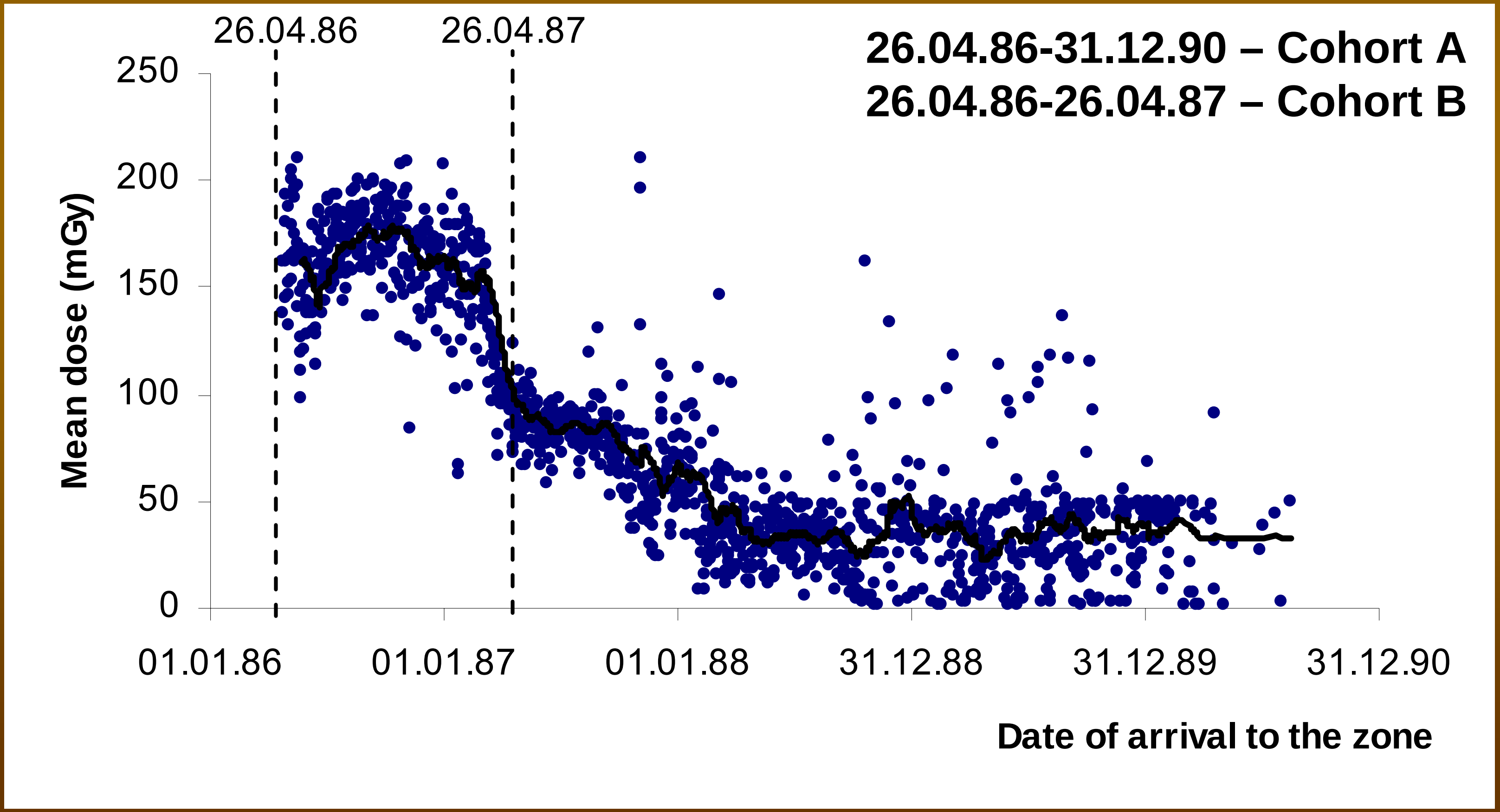
A. National Registry.

B. Solid cancers.

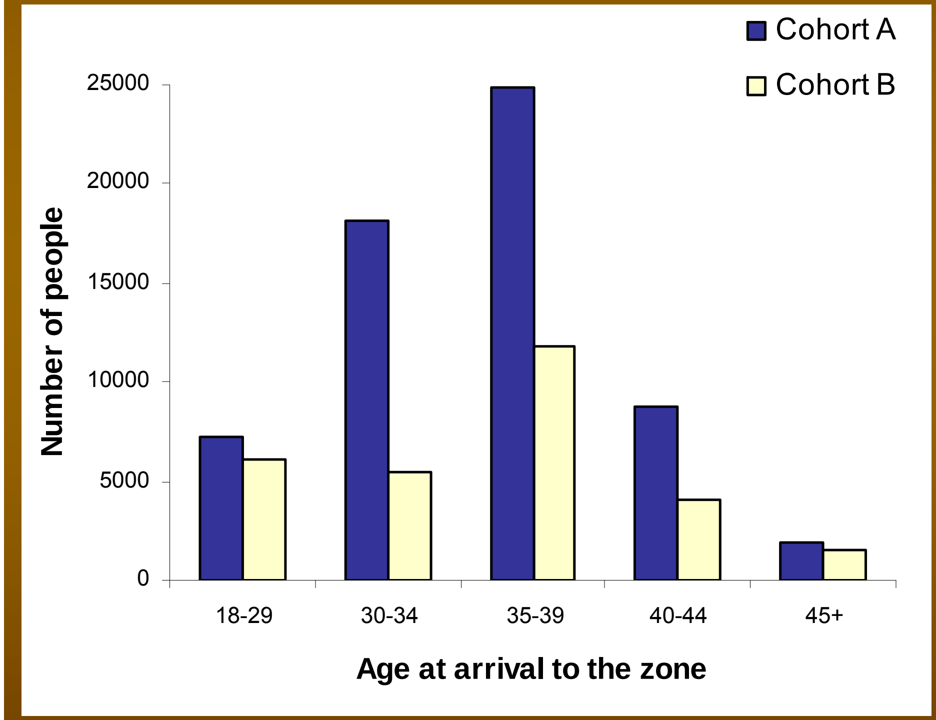
C. Leukemias.

D. *Non-cancer diseases*.

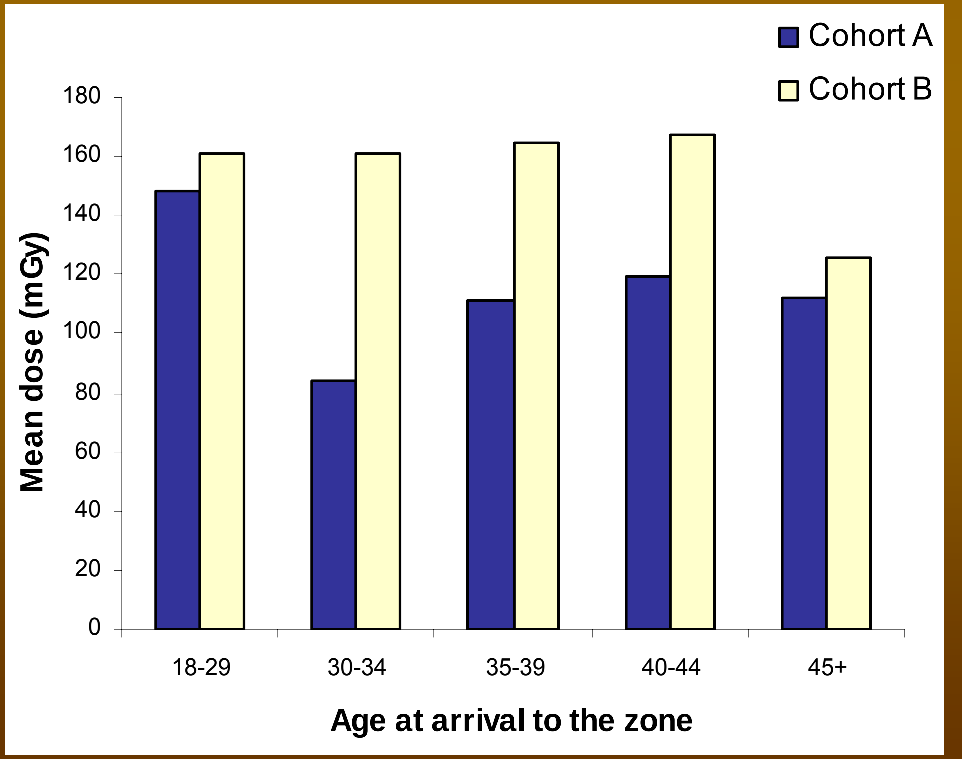
# MEAN DOSE RECEIVED BY EMERGENCY WORKERS AS A FUNCTION OF THE DATE OF ARRIVAL TO THE 30-KM ZONE



# DISTRIBUTION OF EMERGENCY WORKERS AND MEAN DOSE BY AGE GROUPS OF EMERGENCY WORKERS




**26.04.86-31.12.90 – Cohort A**
**26.04.86-26.04.87 – Cohort B**



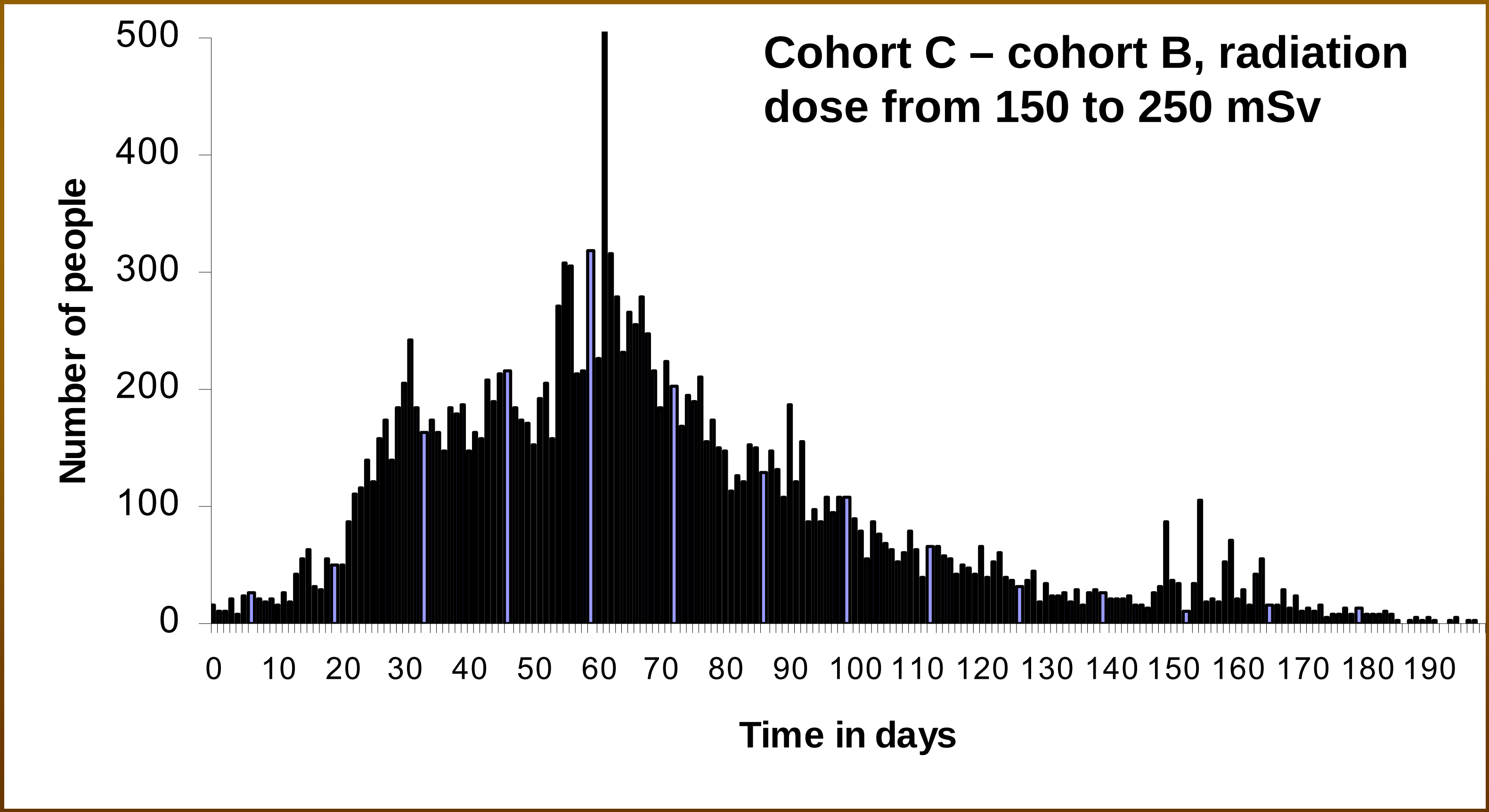
# ESTIMATES OF DEPENDENCE OF DISEASES OF THE CIRCULATORY SYSTEM ON DOSE IN EMERGENCY WORKERS

| Disease | ICD-10 | Cohort A | | | Subcohort B | | |
|---|---|---|---|---|---|---|---|
| | | Number of cases | *p* | ERR/Gy 95% CI | Number of cases | *p* | ERR/Gy 95% CI |
| Diseases of the circulatory system | I00-I99 | 32 189 | 0.08 | 0.18<br>-0.03; 0.39 | 16559 | 0.93 | 0.01<br>-0.21; 0.23 |
| Diseases associated with increased blood pressure | I10-I15 | 15 484 | 0.08 | 0.26<br>-0.04; 0.56 | 8238 | 0.33 | 0.16<br>-0.18; 0.50 |
| Essential hypertension | I10 | 11 910 | 0.04 | 0.36<br>0.005; 0.71 | 6338 | 0.31 | 0.20<br>-0.19; 0.59 |
| Hypertensive heart disease | I11 | 7 680 | 0.85 | 0.04<br>-0.36; 0.44 | 4190 | 0.82 | 0.05<br>-0.41; 0.52 |
| Ischaemic heart disease (IHD) | I20-I25 | 10 942 | 0.02 | 0.41<br>0.05; 0.78 | 6116 | 0.59 | 0.10<br>-0.29; 0.49 |
| Acute myocardial infarction | I21 | 948 | 0.74 | 0.19<br>-0.99; 1.37 | 534 | 0.62 | 0.31<br>-0.15; 0.86 |
| Other acute IHD | I24 | 849 | 0.22 | 0.82<br>-0.62; 2.26 | 471 | 0.11 | 1.39<br>-0.59; 3.37 |
| Angina pectoris | I20 | 6 613 | 0.24 | 0.26<br>-0.19; 0.71 | 3763 | 0.99 | -0.004<br>-0.48; 0.48 |
| Chronic IHD | I25 | 7 021 | 0.34 | 0.20<br>-0.23; 0.63 | 4032 | 0.93 | -0.02<br>-0.48; 0.44 |
| Other heart diseases | I30-I52 | 3 572 | 0.35 | -0.26<br>-0.81; 0.28 | 1841 | 0.30 | -0.33<br>-0.94; 0.28 |
| Cerebrovascular diseases | I60-I69 | 12 832 | <0.01 | 0.45<br>0.11; 0.80 | 6997 | 0.04 | 0.39<br>0.004; 0.77 |
| Diseases of arteries, arterioles and capillaries | I70-I79 | 3 934 | 0.10 | 0.47<br>-0.15; 1.09 | 2267 | 0.36 | 0.29<br>-0.38; 0.97 |
| Diseases of veins, lymphatic vessels and lymph nodes | I80-I89 | 5 572 | 0.25 | -0.26<br>-0.70; 0.18 | 2942 | 0.02 | -0.57<br>-1.03; -0.12 |

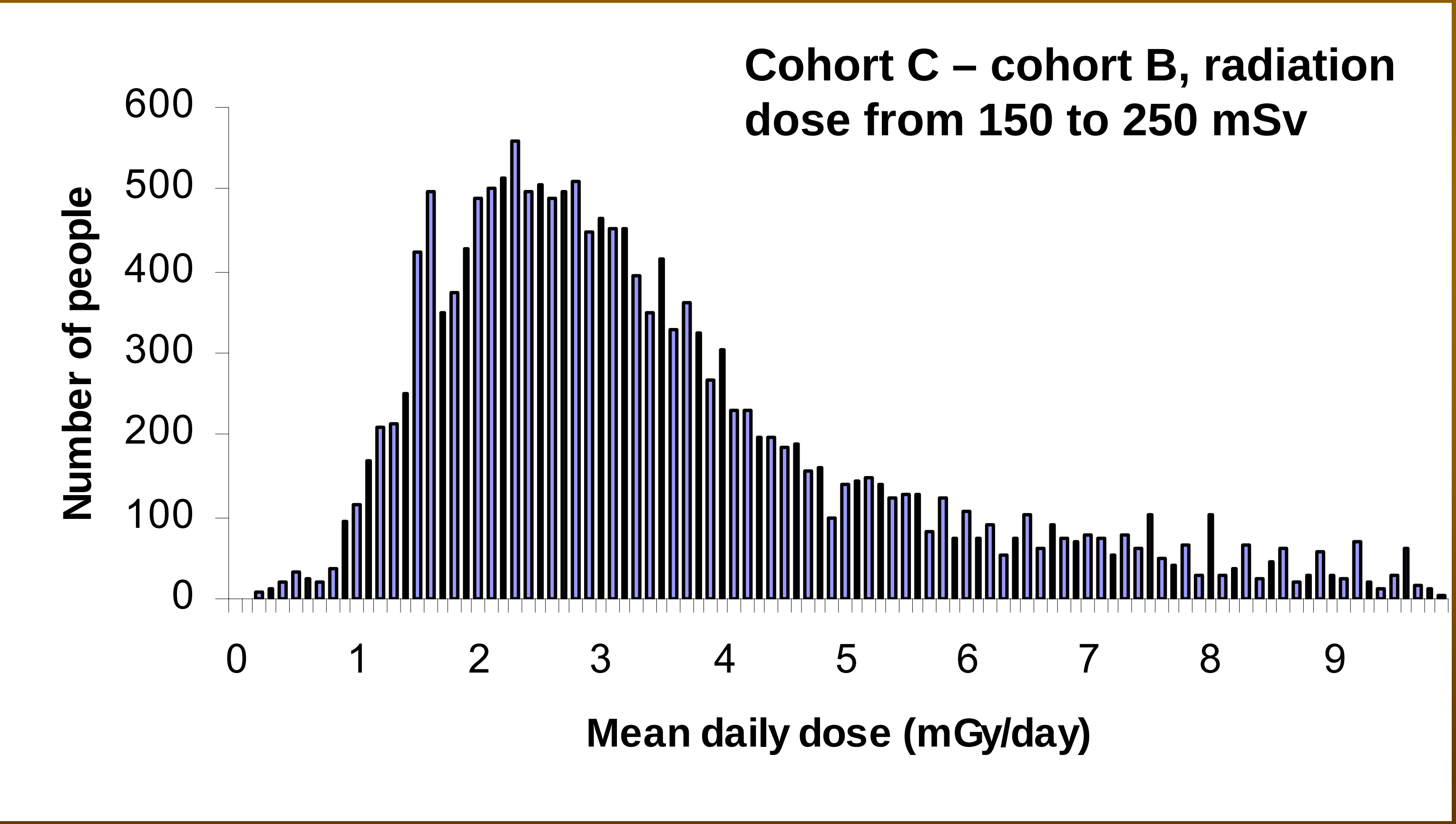
# RELATIVE RISK OF CEREBROVASCULAR DISEASES AS A FUNCTION OF DOSE AND LENGTH OF STAY IN THE 30-KM ZONE OF THE CHNPP

| External radiation dose, mGy | Length (weeks) of stay in the 30-km zone | | |
|---|---|---|---|
| | < 6 | 6 – 12 | > 12 |
| > 150 | 1.18 (1.00; 1.40) | 1.02 (0.86; 1.20) | 1.00 (0.84; 1.19) |
| 50 – 150 | 1.03 (0.88; 1.20) | 0.99 (0.83; 1.17) | 0.90 (0.79; 1.04) |
| < 50 | 0.92 (0.78; 1.11) | 0.97 (0.84; 1.12) | 1 |

# DISTRIBUTION OF EMERGENCY WORKERS OF THE COHORT C BY TIME SPENT IN THE 30-KM ZONE

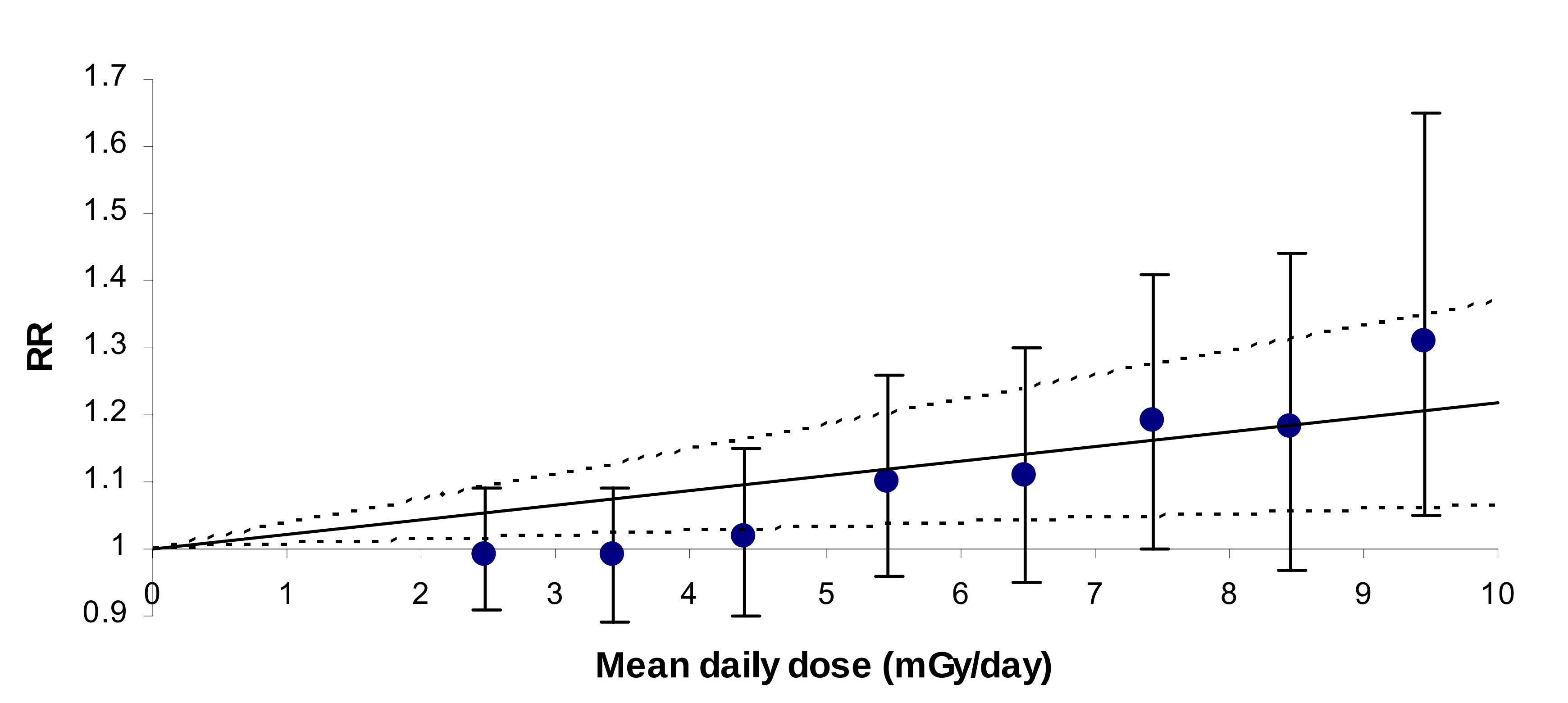


# DISTRIBUTION OF EMERGENCY WORKERS OF THE COHORT C BY MEAN DAILY DOSE



# RELATIVE RISK (RR) OF CEREBROVASCULAR DISEASES IN DIFFERENT DOSE GROUPS FOR EMERGENCY WORKERS OF THE COHORT C

**Cohort C – cohort B, radiation dose from 150 to 250 mSv**



# Main sources and pathways of occupational exposure of workers inside the Object Shelter

**External exposure:**

- Gamma-field from long-lived fission radionuclides - gamma-emitters (mainly $^{137}Cs$, $^{60}Co$ and others).
- Distance beta exposure of open skin area and eye lenses

**Internal exposure:**

- Fuel containing material (FCM) with total fuel-radionuclide activity: about $5.2 \cdot 10^5$ TBq (14 MKi)
- Inhalation of fission radionuclides beta-emitters and fuel aplha-emitters (mainly $^{238,239,240}Pu$, $^{241}Am$)
- Ingestion of radionuclides concerning swallowing during skin contamination

# MAIN PROBLEMS

- Classification of critical works
- Individual Means of Protection
- Types of radiological control, investigation levels and criteria for radiation-hygiene decisions
- Some results of the radiological control

*Classification of critical works*

## Main works, carried out at present time within framework of stabilization phase in 2004-2006 yy.

- Strengthening of unstable covering
- Strengthening of west and east support of "Elephant" beam
- Creation of basement for metal-constructions for beams B1, B2 reinforcement
- Cutting of apertures for metal-constructions in west counterfort wall and roof
- Mounting of metal-constructions of B1, B2 beams reinforcement
- Installation of metal-constructions at 4-th cascade of north wall

# Classification of critical works

## CRITICAL WORK TYPES

Within framework of five main tasks for stabilization phase, 5 radiologically critical types of works are carried out

| Type | Description of the work |
|---|---|
| 1 | Electric welding |
| 2 | Assembling works, clearing of work area (without types 1 and 5) |
| 3 | Work place preparation |
| 4 | Drilling, boring, battering |
| 5 | Abrasive cutting of metal |

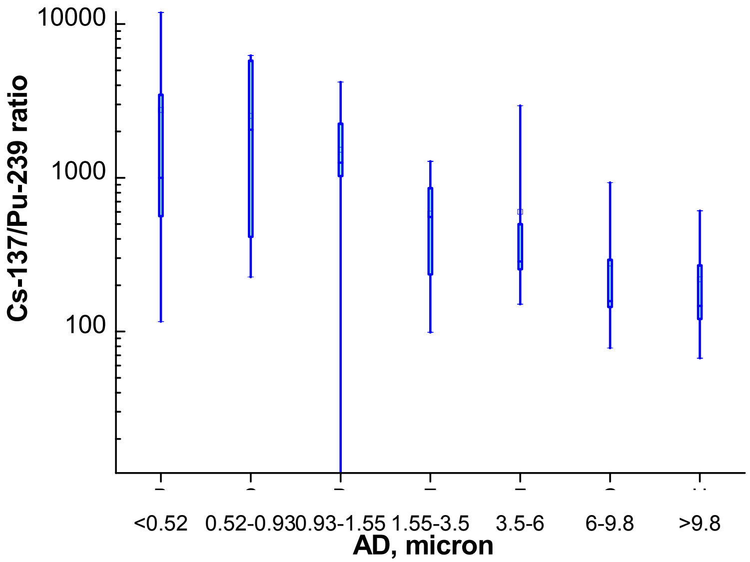
# Main forms of radiological control

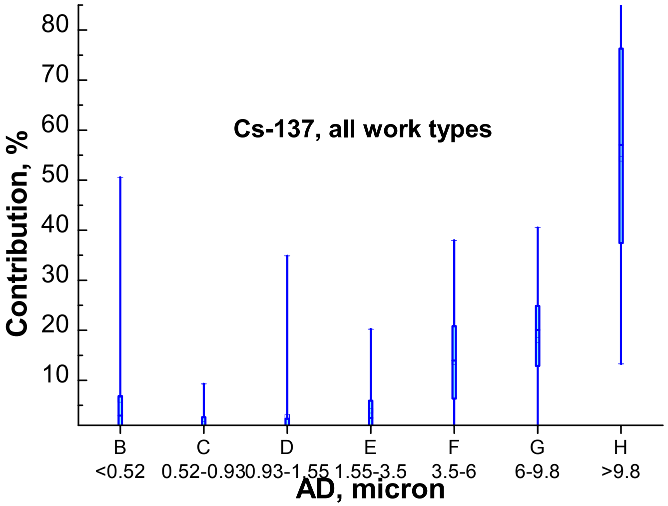
- Individual routine shift control of external gamma exposure
- Control of radioaerosols dispersion and air concentration
- Whole-Body Counters (WBC) control of $^{137}Cs$ body burden
- Control of fuel-radionuclide daily excretion based on radio-chemical and alpha-spectrometrical analysis of samples
- “Nose swab” daily individual control of fuel and fission radionuclides contamination

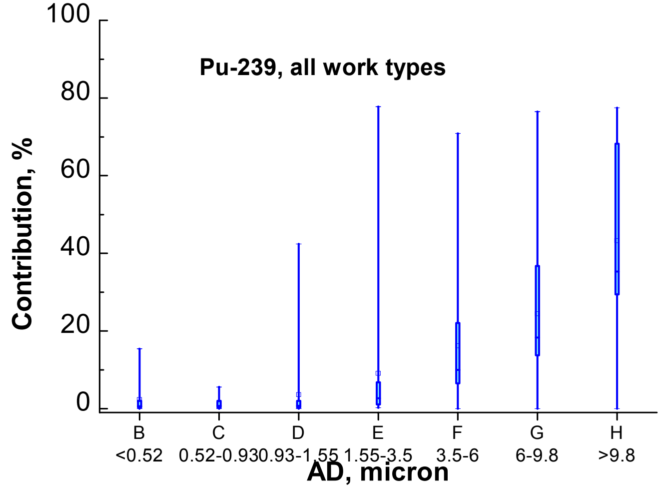
## *Some results of the radiological control*

# AEROSOL MONITORING WITHIN FRAMEWORK OF THE OPERATIONAL CONTROL

Equipment for air sampling during operational control:
*Marple personal impactor 290S*



**Investigation levels and criteria for radiation-hygiene decisions**

# General scheme of carrying out of IDC of internal exposure of SIP personnel

$i$ – day of the shift

DIL – derived investigation level (the level of the initiation of the special control)

UC – urgent control

The level of $^{137}$Cs content in the body (WBC control):

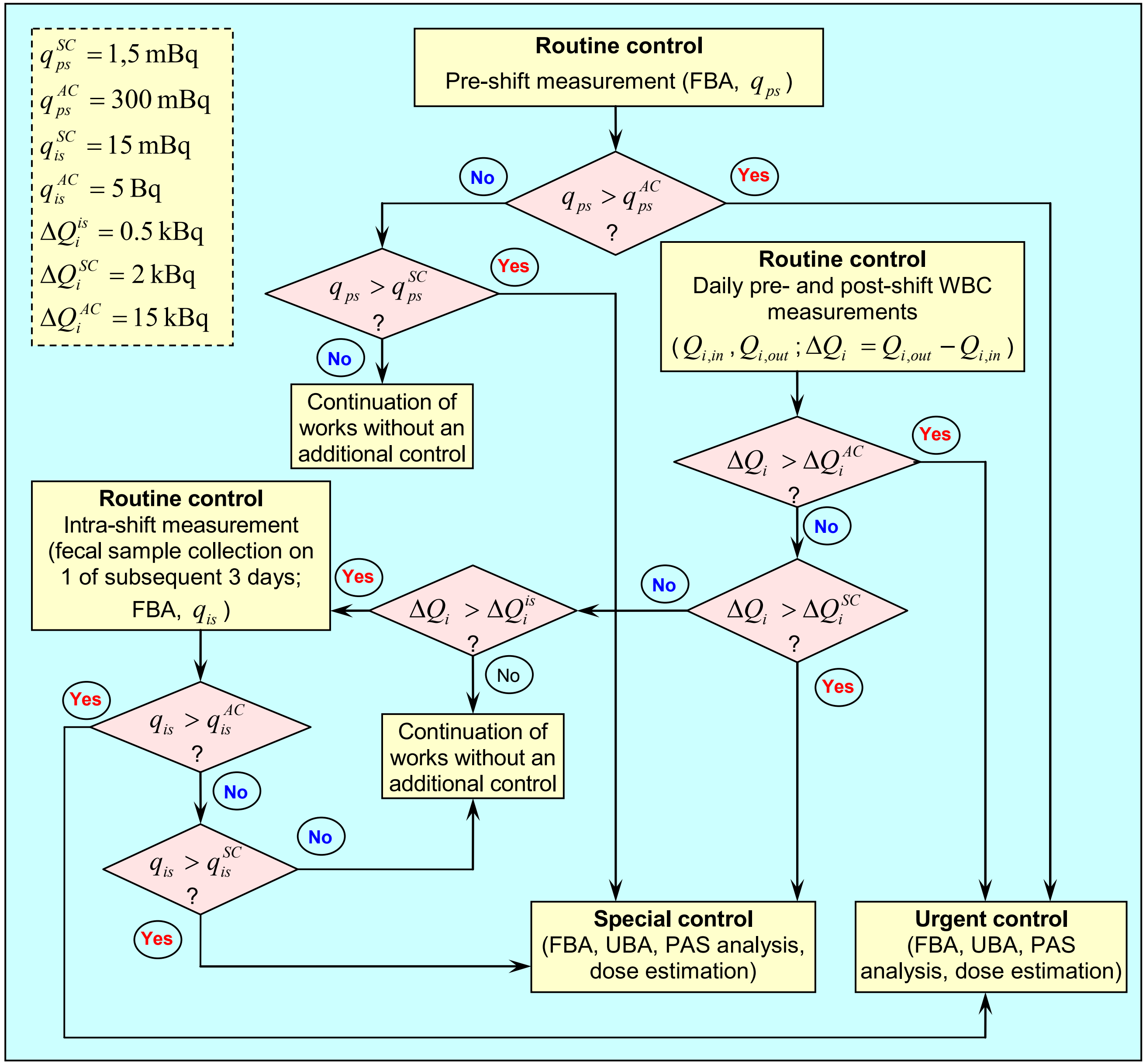
- $Q_{i,in}$ – daily pre-shift control
- $Q_{i,out}$ – daily post-shift control
- $\Delta Q_i = Q_{i,out} - Q_{i,in}$ – an elevation of the daily content
- $\Delta Q_i^{is}$ – the level of initiation of the intra-shift control of a fecal sample
- $\Delta Q_i^{SC}$ – DIL
- $\Delta Q_i^{AC}$ – the level of initiation of UC

Control of the $^{239+240}$Pu content in daily samples:

- FBA – fecal sample
- UBA – urine sample

The level of $^{239+240}$Pu content in the daily fecal samples:

- $q_{ps}$ – pre-shift control
- $q_{is}$ – intra-shift control
- $q_{ps}^{SC}$ – DIL for the pre-shift control
- $q_{ps}^{AC}$ – the level of initiation of UC by results of the pre-shift control
- $q_{is}^{SC}$ – DIL for the intra-shift control
- $q_{is}^{AC}$ – the level of initiation of UC by results of the intra-shift control



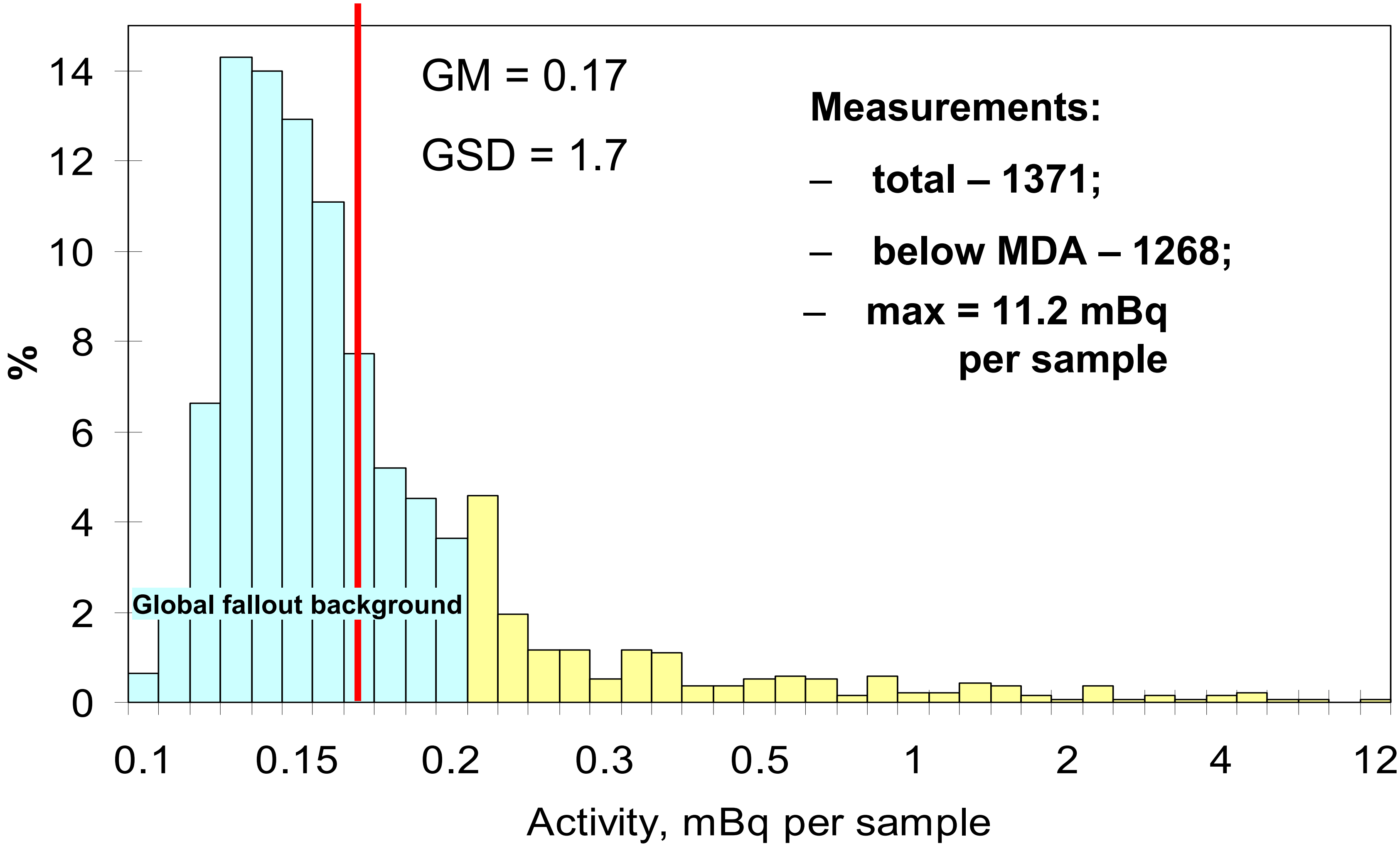
*Some results of the radiological control*

# Total numbers of measurements within framework of biophysical control

| | Fecal samples | Urine samples | WBC | Smears |
|---|---|---|---|---|
| Check-in control | 1 371 | | 2 267 | |
| Routine control | 1 807 | | | 15 472 |
| Special control | 765 | 303 | 303 | |

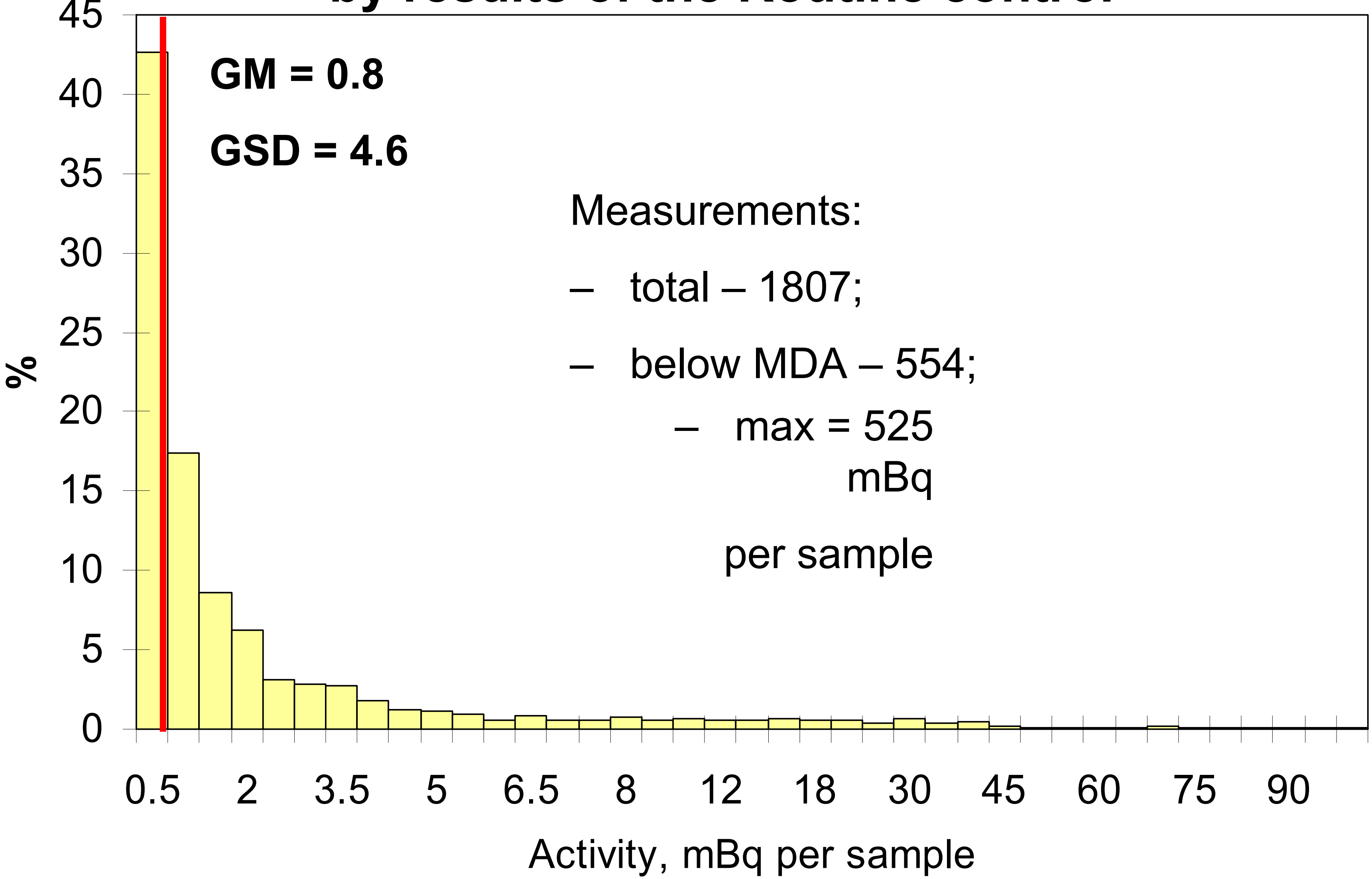
*Some results of the radiological control*

# Distribution of fecal samples contamination with Pu-239 by results of the Check-in control



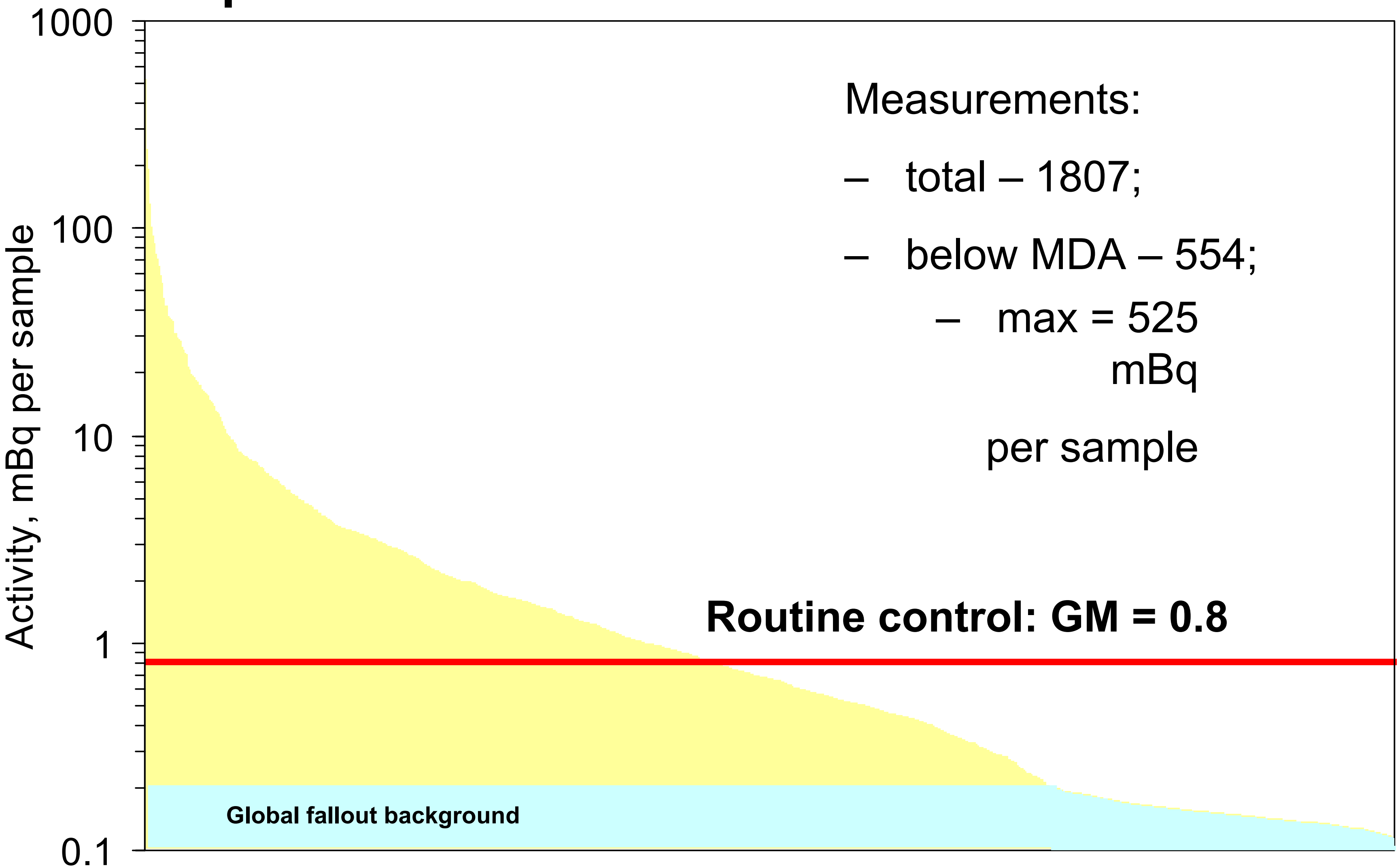
***Some results of the radiological control***

# Distribution of fecal samples contamination with Pu-239 by results of the Routine control



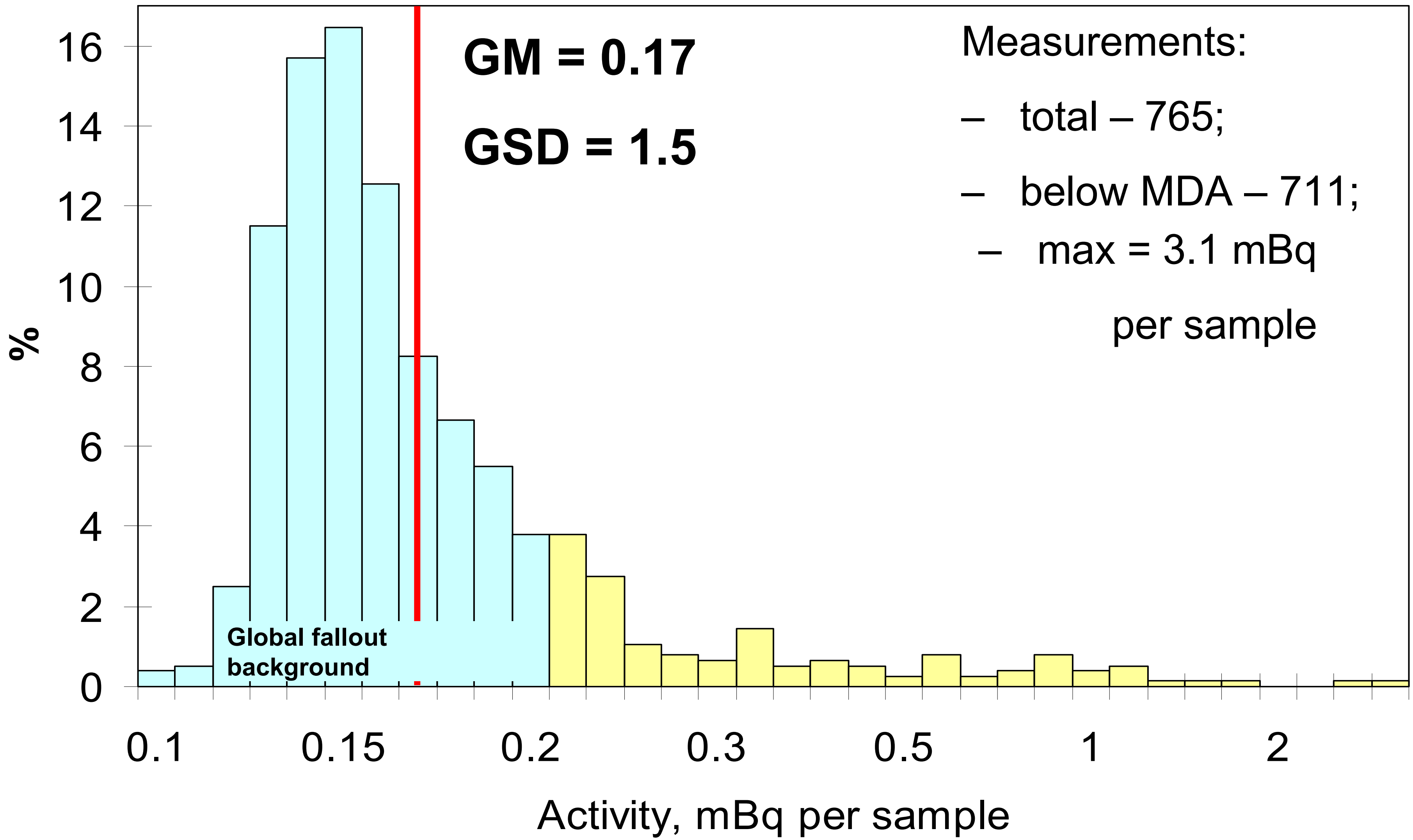
*Some results of the radiological control*

# Results of measurements of Pu-239 content in fecal samples within a framework of the Routine control



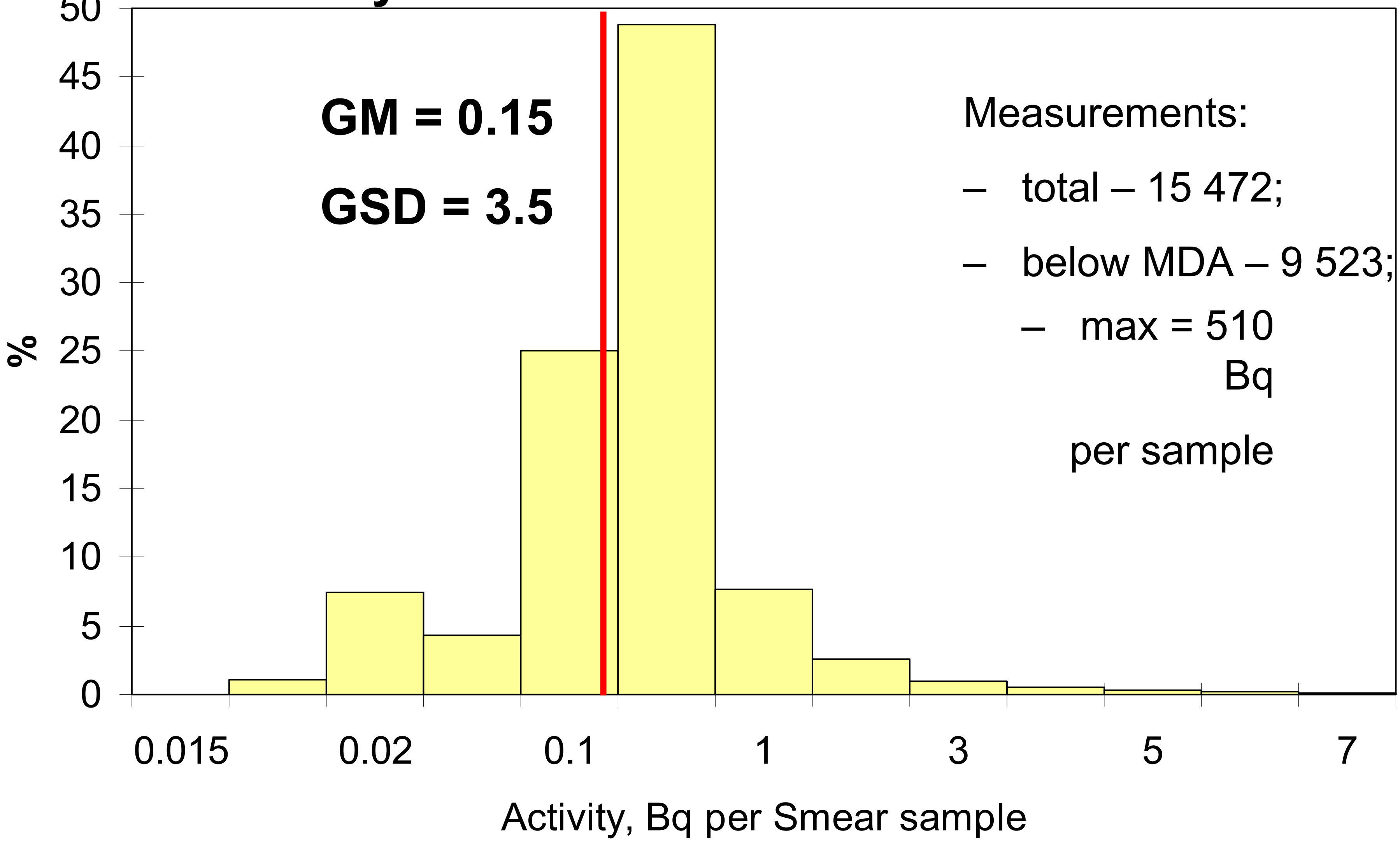
*Some results of the radiological control*

# Distribution of fecal samples contamination with Pu-239 by results of the Special control



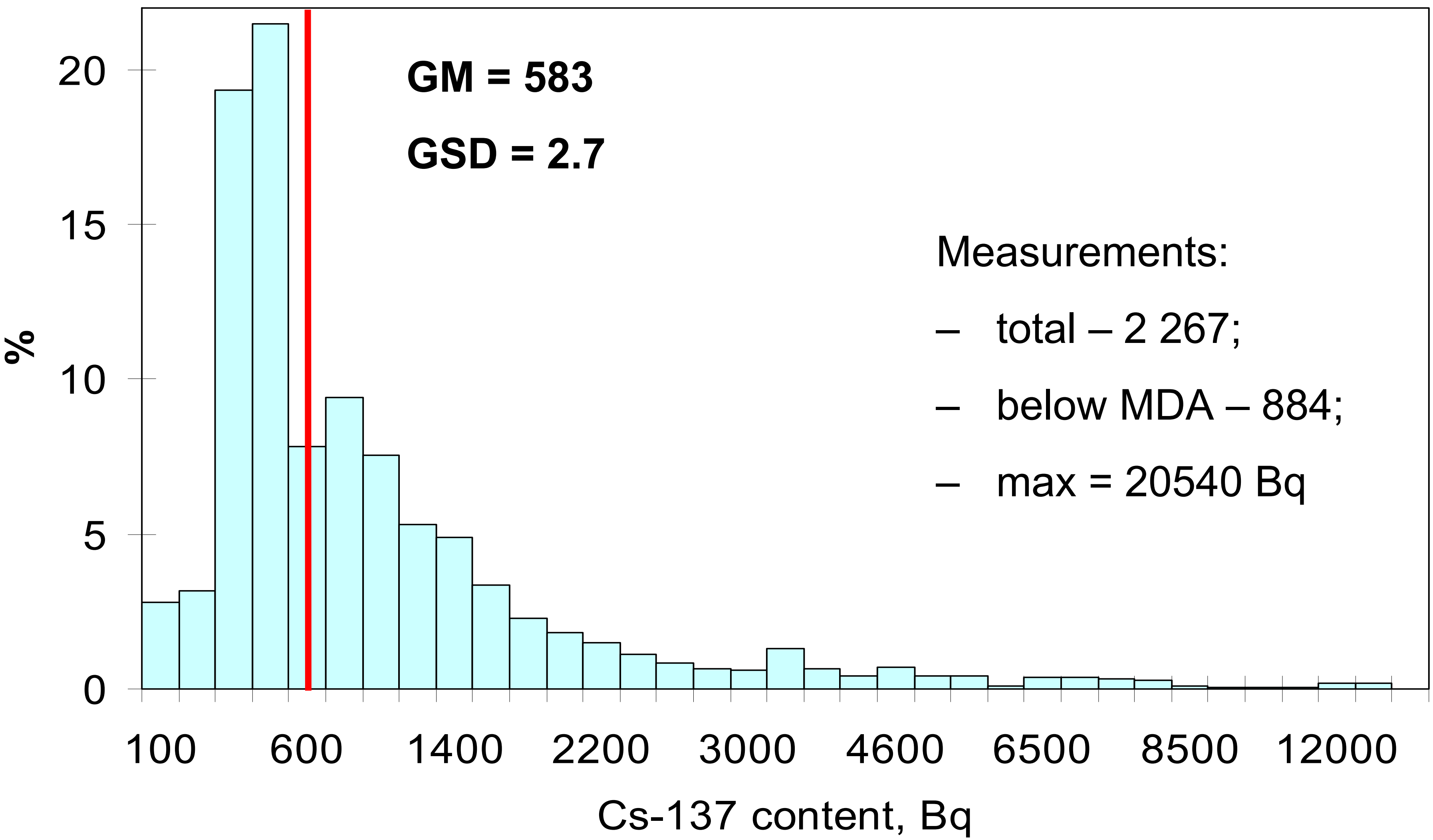
*Some results of the radiological control*

# Distribution of nose swabs β-activity by results of the Routine control



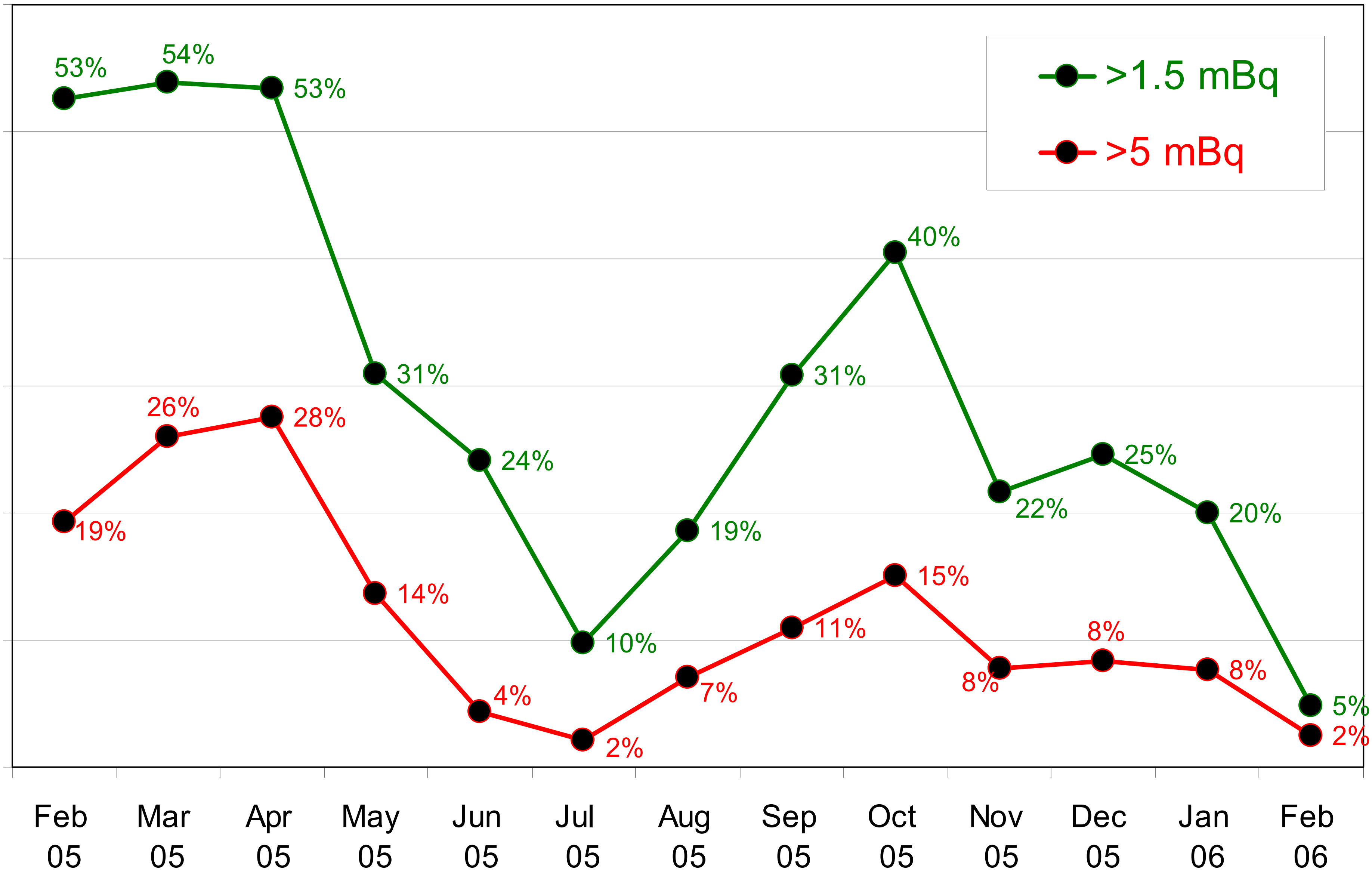
*Some results of the radiological control*

# Distribution of WBC measurements of Cs-137 content by results of the Check-in control ("Chernobyl background")



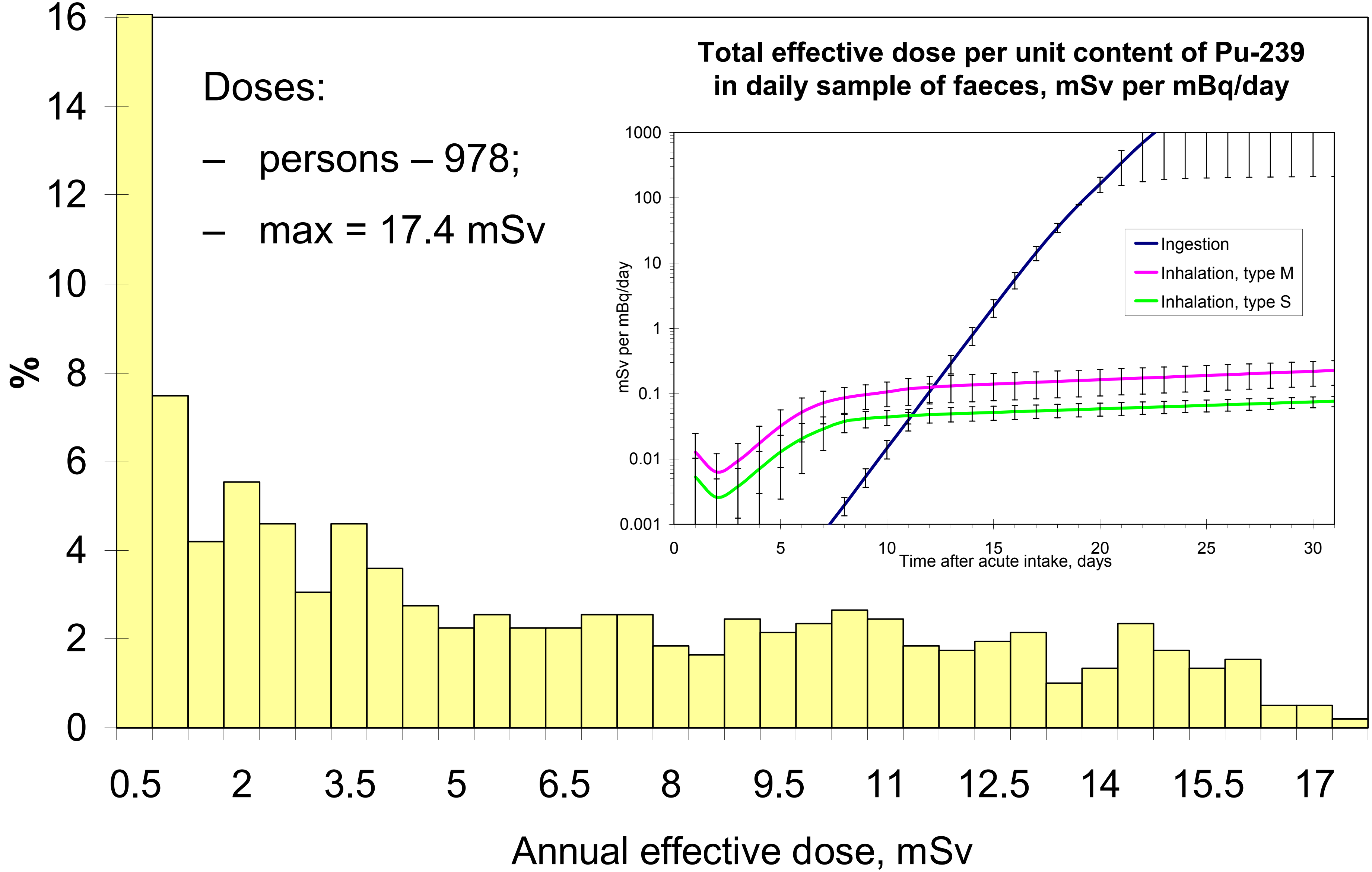
## Some results of the radiological control

**The percent of fecal samples with Pu-239 contamination over derived investigation levels 1.5 mBq per sample and 5 mBq per sample (Routine biophysical control)**



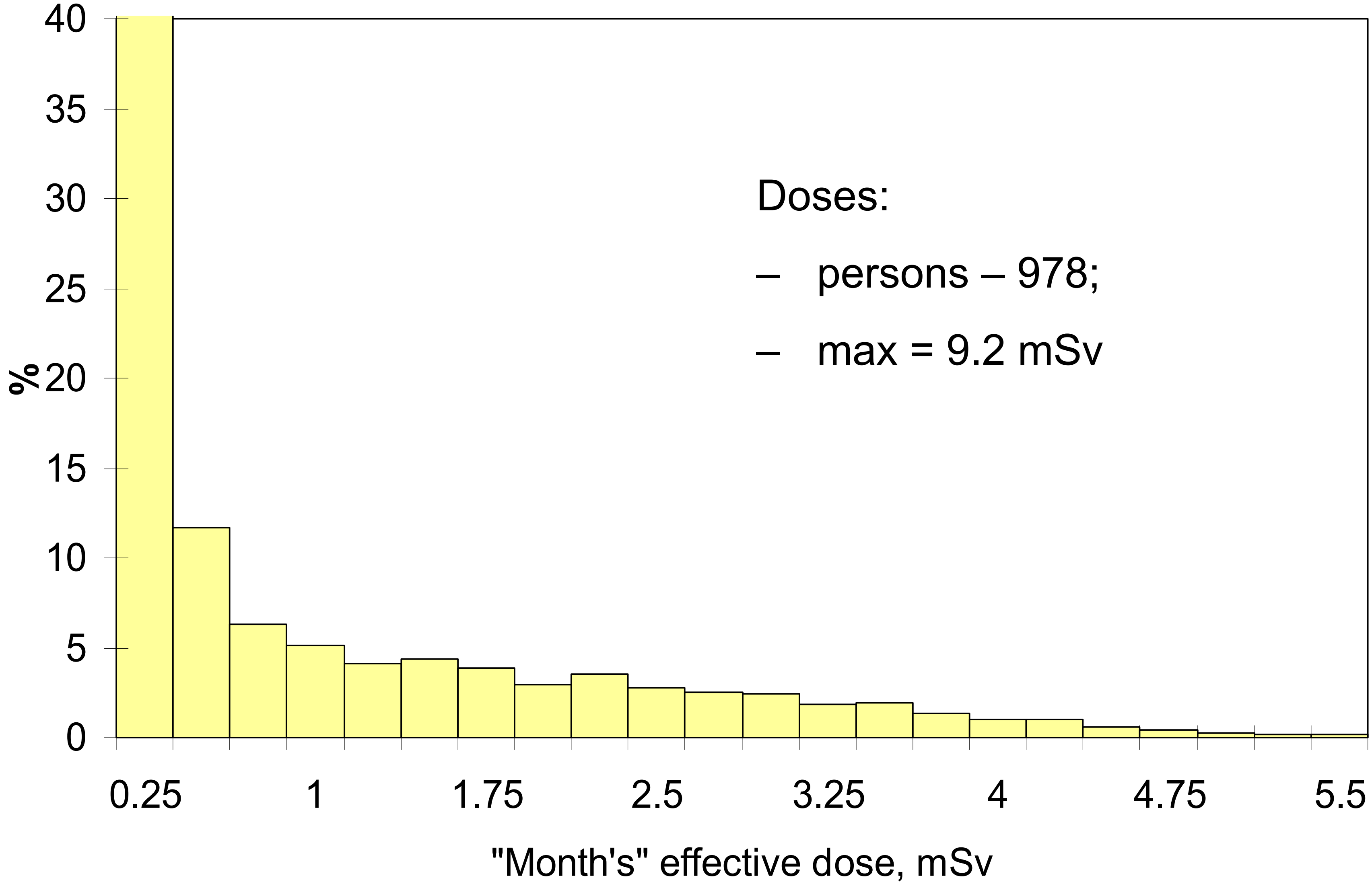
***Some results of the radiological control***

# Distribution of annual effective doses



***Some results of the radiological control***

# Distribution of “month’s” effective doses



# Preliminary conclusions

1. System of check-in, routine, operational and special control of internal exposure doses for SIP personnel is developed and functioning.
2. Established set of investigation levels and criteria for radiation hygienic decisions provides rather low internal doses.
3. Reasonable combination of daily pre- and post-shift WBC measurement of $^{137}Cs$ body burden with control of $^{239}Pu$ contamination excretion samples is realized.
4. Two next directions of improvement of control system are proprietary:
   - operational control of radioaerosol solubility types (“Lung Classes”)
   - special management of sample collection for decreasing probability of their external contamination.

NCRP Annual Meeting
3 April 2006

# Radiation Dosimetry for Highly Contaminated Ukrainian, Belarusian, and Russian Populations, and for Less Contaminated Populations in Europe

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Bethesda, MD 20892
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# Radionuclide inventories and releases

| Radionuclide | Core inventory (PBq) | Activity released (PBq) |
|---|---|---|
| $^{131}I$ | 3200 | 1800 |
| $^{134}Cs$ | 170 | 54 |
| $^{137}Cs$ | 260 | 85 |
| $^{90}Sr$ | 220 | 10 |
| $^{239}Pu$ | 0.96 | 0.03 |
| $^{133}Xe$ | 6500 | 6500 |

# Populations

- Persons evacuated from contaminated areas (116 000)
- Persons who continued to live in contaminated areas (5 million)

# Persons evacuated from contaminated areas

| | |
|---|---|
| Ukraine | 91,406 |
| Belarus | 24,725 |
| Russia | 186 |
| | |
| Total | 116,317 |

(to end of 1986 from 187 settlements)

# DOSES TO EVACUEES

| Location | Whole-body dose (mGy) | Thyroid dose (mGy) |
|---|---|---|
| Pripyat | 17 | 170 |
| Ukraine | 17 | 330 |
| Belarus | 31 | 1000 |

# CONTAMINATED AREAS

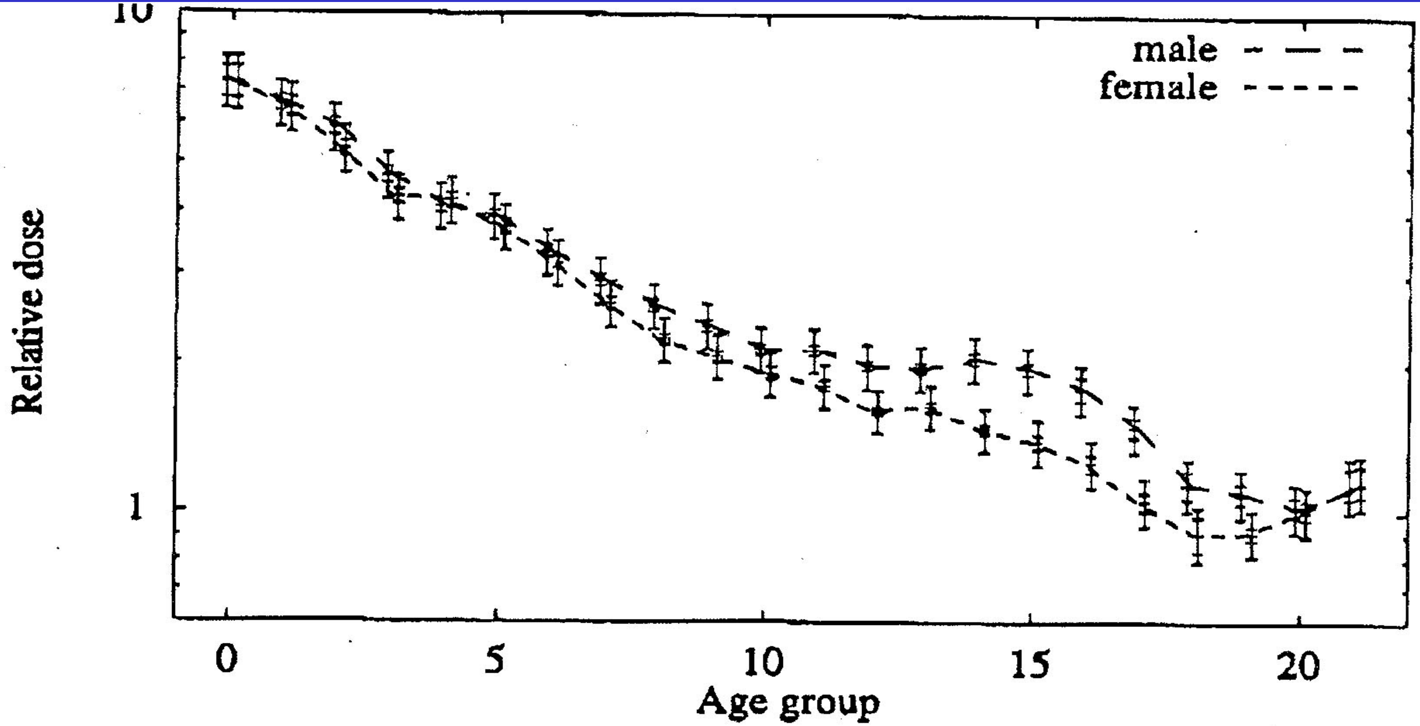
| $^{137}Cs$ ($kBq\ m^{-2}$) | Area ($km^2$) | Population (thousands) |
|---|---|---|
| 37-185 | 116 900 | 4 386 |
| 185-555 | 19 100 | 580 |
| 555-1480 | 7 200 | 193 (273) |

# All contaminated areas

Average thyroid dose:  300 mGy

Most exposed infants:  1000 mGy or more

# Age-sex dependence of the thyroid doses in Ukrainian residents following Chornobyl



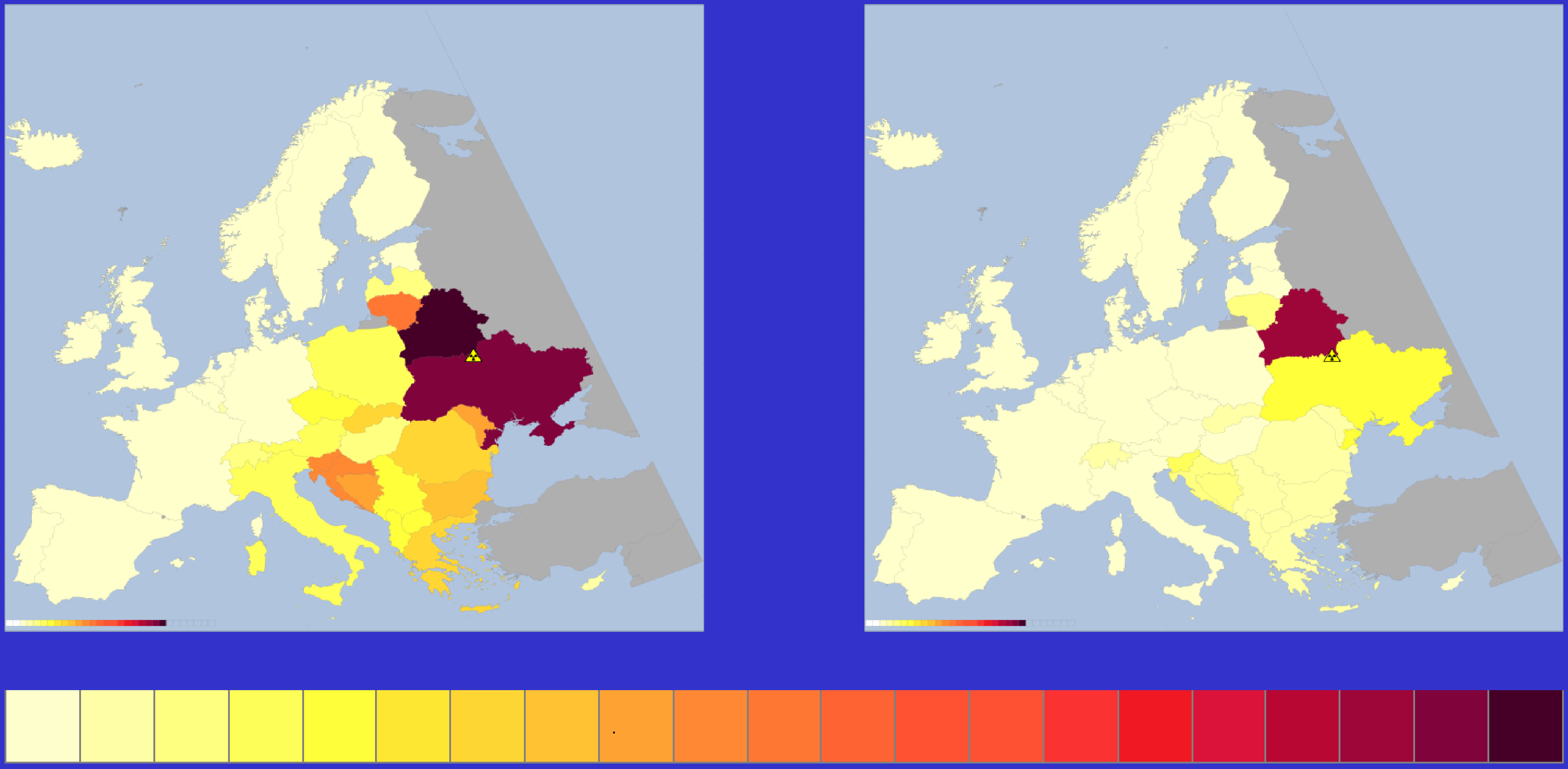
# All contaminated areas

Average whole-body dose (mGy) 1986-1995

| | External | Internal | Total |
|---|---|---|---|
| Russian Fed. | 4 | 2.5 | 6.5 |
| Belarus | 5 | 3 | 8 |
| Ukraine | 5 | 6 | 11 |
| | | | |
| Average (10 years) | 5 | 3 | 8 |
| Average (lifetime) | 9 | 4 | 13 |

# Thyroid doses in Europe (mGy)

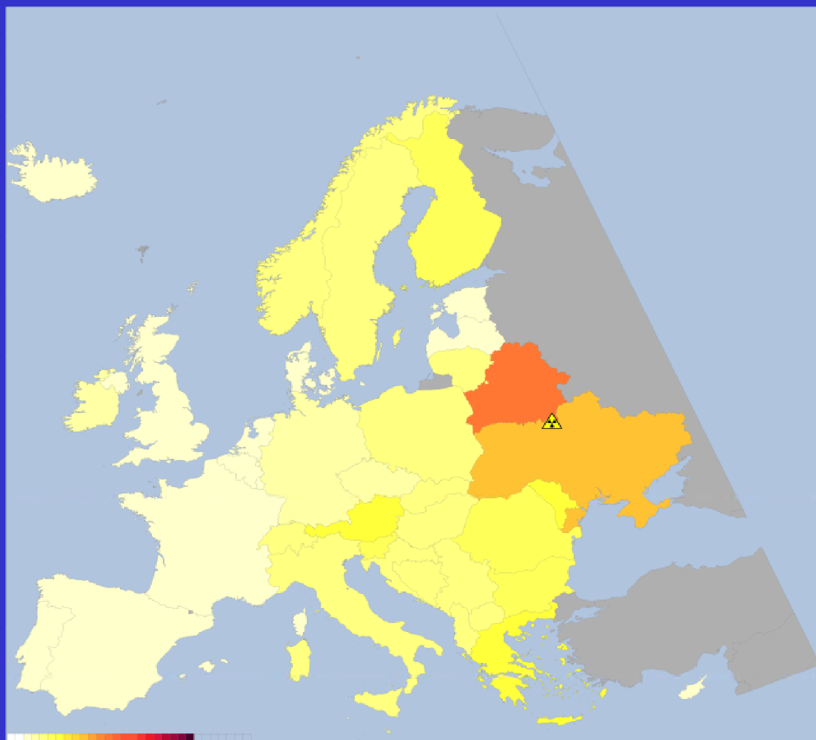
## Children (<5 y) | Adults



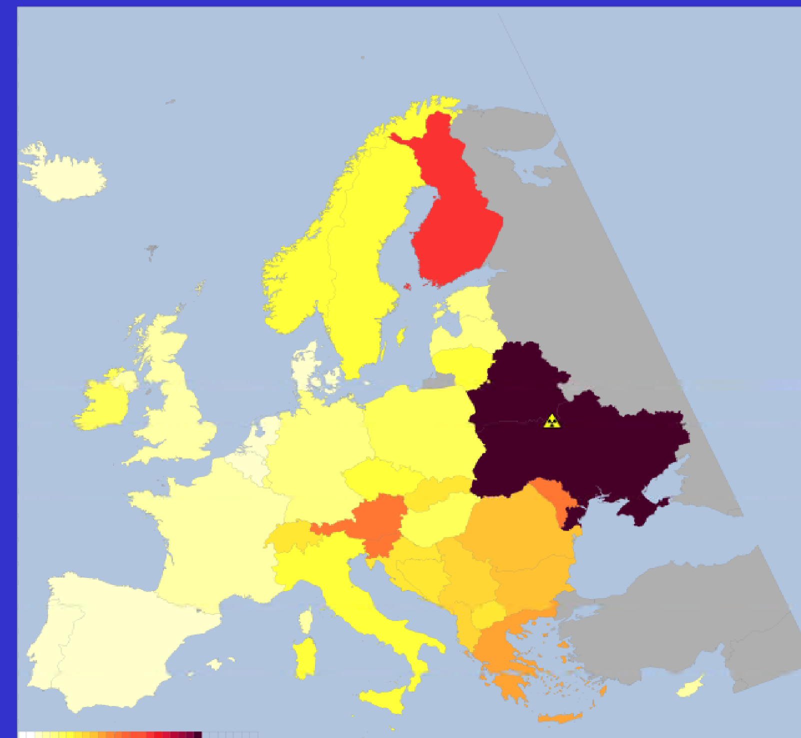
0 10 20 30 40 mGy

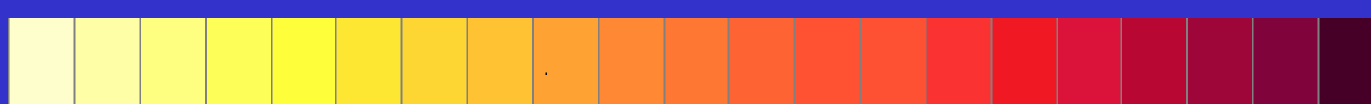
# Effective doses in Europe (mSv)

## 1986



## 1986-2005





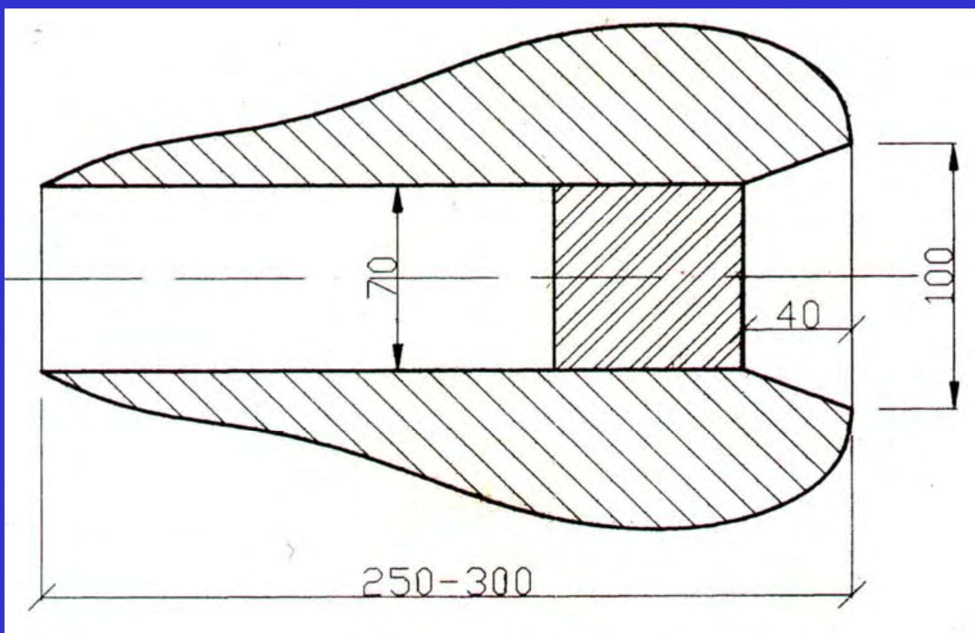
# METHODS OF DOSE ESTIMATION

- **Based on measurements:**
  - **0.4 million direct thyroid measurements**
  - **measurements of whole-body burdens**
  - **1 million measurements of $^{137}Cs$ in milk and other foodstuffs**
  - **Several million measurements of $^{137}Cs$ deposition on the ground.**
- **Use of models for interpolation and extrapolation.**

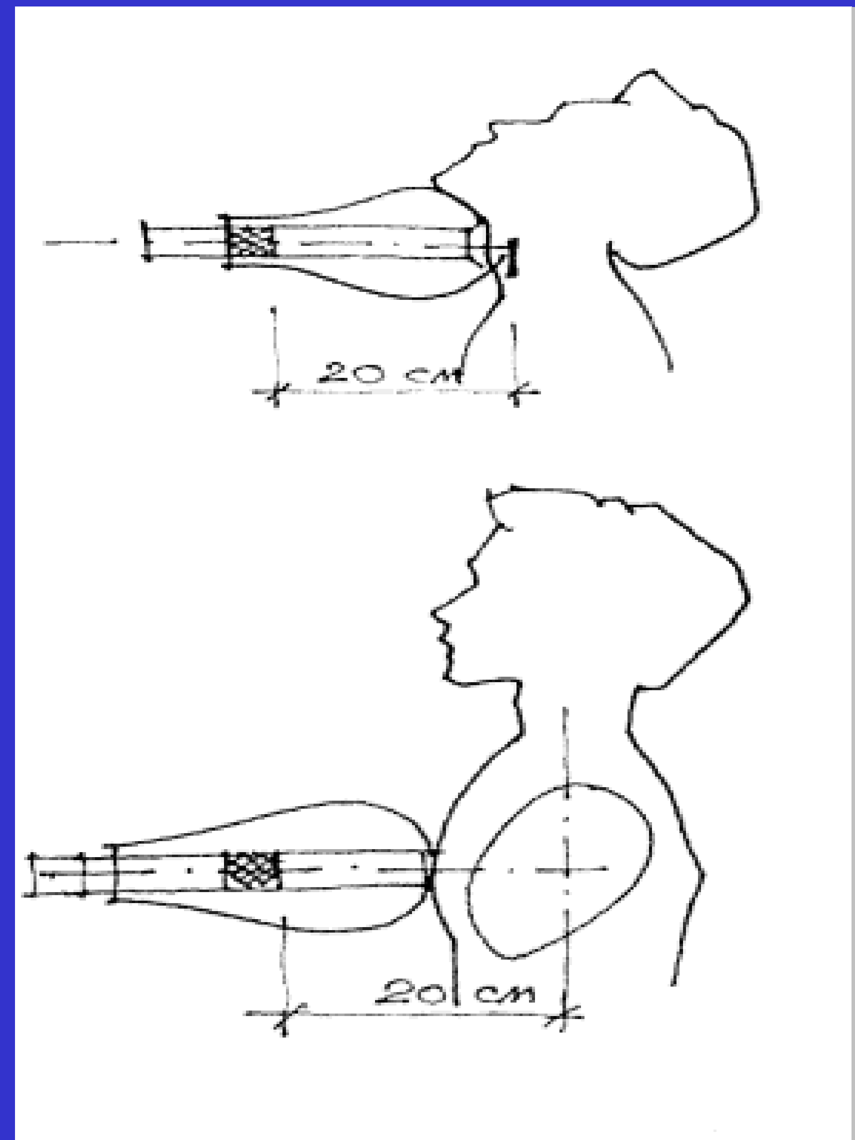
# THYROID DOSE ESTIMATION

- Mainly due to the consumption of fresh cow's milk contaminated with $^{131}I$ (half-life of 8 days).
- The thyroid dose was essentially delivered within two months after the accident.
- Based on the analysis of 0.4 million direct thyroid measurements.

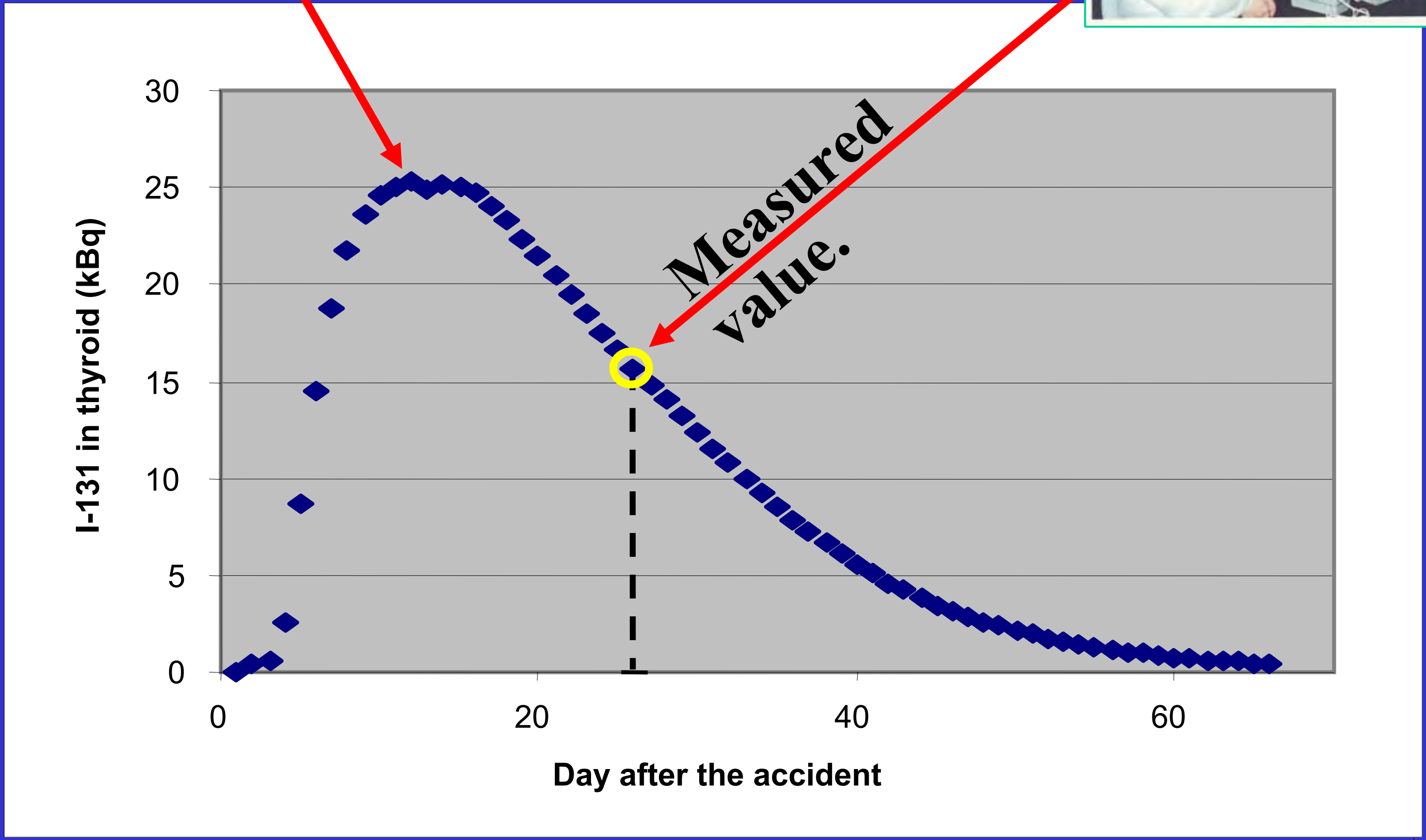
# The lead collimator and measurement geometries (thyroid and lungs)




The lead collimator



Curve derived from $^{131}I$ models plus data from questionnaire.



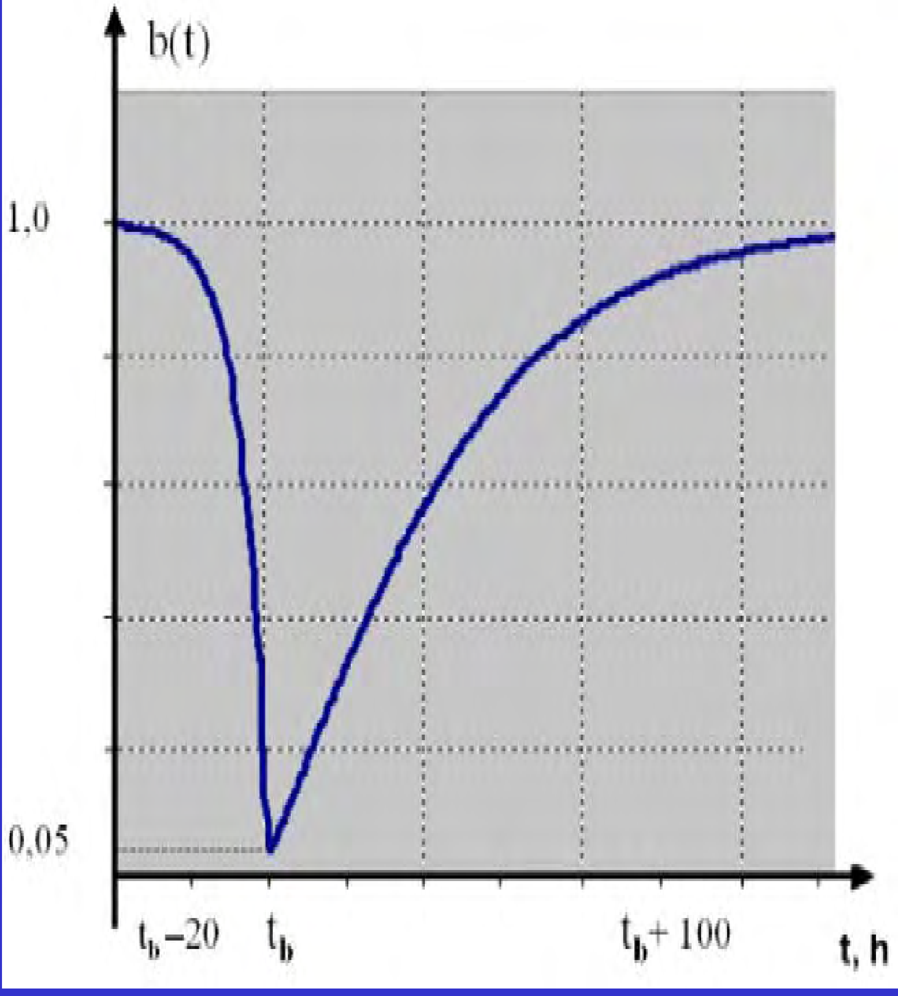

Thyroid dose is pro-portional to area beneath curve.

# Personal data

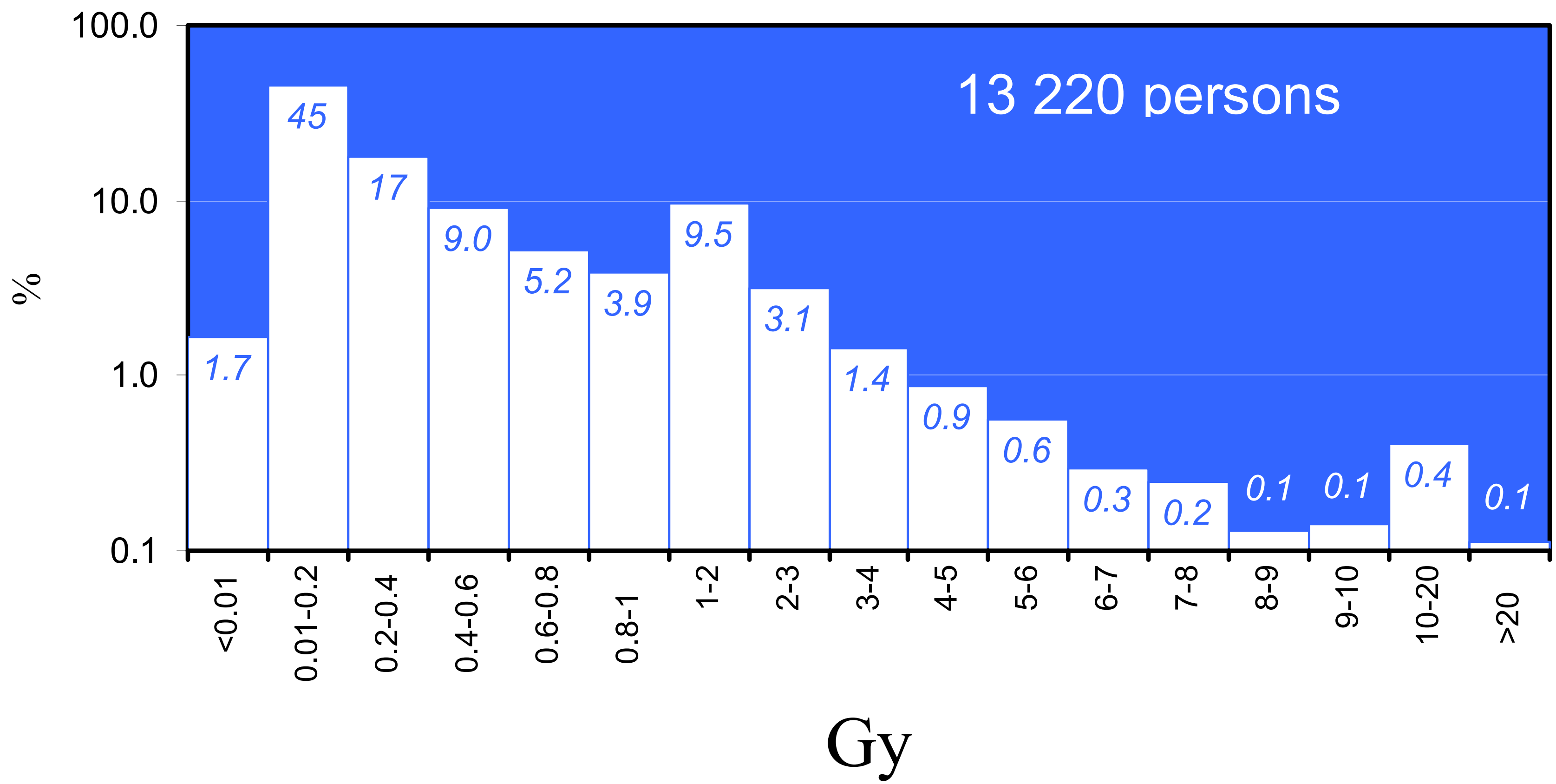
- Residence history during the first two months following the accident.
- Origin of milk, milk products, and leafy vegetables that were consumed.
- Consumption rates of milk, milk products, and leafy vegetables.
- Iodine prophylaxis (if conducted).

# Thyroid blockade with stable iodine

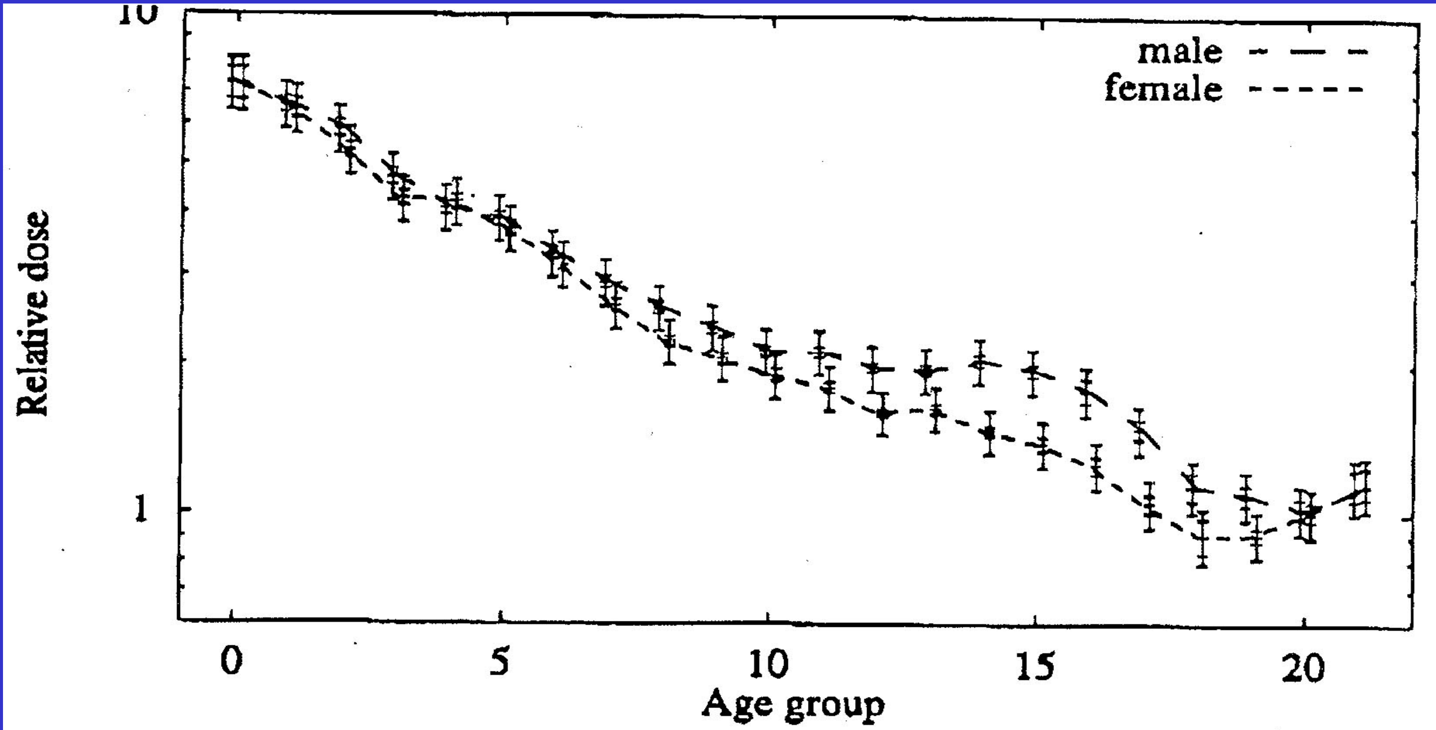
- *The time t on the abscissa is the time when the KI pill is ingested*
- *The time $t_b$ corrresponds to an acute intake of $^{131}I$*
- *b(t) is the thyroid dose resulting from the intake of $^{131}I$*



# Distribution of cohort subjects in Ukraine according to individual thyroid dose



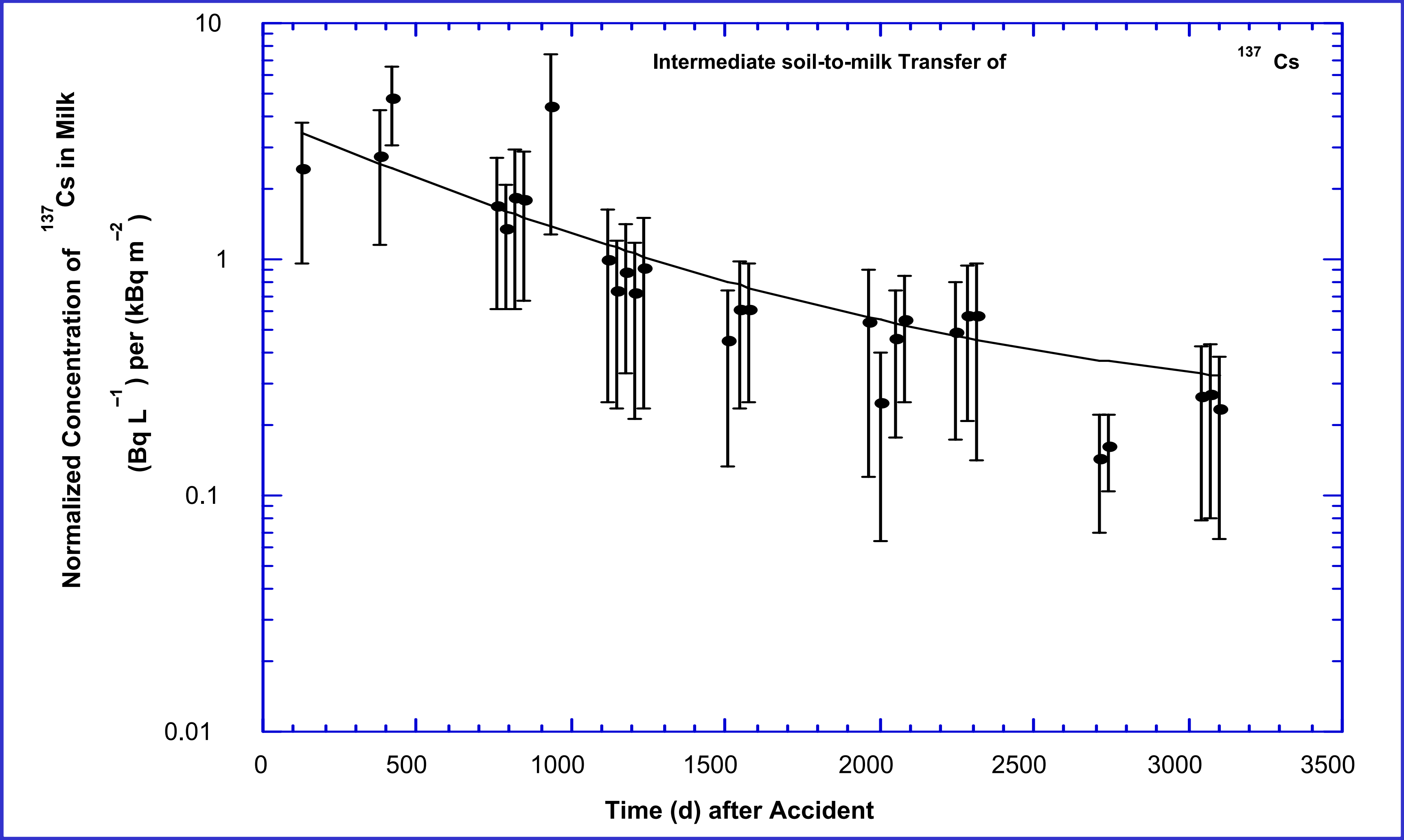
# Age-sex dependence of the thyroid doses in Ukrainian residents



# WHOLE-BODY DOSE ESTIMATION

- $^{134}Cs$ (half-life of 2 y) and $^{137}Cs$ (half-life of 30 y) are the main contributors to the whole-body doses from external irradiation and from internal irradiation.
- The whole-body doses from $^{137}Cs$ will continue to be delivered, at low to very low rates, for several decades.

# $^{137}Cs$ concentrations in milk as a function of time after the accident



# CONCLUSIONS

- The atmospheric releases that occurred during the Chernobyl accident led to the contamination of vast areas of land, mainly in Ukraine, Belarus, and Russia.
- With a few exceptions, only thyroid doses and whole-body doses have been estimated.
- For most people, the thyroid doses are mainly due to the consumption of fresh cow's milk contaminated with $^{131}I$. The thyroid doses were delivered within two months after the accident are were about 10 times greater for infants than for adults. Thyroid doses greater than 1 Gy were not uncommon.
-The whole-body doses, either from external or from internal irradiation, are mainly due to $^{137}Cs$. They will continue to be delivered, at a low or very low rate, for several decades. For most people, the whole-body doses are a few percent of the thyroid doses.

# Thyroid Cancer Among Populations Exposed to Radiation from Chernobyl

Elaine Ron
Division Of Cancer Epidemiology And Genetics
Radiation Epidemiology Branch
April 4, 2006

# Radiation Exposure

**Radiation Hotspots**


- $^{131}$I & $^{137}$Cs principal radionuclides
- 50 million Ci (1.8 EBq) of $^{131}$I released
  - >70% of dose
  - inhaled and ingested
  - concentrates in the thyroid
  - thyroid dose 15-20 times higher than overall body dose

# Affected Populations

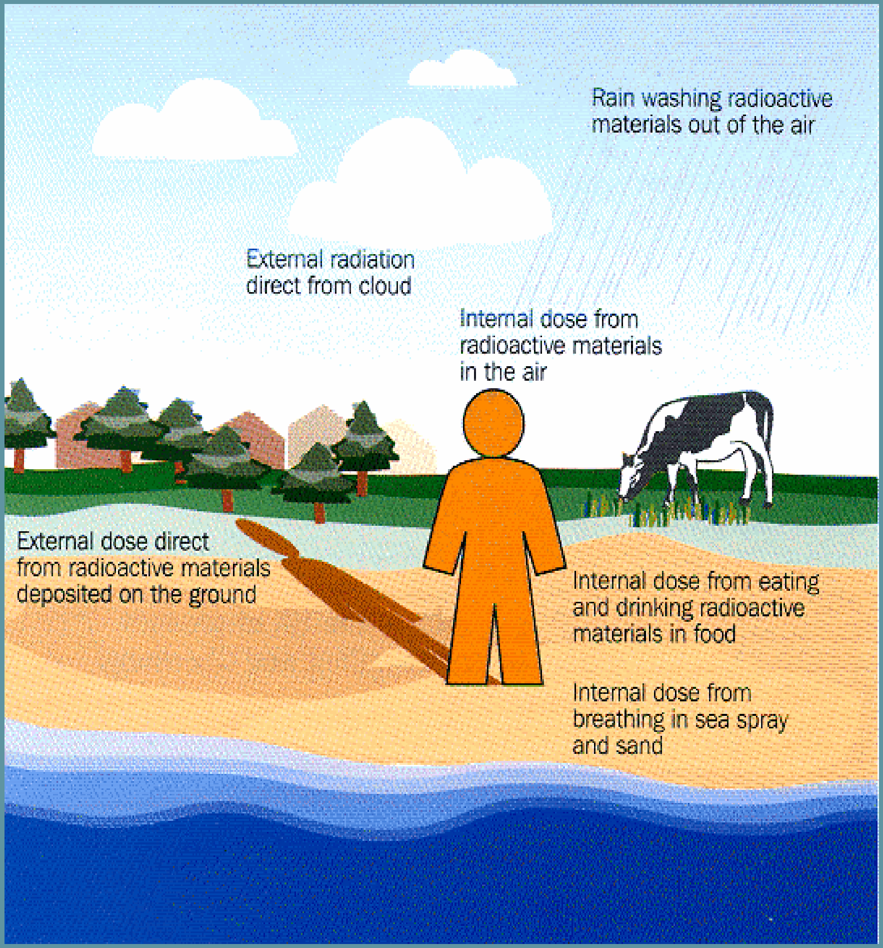
Residents of contaminated areas

- 5 million in Ukraine, Belarus and Russia
- 116,000 people evacuated from area within 30 km of plant
- About 400,000 living in “areas of strict control”

# Population Thyroid Doses

- Wide range of doses depending on;
  - Age at exposure
  - Level of ground contamination
  - Milk consumption
  - Origin of milk
- Intake of stable iodine tablets 6-30 hours after accident reduced thyroid dose of Pripyat residents by a factor of about 6
- Average thyroid doses 0.03-0.3 Gy

# Exposure Pathway




- Fallout-grass-cow-milk
- Dose inversely proportional to thyroid mass, so higher dose to children
- Dose larger in iodine deficient areas (uptake higher)

# Population Doses

$^{131}I$ population dose estimates primarily based on 350,000 direct measurements of exposure rate performed using radiation detectors placed against the neck with the first few weeks following the accident

# Describing Radiation-related Risks

- Excess Relative Risk (ERR)

  Percentage change in risk for a given dose (Relative risk minus one)

- Excess Absolute Rate (EAR)

  Absolute change in rates for a given dose (Rate difference)

- ERR and EAR can vary with dose, age at exposure, gender, attained age, time since exposure, and other factors
- ERR and EAR provide complementary information

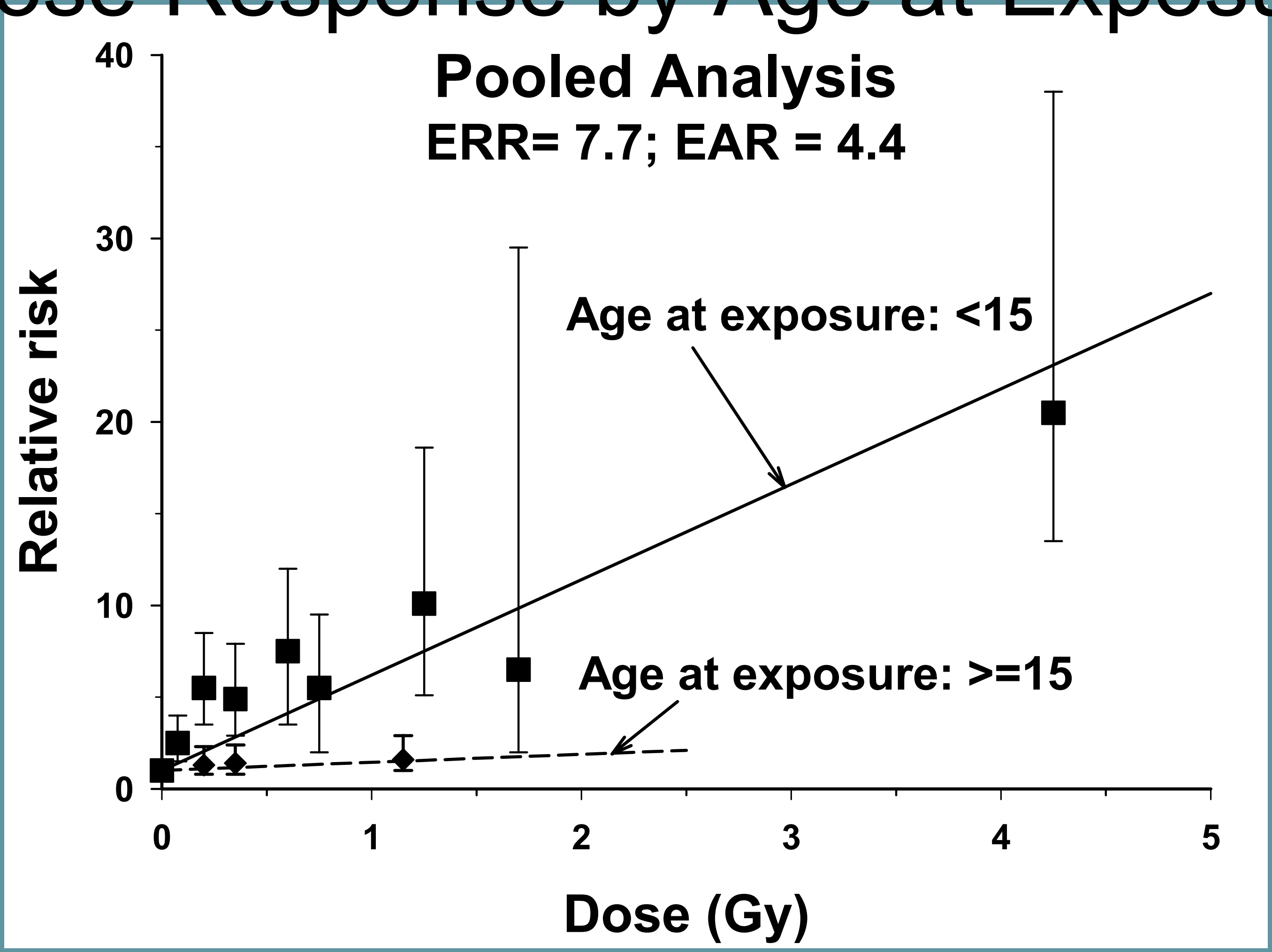
# Background

- Prior to Chernobyl, limited data on cancer risk from radioiodines
- Most information on $^{131}I$ came from studies of adults exposed to medical radiation and children exposed to fallout
  - Little evidence of a dose response for thyroid cancer among adult patients
  - Data on childhood exposure are sparse

# External Radiation and Thyroid Cancer

- Linear dose-response
- Risk increases with decreasing age at exposure
- Risk elevated throughout life; peak about 15-30 years after exposure
- Papillary carcinoma is principal cell type; frequently multicentric with lymph node metastases

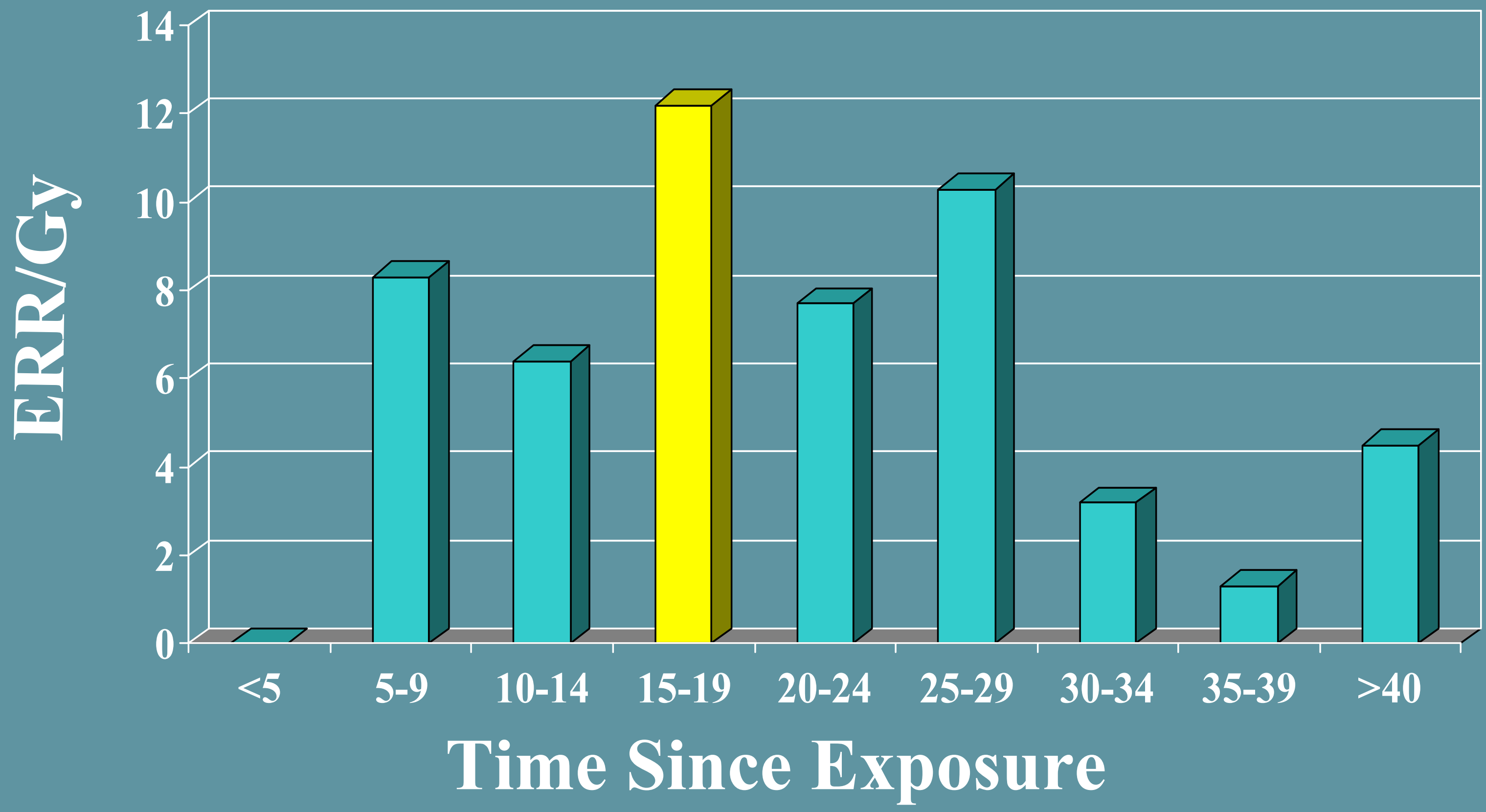
# Thyroid Cancer & External Radiation Risk
# Dose Response by Age at Exposure




*Ron et al, 1995*

# Thyroid Cancer & External Radiation Risk

## Pooled Analysis




Ron et al, 1995

# What Do We Want to Know about $^{131}I$?

- Is $^{131}I$ as carcinogenic as external radiation
- Are patterns of risk the same?
- Is the clinical course of thyroid cancer similar?

# Reasons for Possible Differences Between $^{131}I$ and External Radiation

**Physical**

- Low dose rate of $^{131}I$
- Non-uniform distribution of $^{131}I$
  
  *Cell killing at high doses*

**Epidemiological**

- Underlying thyroid disease
- Uncertainties in dose
- Limited statistical power

# Chernobyl: First Reports

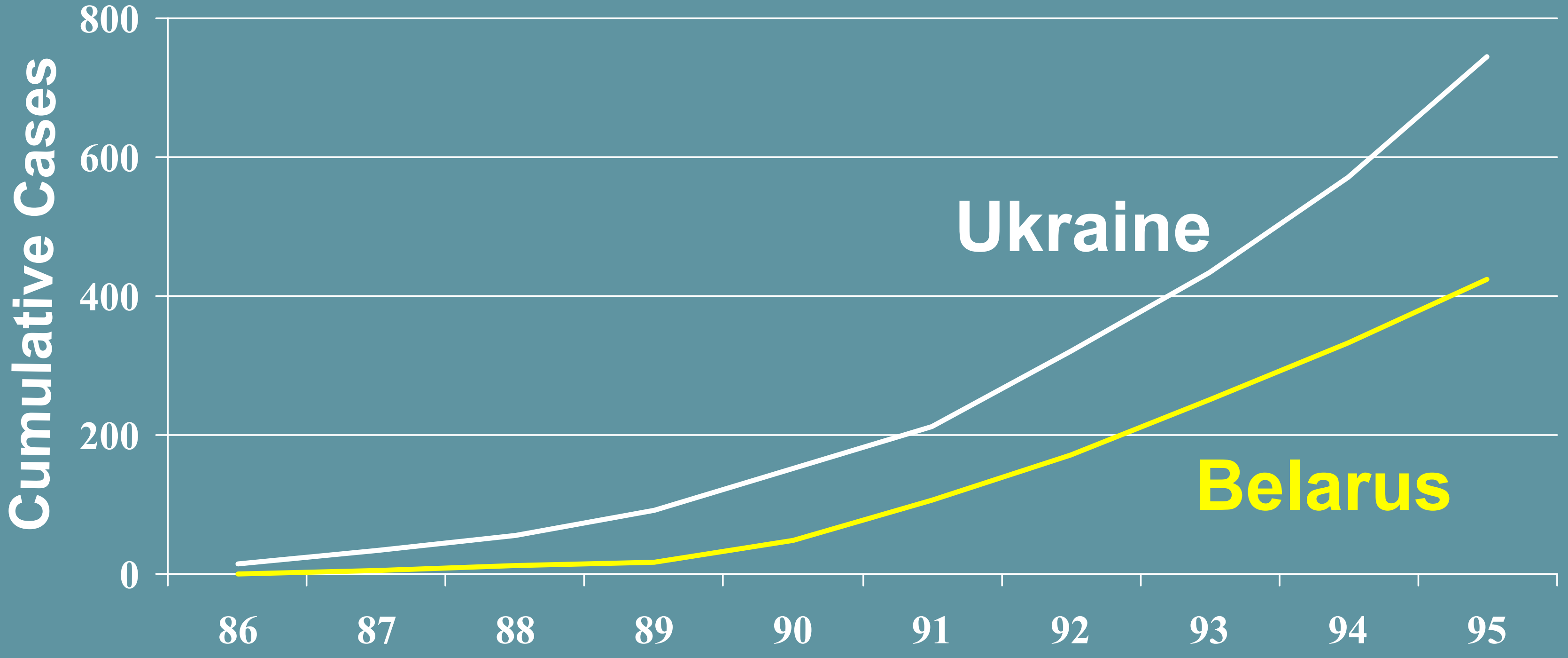
Ukraine

Prisyazhiuk et al, Cancer in the Ukraine, post-Chernobyl. Lancet, 1991

Belarus

Kazakov et al, Thyroid cancer after Chernobyl. Nature, 1992

# Pediatric Thyroid Cancers*
# The First Ten Years




*children & adolescents

# Initial Reports: Descriptive Studies of Children

- Elevated thyroid cancer incidence occurred in Belarus, Ukraine and Russia, especially in Gomel, Belarus
- Short latency: first cancers noted within 5 years of exposure
- ~2000 cancers in contaminated areas of Belarus, Ukraine, Russia, 1990-98
- >90% papillary; aggressive, solid or solid-follicular variant

# Limitations of Early Reports

- Primarily case reports or descriptive studies
- No individual dose measurements
- Impact of screening and better reporting not measured
- Modifying factors rarely considered

# Thyroid Cancer Associated with $^{131}$I Exposure from Chernobyl
(Belarus)

| | Thyroid Dose (Gy) | | | |
|---|---|---|---|---|
| | <0.3 | 0.3- | 1+ | OR (95% CI) |
| Cases (n=107) | 64 | 26 | 17 | 1.0 |
| Controls (n=214) | | | | |
| *Population* | 88 | 15 | 4 | 2.1 (1.7 - 5.8) |
| *Medical* | 84 | 19 | 4 | 2.6 (1.4 - 4.8) |

Cases accrued 1987-92

OR >1 Gy vs 0.3 Gy = 5.4 (95% CI 1.5-16.7)

Astakhova et al, 1998

# Thyroid Cancer Associated with $^{131}$I Exposure from Chernobyl

## (Belarus & Bryansk, Russia)

- Ecological study
- 3 cities and 2729 settlements
- Thyroid cancer cases 1991-1995
- EAR $10^4$ PYR = 2.1 (95% CI 1.0-4.5)
- ERR per Gy = 23 (95% CI 8.6-82)
- Significant excess at mean dose 0.05 Gy

**Jacob et al, 1999**

# Thyroid Cancer Associated with $^{131}$I Exposure from Chernobyl

## Bryansk, Russia

- 26 cases; 52 matched controls
- Diagnosed 1986-1997
- Increased risk with increasing dose, $p<0.009$
- ERR per Gy = 1.7 (95% CI 0.10-3.2)

**Davis et al, 2004**

# Thyroid Cancer Associated with $^{131}I$ Exposure from Chernobyl

Belarus & 4 regions in Russia

- 276 cases, 1300 controls
- <15 y at time of accident
- Majority of subjects had thyroid doses of 16-399 mGy
- Doses higher in Belarus than Russia

**Cardis et al, 2005**

# Thyroid Cancer Associated with $^{131}I$ Exposure from Chernobyl

## Belarus & 4 regions in Russia

| Radiation type | $OR_{Gy}$ (95% CI) |
|---|---|
| Total dose | 5.5 (2.2-8.8) |
| $^{131}I$ | 5.2 (2.2-8.2) |
| All iodine isotopes | 5.2 (2.2-8.3) |
| Adjusted all iodine isotopes * | 5.9 (1.6-10.2) |

***Adjusted for external and long-lived nuclides**
**Cardis et al, 2005**

# Thyroid Cancer Associated with $^{131}I$ Exposure from Chernobyl

## Belarus & 4 regions in Russia

- At 1 Gy, risk 3-fold higher in iodine deficient area than elsewhere (based on soil iodine content)
- KI dietary supplement decreased risk by about one-third

Cardis et al, 2005

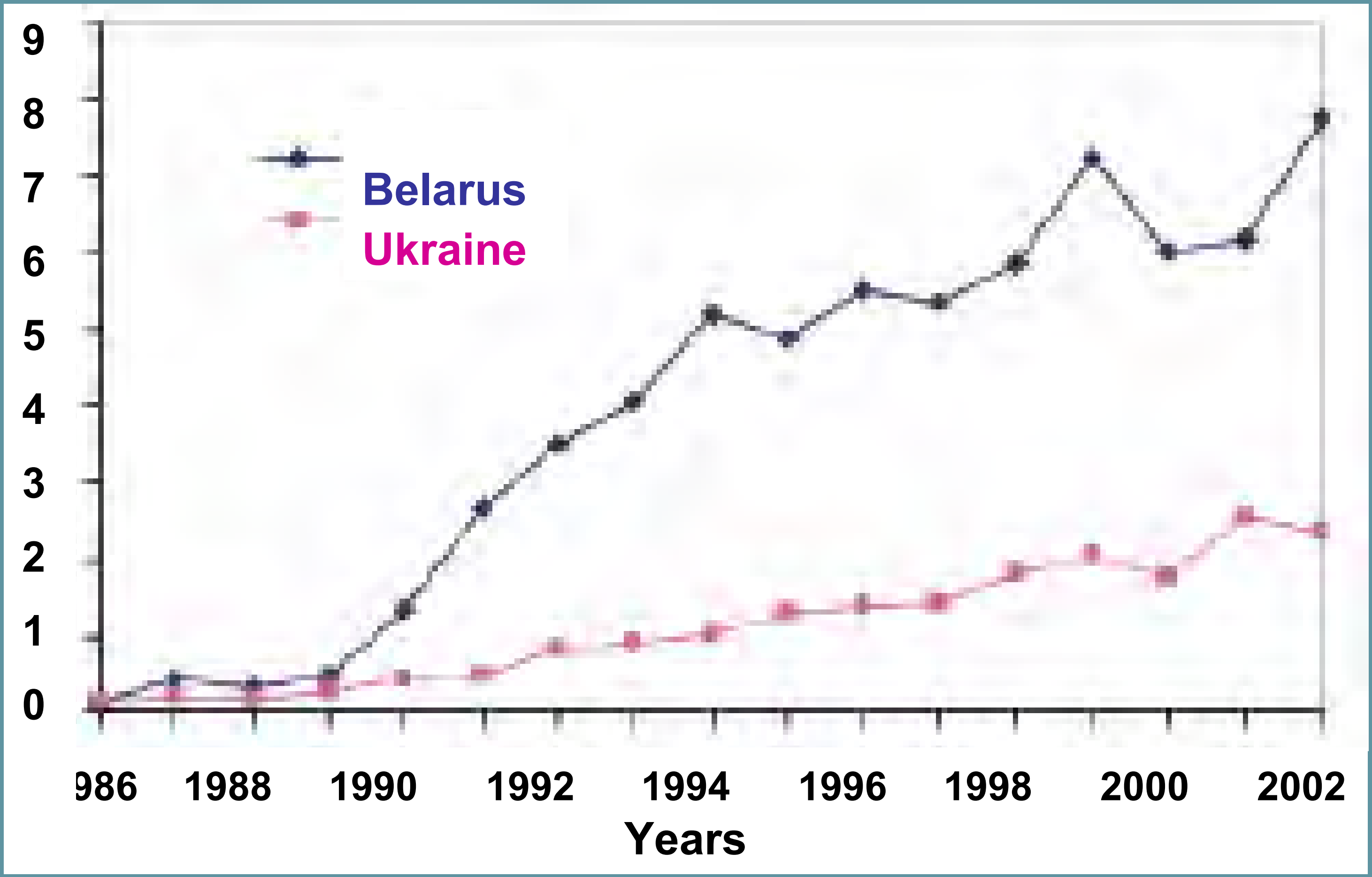
# Thyroid Cancer Associated with $^{131}I$ Exposure from Chernobyl

## Belarus & Ukraine

- Ecological study
- 608 settlements in Ukraine, 426 Belarus with >10 direct $^{131}I$ measurements
- 512 cancers in Ukraine, 577 Belarus
- Thyroid cancer cases 1990-2001
- <18 yr at time of accident
- EAR $10^4$ PYR = 2.7 (95% CI 2.2-3.1)
- $ERR_{Gy}$ = 18.9 (95% CI 11.1-26.7)

**Jacob et al, 2006**

# Thyroid cancer incidence




Jacob et al, 2005; Chernobyl Forum, 2005

# Thyroid Cancer Risk Estimates: External Radiation and $^{131}I$

| | External Radiation | Chernobyl | |
|---|---|---|---|
| EAR/$10^4$ PYGy | 4.4* | N.A.^ | $2.7^{+}$ |
| (95% CI) | (1.9-10.1) | | (2.2-3.1) |
| ERR/Gy (95% CI) | 7.7 (2.1-28.7) | 5.5 (2.2-8.8) | 18.9 (11.1-26.7) |

* Pooled Analysis, Ron et al, 1995
^ Belarus, Russia, Cardis et al, 2005
\+ Belarus, Ukraine, Jacob et al, 2006

# Modifying Factors for Thyroid Cancer Associated with $^{131}I$ Exposure from Chernobyl

- Depend on statistical model used
- Age at exposure
- Attained age
- Time since exposure
- Gender
- Iodine status

# Chernobyl Thyroid Cancers Compared with Spontaneous

| | Chernobyl | Spontaneous |
|---|---|---|
| **Age at Diagnosis** | (%) | (%) |
| <10 | 48 | 29 |
| 10-14 | 52 | 71 |
| **Papillary Carcinoma** | | |
| Solid/follicular | 74 | 35 |
| Classic | 10 | 41 |
| Other | 16 | 24 |
| **Extent of Tumor** | | |
| Extrathyroidal | 49 | 25 |
| Lymph node mets | 65 | 54 |

Williams & Tronko 1996; Pacini et al 1998

# Chernobyl Thyroid Cancers Compared with Spontaneous
## Ukraine

| | Chernobyl (%) | Spontaneous (%) |
|---|---|---|
| Cancer in nodule | 33 | 27 |
| Invasive form | 39 | 23 |
| Regional metastases | 41 | 19 |
| Multifocal | 33 | 24 |

p-values all <0.05

2363 spontaneous; 311 radiation-related
Surgically treated 1990-2003
Similar in age, sex and preoperative exam

Cherenko et al, 2004

# Thyroid Cancer Associated with $^{131}I$ Exposure from Chernobyl

## Bryansk, Russia

- 1 million 15-69 year olds
- 1051 thyroid cancers diagnosed 1986-98
- Grouped doses
- No dose response using either internal or external comparison groups

Ivanov et al, 2003

# Chernobyl-Related Thyroid Cancer

## Belarus

| Age at Dx | | RR# by Period of Diagnosis 1980-86 | 1987-91 | 1992-96 | 1997-2001 |
|---|---|---|---|---|---|
| 0-14 | M | 0.9 | 1.9* | 2.1* | 1.4 |
| | F | 0.7 | 3.1* | 2.1* | 2.2* |
| 15-34 | M | 1.1 | 1.1 | 1.3 | 3.2* |
| | F | 0.5 | 1.0 | 1.1 | 1.7* |
| 35-54 | M | 1.3 | 0.9 | 0.9 | 1.5* |
| | F | 0.9 | 0.8 | 0.9 | 1.4* |
| 55+ | M | 1.0 | 0.7 | 1.3 | 0.9 |
| | F | 0.9 | 0.8 | 0.9 | 1.1 |

**# Rate ratio of incidence in higher exposure vs lower exposure areas**
*** Lower 95% CI >1.0**

# Summary (1)

- Excess thyroid cancers still occurring among persons exposed <age 20
- Thyroid cancer risk appears to decrease with increasing age at exposure
- Risk among persons exposed as adults not yet known
- The number of thyroid cancers is larger among women, but role of gender is not clear in regard to radiation risk
- Iodine deficiency enhances the risk of thyroid cancer, while iodine prophylaxis appears to reduce the risk

# Summary (2)

- While the long-term risks cannot yet be quantified, probably can expect an excess of thyroid cancers for several more decades
- It is not certain, however, whether the risk will increase or stabilize over time
- The number of reported deaths from the disease has been relatively low (8 or <1%)
- The magnitude and patterns of risks are compatible with the pooled estimates of thyroid cancer risk from external irradiation

# Future Needs

- Additional data on adult and *in utero* exposure
- Evaluation of clinical course as exposed individuals age
- Quantification of the affects of iodine deficiency and supplementation
- Due to uncertainties regarding the future, long-term follow-up is necessary

# (1) Estimates of mean effective doses (mSv) for population groups of interest

| Population | Approximate size of population | Mean effective dose (mSv) |
|---|---|---|
| Liquidators (1986-1987, 30 km zone) | 240,000 | 100 |
| Evacuees of 1986 | 116,000 | 33 |
| Persons living in contaminated areas:<br>*-Deposition density of 137Cs>37 kBq/m²*<br><br>*- Deposition density of 137Cs>555 kBq/m²* | <br><br><br>5,200,000<br><br>270,000 | <br><br><br>10<br><br>50 |

# (2) Some chronic diseases studied after Chernobyl

- Thyroid cancer
- Benign thyroid tumors
- Autoimmune thyroiditis
- Leukemia
- Breast cancer
- Bladder cancer
- Kidney cancer
- All cancers
- Cataracts
- Cardiovascular disease

# (3) Two methods of studying

1. Risk projection:

   Risk models from other studies plus Chernobyl doses

   Advantages: More statistical power and precise confidence intervals

   Disadvantages: Need for extrapolation

2. Empirical epidemiologic studies in affected populations:

   Advantages: No need for extrapolation

   Disadvantages: Lack of statistical power

# (4) Model for leukemia incidence per $10^4$ person-years Gy*

$$EAR = (\beta_{s,e}\, \text{dose} + \gamma_{s,e}\, \text{dose}^2)\, \exp\{\theta_{s,e}\, t/20\}$$

where s is sex,
e is age at exposure,
t is time since exposure

*Preston et al., *Rad Res* 1994.

# (5) Predicted number of cases of leukemia by year of follow-up

| Year | Cases |
|---|---|
| 2000 | 110 (111?) |
| 2005 | 172 |
| 2010 | 253 |

## (6) Power estimates for leukemia
## Assumes tracing + interviewing rate=75%
## 3 different years of follow-up

| Year | True RBE | Power (%) |
|---|---|---|
| 2000 | 1.0 | 88 |
| 2000 | 0.5 | 47 |
| 2000 | 0 | 5 |
| 2005 | 1.0 | 97 |
| 2005 | 0.5 | 61 |
| 2005 | 0 | 5 |
| 2010 | 1.0 | 99 |
| 2010 | 0.5 | 71 |
| 2010 | 0 | 5 |

# (7) Leukemia following *in utero* exposure from Chernobyl

I. Ecological Studies

| Reference | Country | Results |
|---|---|---|
| Petridou (1996) | Greece | Increased risk |
| Steiner (1998) | Germany | No increase in risk |
| Ivanov (1998) | Belarus | No increase in risk |
| Noshchenko (2001) | Ukraine | No increase in risk |

# (8) Leukemia following exposure from Chernobyl in *childhood*

I. Ecological Studies

| Reference | Country | Results |
|---|---|---|
| Parkin (1993, 1996) | Europe | No increase in risk |
| Gapanovich (2001) | Belarus | No increase in risk |
| Ivanov (1993) | Belarus | No increase in risk |
| Ivanov (2002, 2003) | Russia | No increase in risk |

# (9) Leukemia following exposure from Chernobyl in *childhood*

II. Case-Control Studies

| Reference | Study Design | Country | N cases | Results |
|---|---|---|---|---|
| Noshchenko (2002) | Case-Control | Ukraine | 98 | Significant positive association in males |
| Davis (2005) | Case-Control | Ukraine | 268 | Significant increase in risk |
| | | Belarus | 114 | Increase in risk |
| | | Russia | 39 | No increase in risk |

# (10) Leukemia following exposure from Chernobyl in *adults* residing in contaminated areas

I. Ecological Studies

| Reference | Country | Results |
|---|---|---|
| Bebeshko (1997) | Ukraine | Increase in risk over time not related to level of contamination |
| Ivanov (1997) | Russia | |
| Prisyazhniuk (1995) | Ukraine | |

# (11) Leukemia in *liquidators* following exposure from Chernobyl

| Reference | Country | Results |
|---|---|---|
| Rahu (1997) | Estonia | Little information about risks |
| Shantyr (1997) | Russia | |
| Tukov (1993) | Russia | |
| Buzunov (1996) | Ukraine | Increase in risk not related to dose |
| Ivanov (2003) | Russia | A two-fold increase in risk |

# (12) Breast cancer following exposure from Chernobyl

I. Ecological Studies

| Reference | Country | Results |
|---|---|---|
| Prysyazhnyuk (2002) | Ukraine | Significantly increased incidence compared to the general population |
| Ostapenko (1998) | Belarus | Increase in risk over time |
| Pukkala (2006) | Ukraine, Belarus | Increase in risk, significant during the period 1997-2001 |

# (13) Autoimmune thyroiditis following exposure from Chernobyl

| Reference | Country | Results |
|---|---|---|
| Ito (1995) | Belarus, Russia, Ukraine | Significantly positive |
| Yamashita (1997) | Belarus, Russia, Ukraine | Null |
| Dedov (1993) | Russia | Significantly positive |
| Kasatkina (1997) | Russia | Significantly positive |
| Pacini (1998) | Belarus | Significantly positive |
| Vermiglio (1999) | Russia | Significantly positive (prevalence decreased 4-fold over time) |
| Vykhovanets (2004) | Ukraine | Significantly positive |
| Avetisian (1996) | Ukraine | Positive |
| Lomat (1997) | Belarus | Positive |

# Psychological and Perceived Health Effects of the Chornobyl Disaster: A 20-Year Review

Evelyn J. Bromet, Ph.D.
State University of New York, Stony Brook
April 3, 2006

# 2006 Report of the Chornobyl Forum

"The mental health impact of Chernobyl is the largest public health problem caused by the accident to date."

# Significance of mental health impacts

Poor mental health →

- A leading cause of disability worldwide
- Poor quality of life
- Decreased productivity
- Poor physical health
- Overutilization of medical services
- Mortality

# Psychological consequences of disasters

- Over the past 100 years, many descriptive epidemiologic and clinical studies of the psychological impact of natural and human-made disasters

# Psychological impact

- Depression (suicide)
- Anxiety (especially post-traumatic stress)
- Somatic symptoms (fatigue, weakness, headaches, joint and muscle pain)
- Substance abuse

# Magnitude

- Excess morbidity associated with disasters estimated at 20% during the first year
- Severity and chronicity are disaster-specific
- Psychological aftermath > severe and prolonged after toxic disasters

# Risk factors

- Personal: female; having young children; prior psychiatric or alcohol history; poverty; low social support; poor physical health
- Disaster: magnitude & severity of exposure; evacuation; death of a loved one; physical threat
- Post-disaster: inadequate practical or emotional support; inadequate or inappropriate professional interventions; media coverage

# Two post-disaster risk factors unique to toxic disasters

Stigma

&

Fear of cancer or congenital abnormalities

# Radiation events and stigma

- Stigma from society

  a-bomb survivors – *hibakusha* (explosion-affected people)

  Chornobyl evacuees - *pereselentsy* (resettlers)

- Stigma from medical community: derogatory dx when patients presented with health-related anxiety

  *a-bomb neurosis*

  *radiophobia*

# Stability of health fears

Worry that your health affected from TMI? (10 yrs)

N=156 TMI area women

40% no

17% unsure

43% yes

Health affected by Chornobyl? (12 yrs later)

N=213 women from 7 contaminated Oblasts

11% no

49% yes, somewhat

40% yes, very

# 1. Context of the research

- Prior to Chornobyl, no tradition of:

  epidemiology   western psychiatry   psychiatric epid

- No baseline data on prevalence of mental illness, mental retardation, dementia, alcoholism, or suicide

## 2. Reliable psychological research began 7 years later

Acute psychological effects, and effects during first 6 years, were not documented at the time they occurred

# 3. Complex web of exposures

- Radiation
- Evacuation -- abortion assembly-lines
- Battle for residency permits
- Alarmist reports in news media
- Distrust in government authorities
- Physicians' attributing health problems to Chornobyl
- <u>Intensive</u> health monitoring by international community
- Political and social upheaval
- Decline in standard of living

# Areas of research

1. Population-based morbidity studies
2. Cognitive impairment in exposed children
3. Mental health of liquidators

# (1) Population morbidity studies

Inclusion criteria:

- Transparent methodologies
- Generalizable sample
- Comparison group
- Standard mental health measures
- Peer reviewed English-language journals

Exclusion criteria:

- Research on special pop's (Israel; USA)
- Unverified results

# Five morbidity studies

Community study in Bryansk

Community study in Gomel

High risk group study in Kyiv

2 general pop. surveys in Ukraine

# Bryansk

Viinamäki et al., 1995

1. Compared 325 adults in a contaminated village with 278 controls non-contaminated village
2. 7 years after the accident
3. Standard psychological sx scale
4. Exposed >sx controls*
5. Risk factors: female, not having a partner, financial inadequacy, self-rated poor health, uncertain future

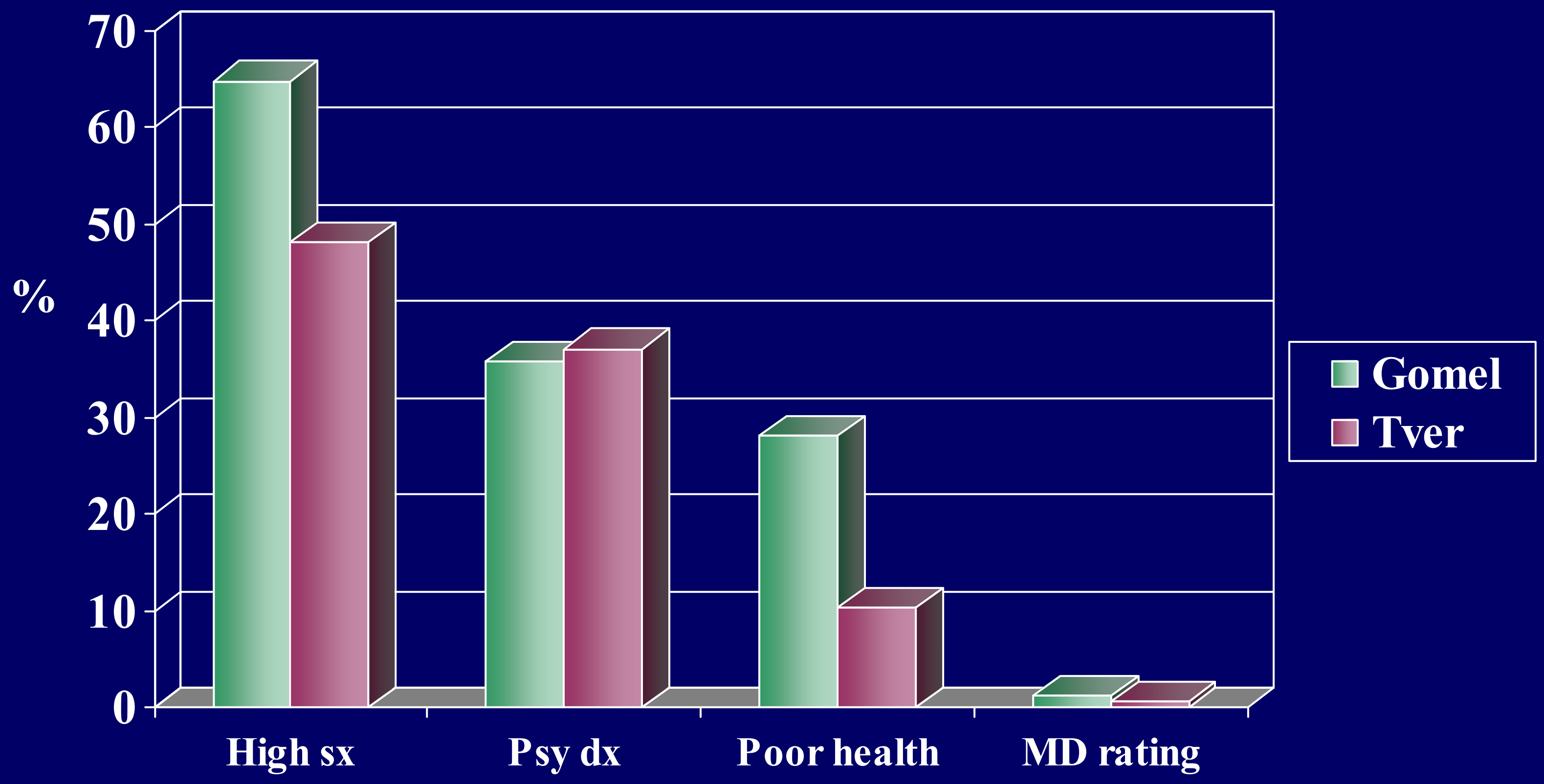
48% vs 34% (F) “minor mental disorder” based on GHQ

# Gomel

## Havenaar et al. 1997

1. Compared 1,617 adults in Gomel to 1,427 controls in Tver, Russia
2. 6.5 years after the Chornobyl accident
3. 2-stage study

# Gomel vs Tver




ORs for self-ratings=significant

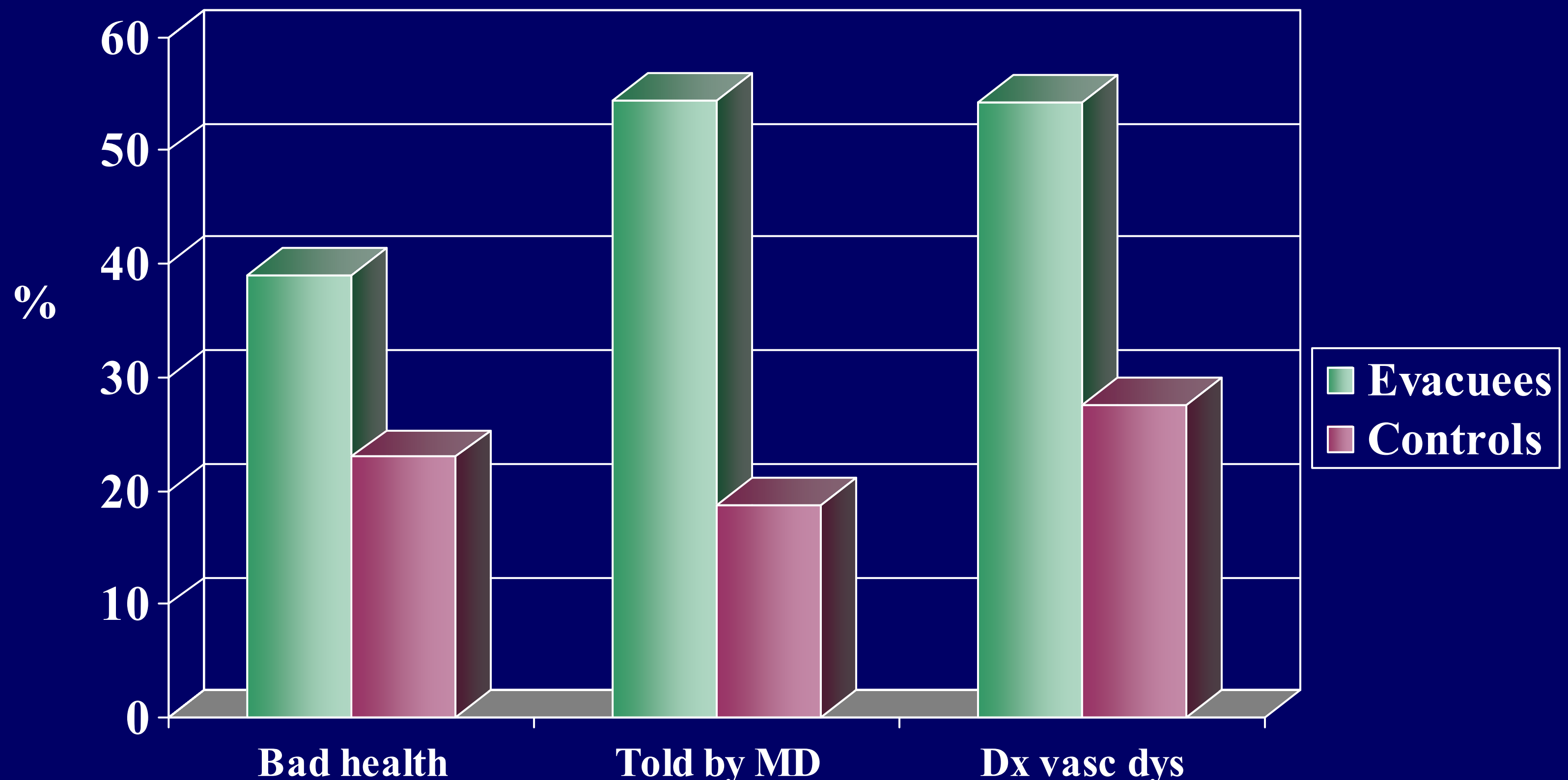
# Kyiv

Bromet et al. 2000*

1. 300 evacuee mother-child dyads (in utero-15 mos at time of accident) with gender-matched classmates
2. 11 yrs after accident
3. Standard psychological sx measures; grades + phy exams, & blood tests (kids)
4. Children's reports similar

*Funded by NIMH

# Evacuee vs control moms' health reports




OR (95%CI): bad health 2.1 (1.4-2.9); MD 5.2 (3.6-7.5); V-D 3.1 (2.2-4.4)

Methodological concern: over-estimated effects because focused on Chornobyl.

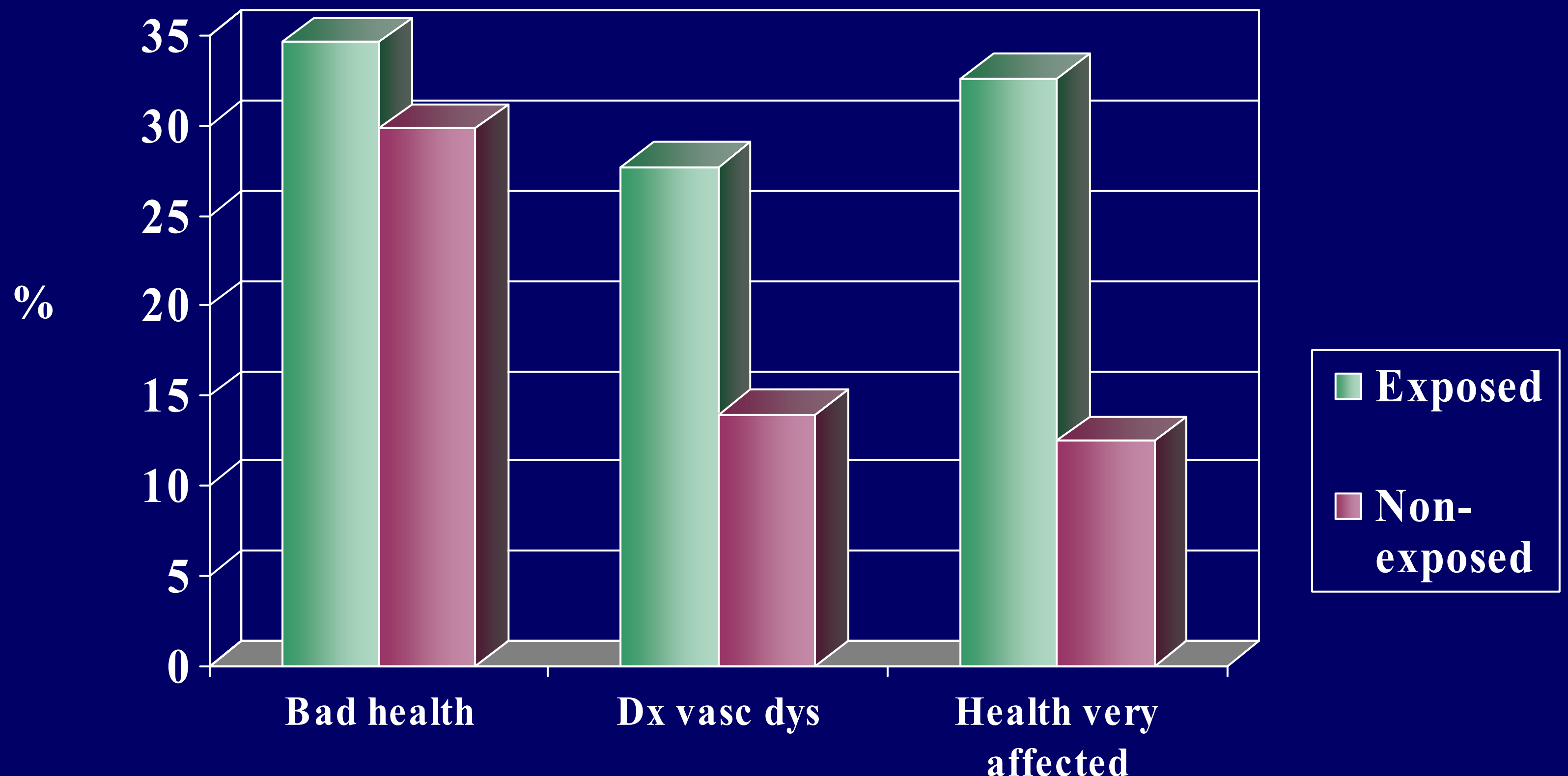
Findings from surveys not focused explicitly on Chornobyl?

# 1998 Ukraine national survey

Bromet et al. 2002 (KIIS)

1. National sample of 1606 adults
2. 12 yrs after accident
3. Added items to an omnibus survey by KIIS
4. Exposed oblasts (N=384) vs other oblasts (N=1,222)

# Exposed vs non-exposed oblasts




ORs for beliefs and vascular dys = significant

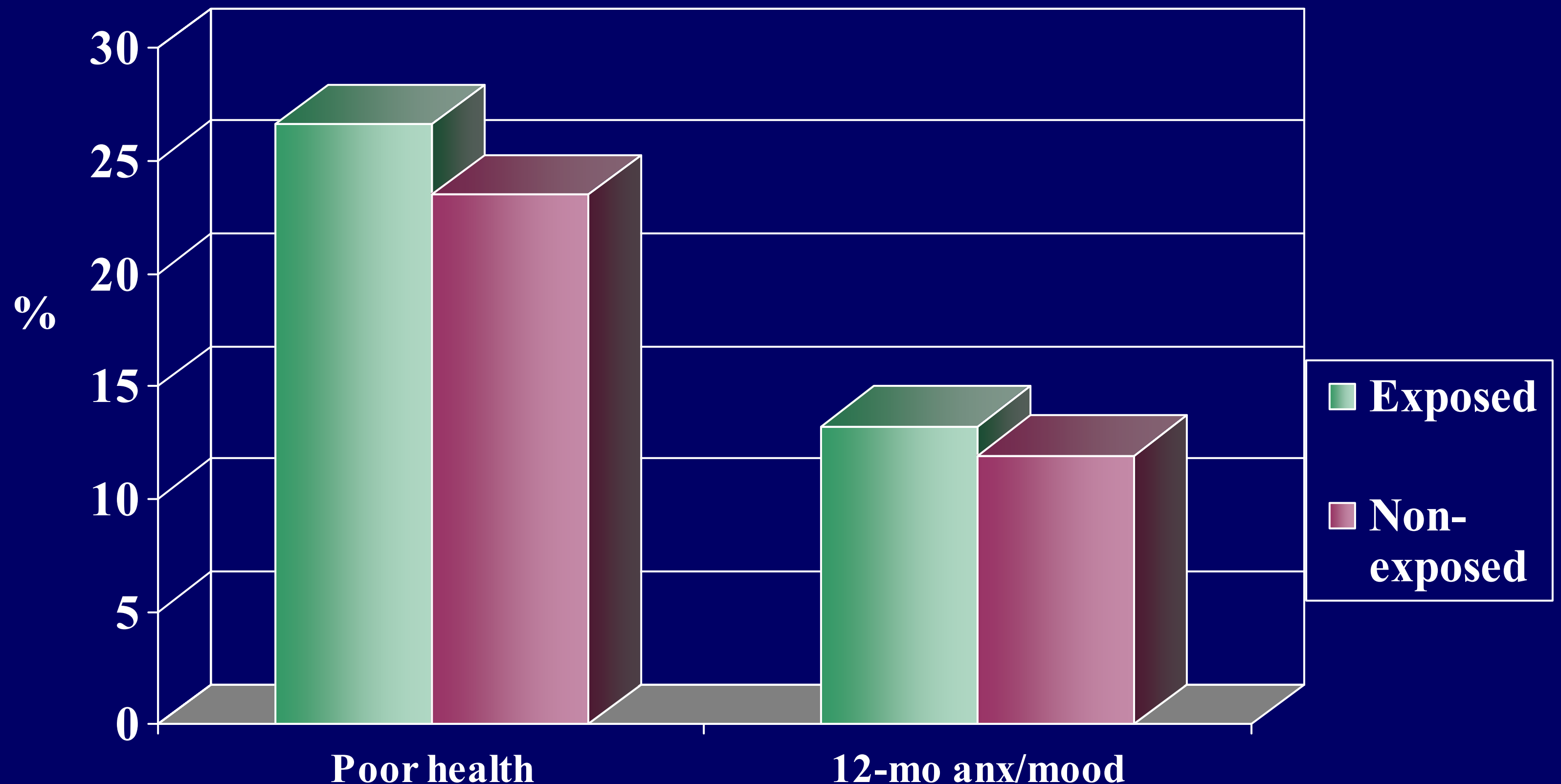
# 2002 national survey of Ukraine*

Bromet et al. 2005 (World Mental Health)

1. National sample of 4,725 adults
2. 16 yrs after accident
3. Focus on psychiatric dx and health
4. Included items about exposure to Chornobyl

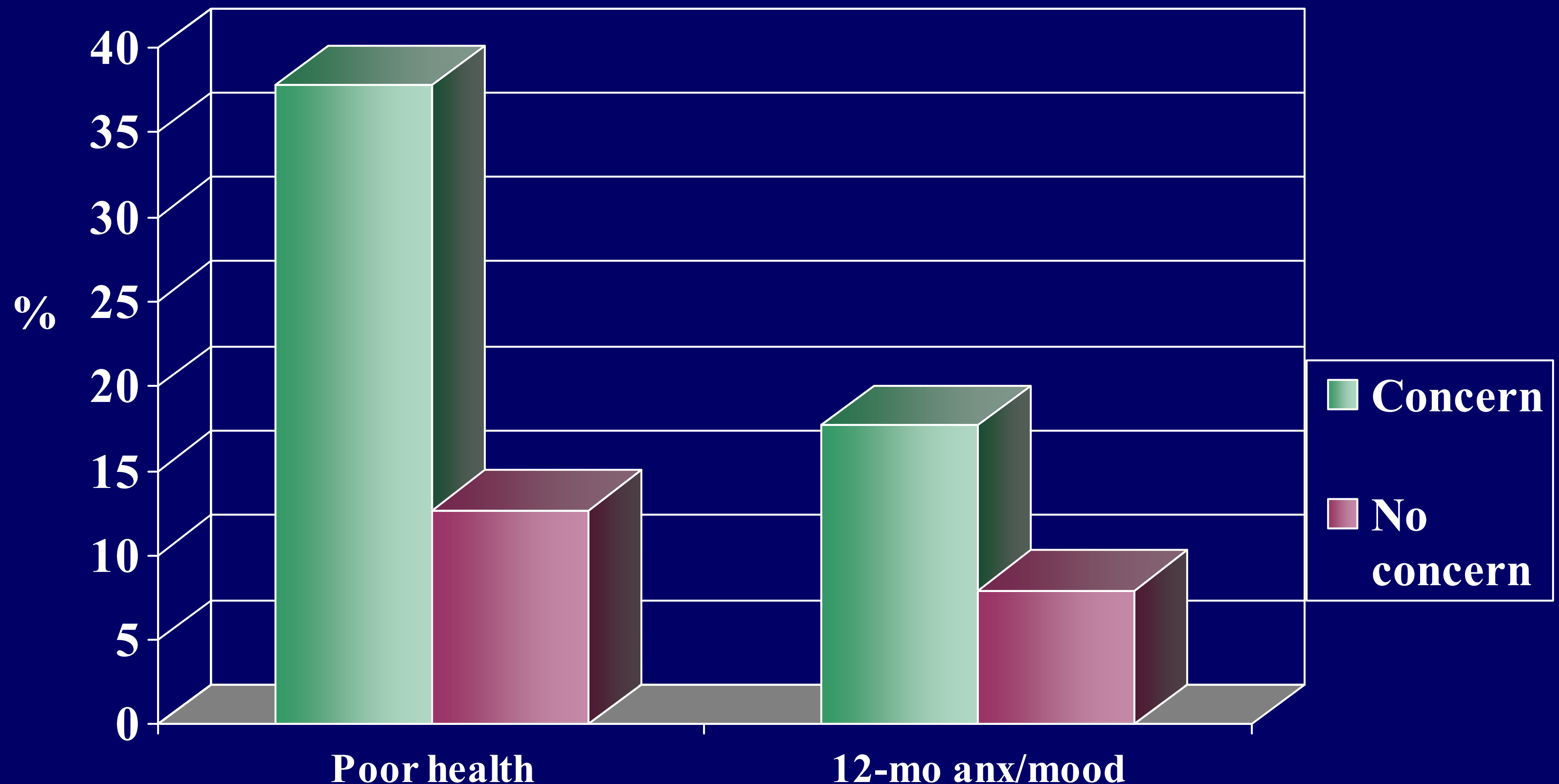
*Funded by NIMH

# Exposed vs non-exposed WMH respondents




380 expo; 4,345 not exposed

# Relationship of Chornobyl-health concerns to health & mental health: Exposed only (N=380)




56% of exposed were concerned about health effects of Chornobyl

# General population studies

Significant long-term consequences

Health-related anxiety from Chornobyl → crucial risk factor

# Sources of evidence

International Pilot Study of Brain Damage In-Utero (WHO) (age 7)

- Additional follow-up in Belarus
- Additional work in Kyiv RCRM

Stony Brook/Kyiv research (age 11)

Israeli study of children expo < age 4 (+ in utero)

# Cognitive Impairment in Children

Each study involved:

- a battery of neuropsychological tests of memory, intelligence, attention
- standard psychological evaluations
- non-exposed comparison group
- Separate analysis of children *in utero*

# Cognitive Impairment in Children

No differences by exposure:

*WHO study (from all 3 republics)

*Stony Brook/Kyiv

*Israeli study: from Gomel (hi expo; N=667), Mogilev & Kyiv (mild expo; N=408), and non-expo regions (N=564)

# Belarus study

1. Ages 6-7; follow-up ages 10-11
2. Low rate of mental retardation

   1.5% expo (N=138) vs 0.8% controls (N=122)
3. Rate of ICD-10 diagnosis*

   41% expo vs 21% controls ($p<0.05$)
4. No dose-response relationship
5. Attributed significant diff's to familial factors

*developmental delays, emotional disorders, tic disorders, etc.

# Kyiv RCRM study

1. N=544 exposed and 759 controls (Kharkiv)
2. Significant diff's in rates of borderline intelligence, mental retardation, emotional disorders, and EEG measures.
3. Subsample of 50 expo and 50 controls
   72% expo vs 28% controls ICD-10 dx
4. Attributed differences to radiation exposure

# Summary of neurocognitive effects in kids

Evidence equivocal

All studies have serious flaws

- *WHO*: flawed execution
- *Stony Brook*: underpowered
- *Israeli study*: sample selection
- *Belarus*: appropriate controls?
- *Kyiv*: appropriate controls? No adjustment for parental IQ and SES

Yet unproven; a-bomb evidence→no effect

# Two concerns

Neurocognitive impairment from radiation (3 reports)

Emotional or alcohol-related consequences of stress

# RCRM in Kyiv

Hypothesis: radiation→psychosis

Incidence of schizophrenia in liquidators from 1990-1997 ranged from 3.2/10,000 to 5.6/10,000 (vs 1.1/10,000 in Ukraine)

- No independent verification of dx
- Population rate ??
- No biological evidence

# Institute of Gerontology: Kyiv

Hypothesis: radiation→accelerated aging: “radiation progeroid syndrome”

Battery of medical and psychological tests to calculate “body age”
Accelerated aging = test value > mean pop value for individuals of same age

Rates of accelerated aging:
High exposure (<Sept ’86): 86% men; 90% women
Low exposure (>Sept ’86): 59% men; 60% women

Authors’ conclusion:
*effect of radiation-induced accelerated aging
*dose related

# Florida/Kiev Polytechnic Institute

Hypothesis: radiation→impairment in brain functioning

N=127 volunteers: a control group and 3 exposure groups (incl 36 eliminators from the RCRM)

Neuropsych battery 1995, 1996, 1997, 1998 (1 hour)

*Eliminators worst performance

*All grps declined over time ($p<0.001$)

??Adjust for age or education or alcohol hx

# Emotional problems: Gomel

Havenaar comm. study in Gomel (N=1617):

No differences between liquidators (~10% of pop) and the rest of the population on GHQ-12 or on psychiatric diagnosis

But not all liquidators were exposed to radiation or stressful conditions

# Emotional effects: RCRM sample

Self-administered MMPI and GHQ-12

Compared liquidators with low (<0.3 Sv; N=54) vs high exposure (N=146)

No differences

# Emotional problems: Kyiv/SB

53% of husbands were liquidators (median age=38)
Asked mothers about their husbands' health

Number of chronic illnesses

Liquidators 2.8$\pm$2.7 vs 1.2$\pm$1.6***

Vascular dystony

Liquidators 38.3% vs 5.9%***

No diff's in smoking or alcohol

# Suicide: Estonia

Rahu et al. 1997

Cohort of ~5,000 cleanup workers assembled in 1992; ave. age at arrival at C. = 32 yrs

No significant excess of cancer deaths (1986-1993)

Significant excess of suicide (SMR=1.52; 95% CI=1.01-2.19)

# Suicide in liquidators (cont)

Rahu et al. (Estonia)

Attributed “substantial excess” to:

1. Forced recruitment
2. Uncertainty about radiation dose and its effects
3. Future radiation-related health risks

# Summary on mental health of liquidators

- Studies of neurocognitive effects are flawed and not convincing
- Suicide findings suggest major emotional aftermath

# Emotional toll

- Long-term, protracted effects on general pop. (especially women and mothers)
- Potentially strong psychological effects in liquidators
- No compelling evidence of brain effects in children or liquidators

# Are the findings from Chornobyl unique?

- Findings are consistent with research on other toxic exposures
- Consistency of the basic findings with other research is crucial aspect of one's ability to generalize (Rothman & Greenland 1998)

| | |
|---|---|
| TMI | A-bomb |
| Bhopal | Tokyo gas attack |
| Chemical spills | Persian Gulf |
| Toxic waste leaks | Occup. Exposures |

# Future directions

- Research on the liquidators
- Analytic epid. studies of risk and protective factors for psychiatric problems
- Three specific targets:

  Medical professionals/health authorities

  Local research communities

  Participants in ongoing research studies

# Rehabilitation of Living Conditions in Territories Contaminated by the Chernobyl Accident: The ETHOS Project

*Jacques LOCHARD*

*Centre d'étude sur l' Evaluation de la Protection dans le domaine Nucléaire (CEPN) - France*

**NCRP Annual Meeting : Chernobyl at Twenty**

**Crystal City Forum, Arlington, Virginia**

**April 3-4, 2006**

# The context of post-accident management in the early 90s

- The public rehabilitation strategies fails to take into account the complexity of the situation created by the long lasting contamination
- Loss of quality of products, commodities and assets
- Inhabitants of the contaminated territories are helpless in front of the contamination
- General feeling among the population of loss of control on daily life, exclusion and abandonment
- Rising concern about the presence of contamination and its potential health consequences
- Loss of confidence in experts and authorities

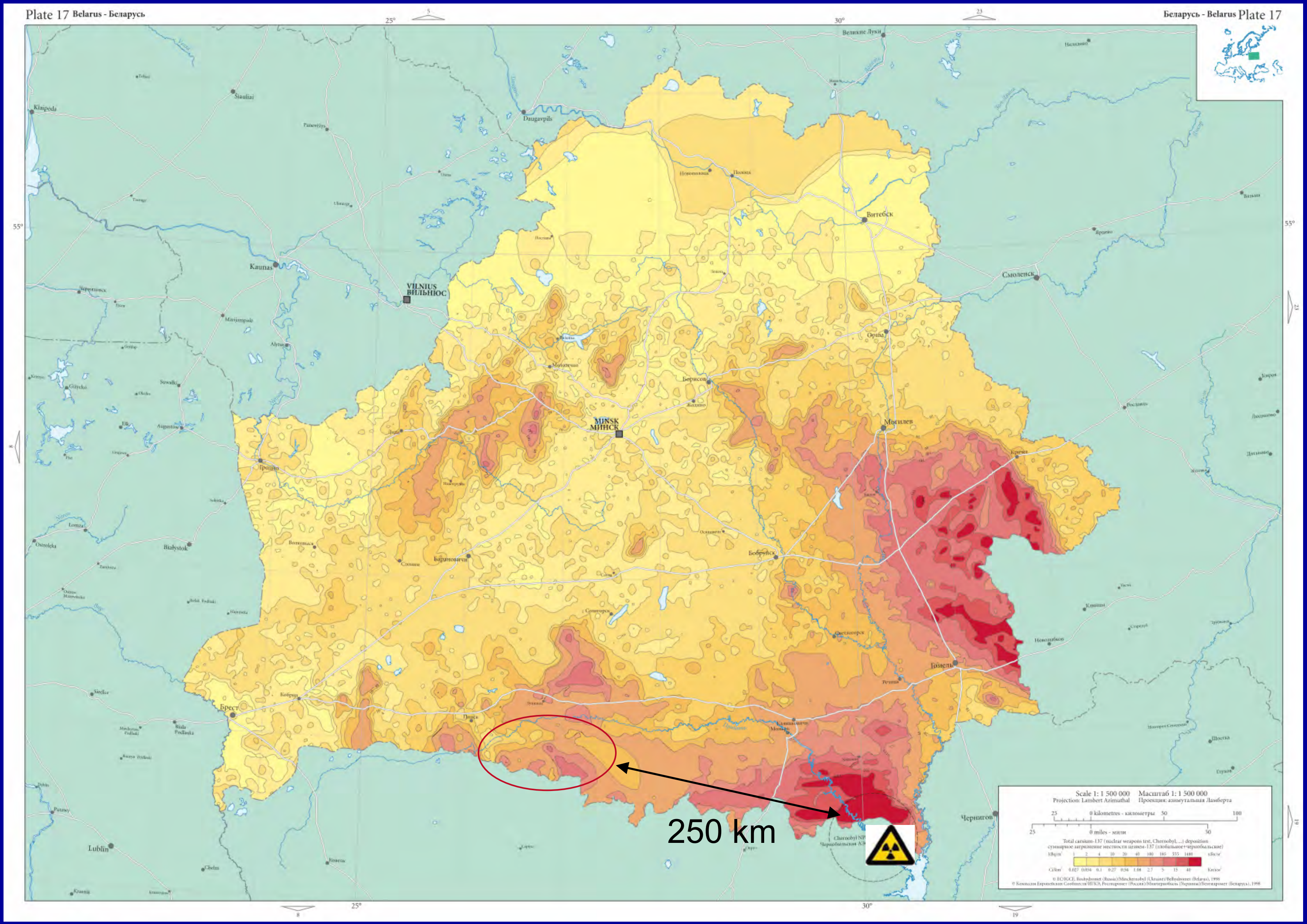
# Why the ETHOS Project in 1996 in Belarus ?

- Despite the large programme of countermeasures implemented by the authorities the radiological situation is worsening:
  - the general economic crisis in the Republic pushes toward a restart of private production
  - the population is generally adopting a resignation attitude vis-a-vis the contamination
  - however the concern on the effects of contamination on health is persisting
- How, in this new context improve the protection of the population living in the contaminated territories ?

# The ETHOS Project

- A pilot project supported by the European Commission to explore new strategies in cooperation with the Belarus Chernobyl Committee to :
  - involve directly the local populations in the management of the radiological situation
  - with the perspective to improve their living conditions on a long term basis
- A multidisciplinary team of 12 members : radiation protection, agronomy and local development, sociology, psychology
- Implemented in the Stolyn District in the South of Belarus, about 250 km East from Chernobyl

# Map of soil contamination of Belarus



# The ETHOS methodology (1)

- An original approach :
  - addressing jointly technical and societal dimensions with a focus on the improvement of the day-to-day quality of life affected by the contamination
  - involving actively all local, regional and national stakeholders in a decentralised approach complementary to the State rehabilitation programme
- An ethical position: the decision to stay or to leave the contaminated territories remains the responsibility of each family

# The ETHOS methodology (2)

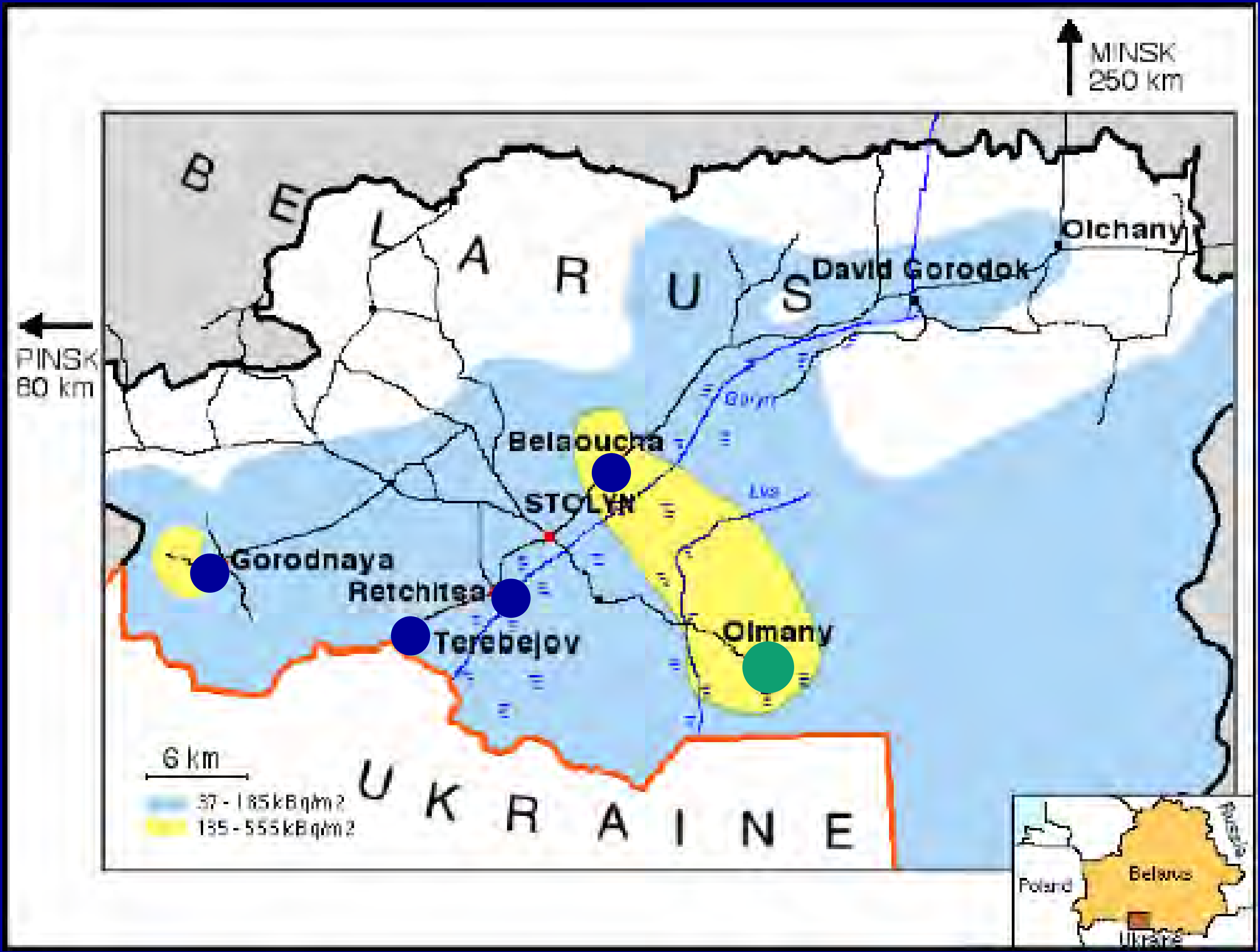
A 5 steps process:

- listening to and learning from the villagers about their concerns and priorities
- setting-up of working groups on specific practical projects
- common expertise and re-qualification of the radiological situation with voluntary stakeholders (measurements, analysis of local habits,…)
- co-identification of actions to improve the radiological quality of foodstuffs and the protection of the inhabitants
- implementation of actions with the support of local professionals and authorities

# Phase 1: 1996 - 1998

- Village of Olmany - 1300 inhabitants
- Co-operation agreement between the Ministry of Chernobyl, the district and village authorities and the ETHOS team
- 12 missions of the ETHOS team- more than 100 days of presence in the village
- 6 working groups involving about 100 inhabitants :
  - protection of children,
  - production of clean milk,
  - commercialisation of clean meat,
  - education on practical radiation protection at school, management of contaminated wastes,
  - shooting of a video film

# Cesium contamination of the Stolyn District



# Phase 1 : 1996 - 1998

## - Main results -

- Significant improvement of the radiological quality of milk
- Reduction of about 1/3 of the internal contamination of young children
- Re-establishment of the marketing of milk and meat produced in the village

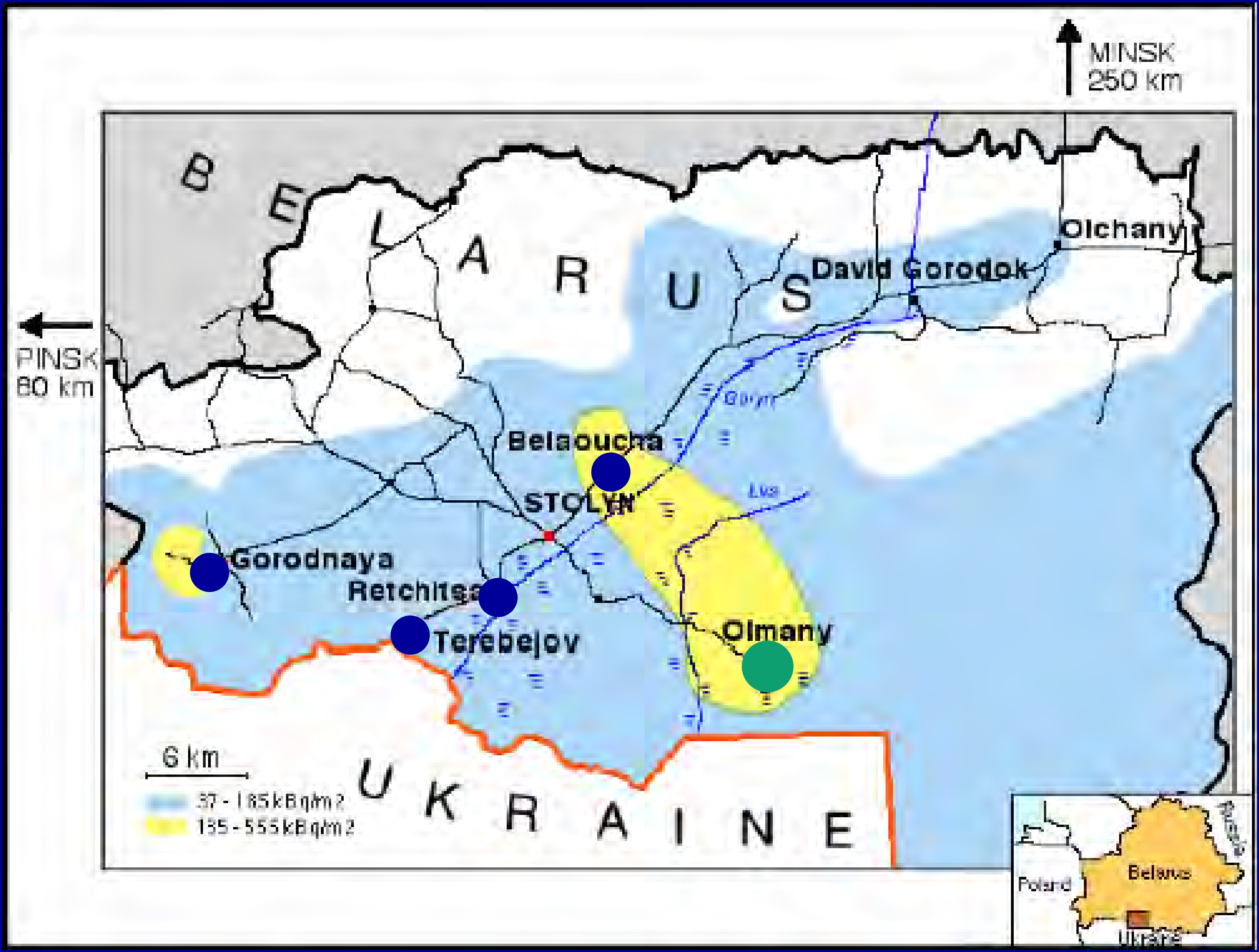
But also:

- Recovery of self confidence and initiative among the inhabitants
- Significant restoration of public confidence and social trust

# Phase 2 : 2000 - 2001

- Request in 1999 from the local and national authorities to widen the approach in 4 other villages in the Stolyn District
- Involvement of local professionals and Belarus regional and national research institutes to :
  - improve the radiation and health surveillance of children
  - produce and market foodstuffs with improved radiological quality
  - develop a practical radiation protection culture at school
  - develop a radiation monitoring at the service of the population
- 8 missions in the District co-financed by the European Commission and French organisations

# Cesium contamination of the Stolyn District



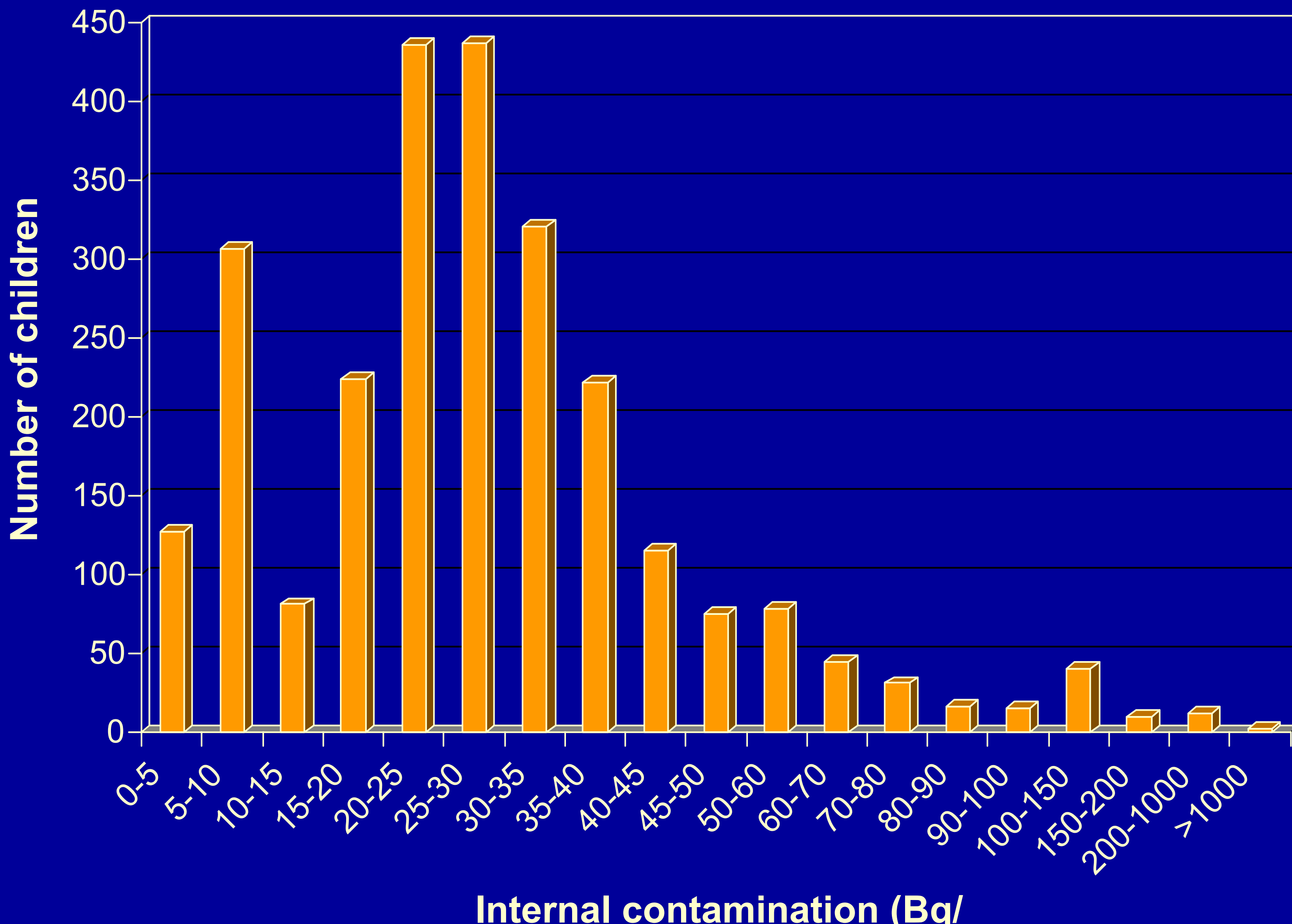
# Phase 2: 2000 - 2001
## - Main results (1) -

- The development of an operational system for the measurement of external dose rates, the contamination of foodstuffs and the internal contamination of inhabitants
- The successful testing of a new technique for the production of good quality potatoes by private farmers
- The delineation of the key elements of a practical radiological protection culture for living in contaminated territories

# Phase 2: 2000 - 2001
## - Main results (2) -

- A co-expertise of the radiological situation of each village validated by all parties :
  - contamination maps
  - range of contamination of foodstuffs
  - radiological quality of milk according pastures
  - distribution of internal contamination
  - margin of manoeuvre on daily intake of children
- The Stolyn International Seminar: 15-16 November 2001
  - 150 local, national and international participants
  - presentation of results by stakeholders
  - final declaration calling for a new initiative building on the results of the ETHOS project

# Results of a whole body campaign



# Influence of the level of contamination of foodstuffs on the daily intake of a child

| | | Maximum contamination | | Minimum contamination | |
|---|---|---|---|---|---|
| Foodstuff | Grams | Bq/kg | Ingested Bq | Bq/kg | Ingested Bq |
| ŹBread | 250 | 60 | 15 | 10 | 2.5 |
| ŹButter | 10 | 400 | 4 | 30 | 0.3 |
| ŹVegetable soup | 300 | 100 | 30 | 10 | 3 |
| ŹMeat | 200 | 300 | 60 | 10 | 2 |
| ŹStewed apples | 150 | 100 | 15 | 10 | 1.5 |
| ŹSauerkraut | 300 | 50 | 15 | 10 | 3 |
| ŹPotatoes | 100 | 100 | 10 | 10 | 1 |
| ŹStewed Źmoorberries | 200 | 2000 | 400 | 100 | 20 |
| ŹChocolate milk | 100 | 2000 | 200 | 10 | 1 |
| | | **Total** | **749** | **Total** | **34.3** |

# Key lessons

- The direct involvement of the population in the day to day management of a contaminated territory is feasible and also necessary to break the vicious circle of exclusion and loss of control
- This involvement must rely on the dissemination within all segments of the population of a "practical radiation protection culture" based on 3 pillars: radiation monitoring, health surveillance and education at school
- To be effective and sustainable, it must also rely on :
  - the social and economic development of the territories
  - a responsible health care approach responding to the precautionary principle
  - a local, national and international co-operation

# Conclusion

- The ETHOS had a large influence on the reflection and development of the science of stakeholder involvement in radiation protection

  ( Cf. NEA/CRPPH recent report on Stakeholders and Radiological Protection: Lessons from Chernobyl after 20 years )

- The ETHOS Project was a turning point in the rehabilitation policy of Belarus and the basis for the development of the CORE Programme (2004 - 2009)

  www.core-chernobyl.org/en/

  and the reflection on rehabilitation strategy preparedness in Europe

  (Cf. SAGE and EURANOS projects)

# LESSONS LEARNED FROM EMERGENCIES: ESTABLISHING INTERNATIONAL REQUIREMENTS AND GUIDANCE

Thomas McKenna,
Elena Buglova, Vladimir Kutkov
NSRW/NS

IAEA
International Atomic Energy Agency

# Severe emergencies were not considered in the preparedness process

- Because considered inconceivable
- Not considering contributed to:
  - Occurrence of accident – TMI
  - Health effects (on and off-site)

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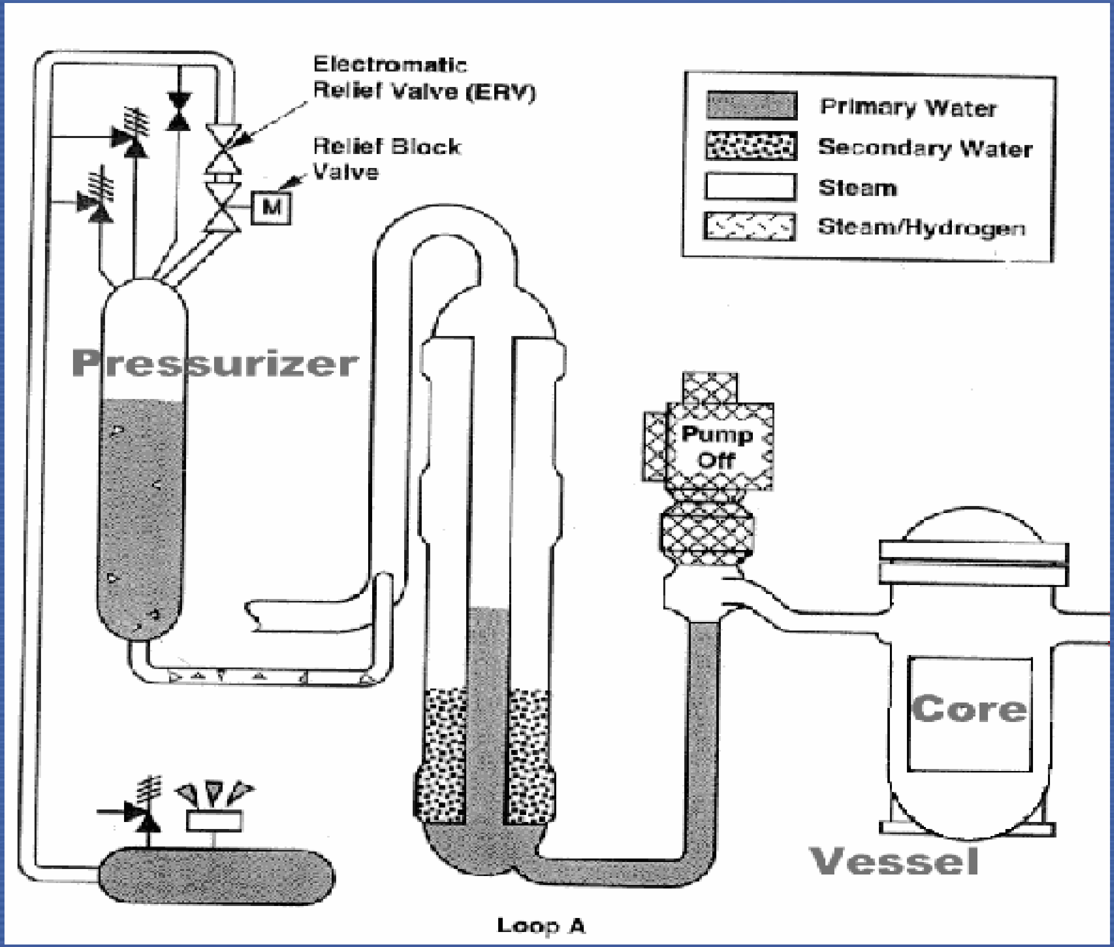
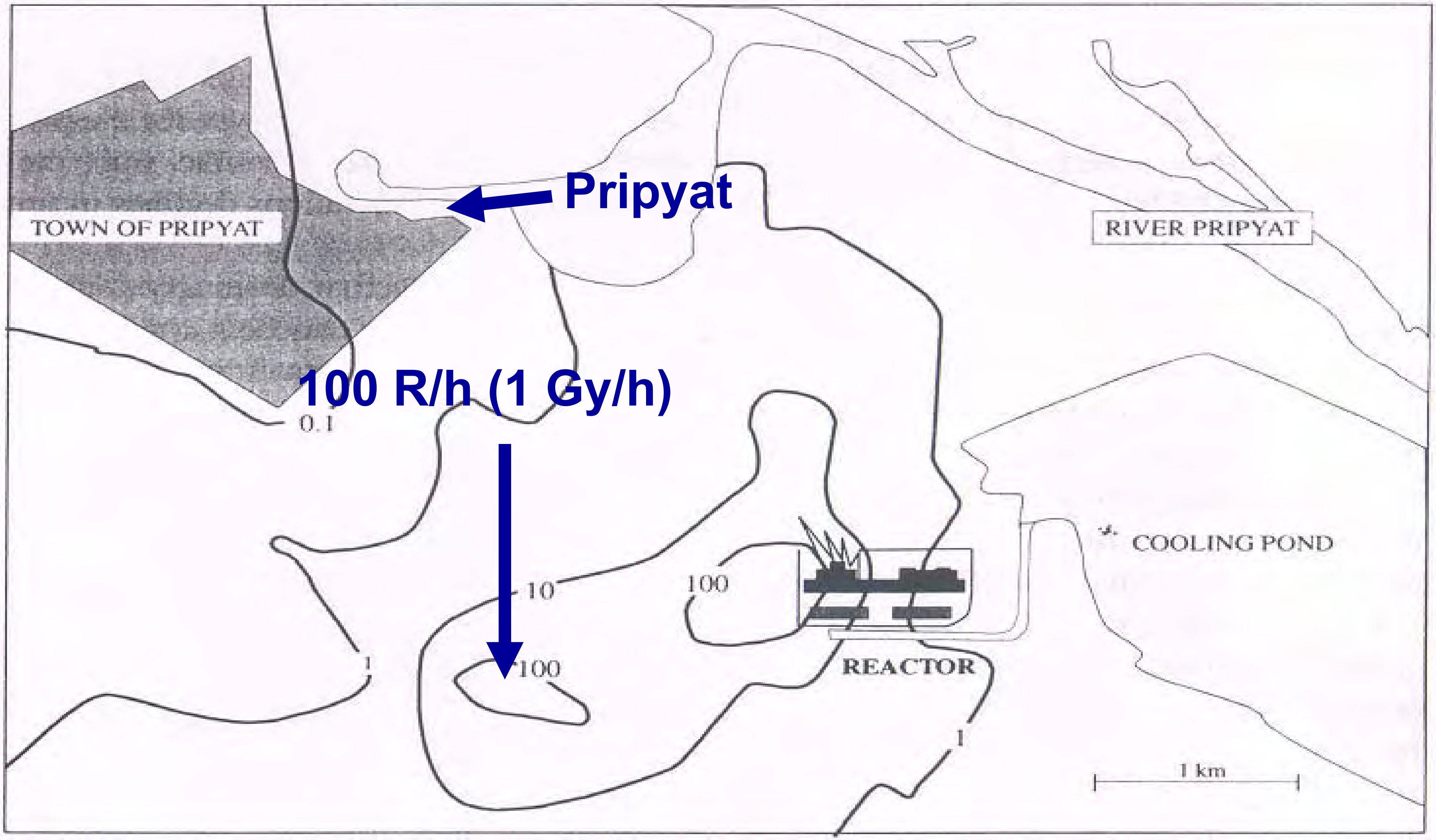
# TMI Emergency – operators could have prevented core melt



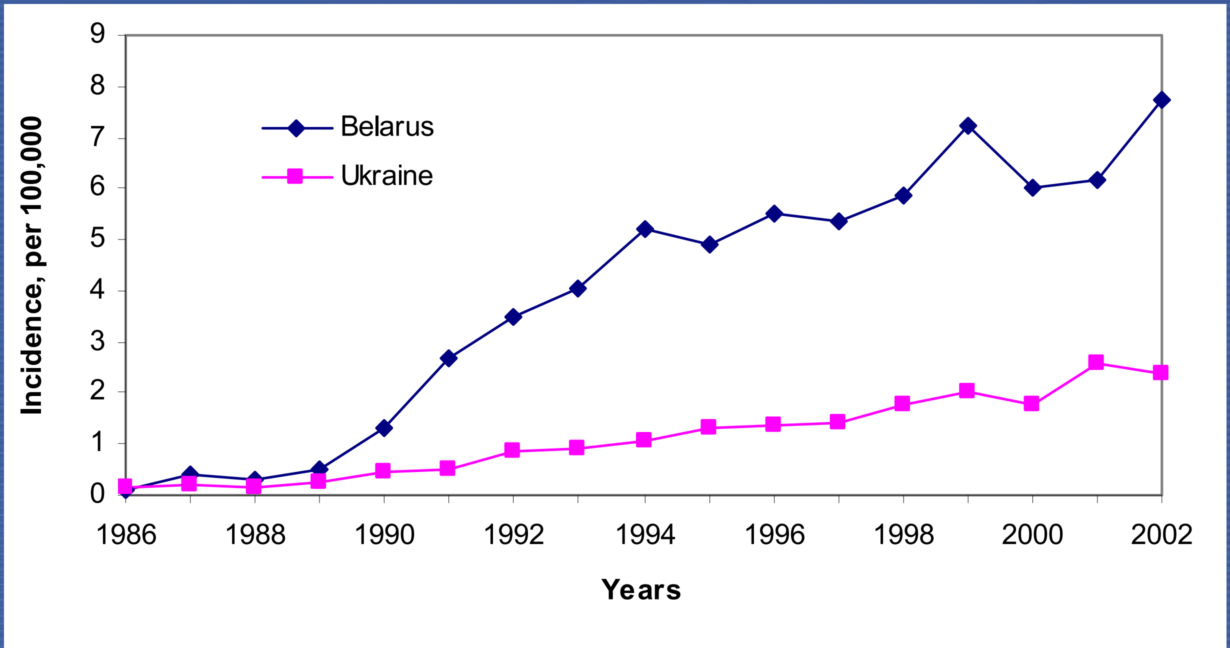

Operators turned the ECCS coolant water off because the pressurizer indicted the vessel was full of water. IT WAS NOT!!!

# Dose rate near Chernobyl, R/h: Delay in action could have been fatal



# Preventable thyroid cancers

- Rapid increase of incidence in children
- Caused by ingestion of milk and leafy vegetables contaminated by $^{131}I$
- Could easily have been prevented




**Incidence rate of thyroid cancer in children and adolescents exposed to $^{131}I$ as a result of the Chernobyl emergency**

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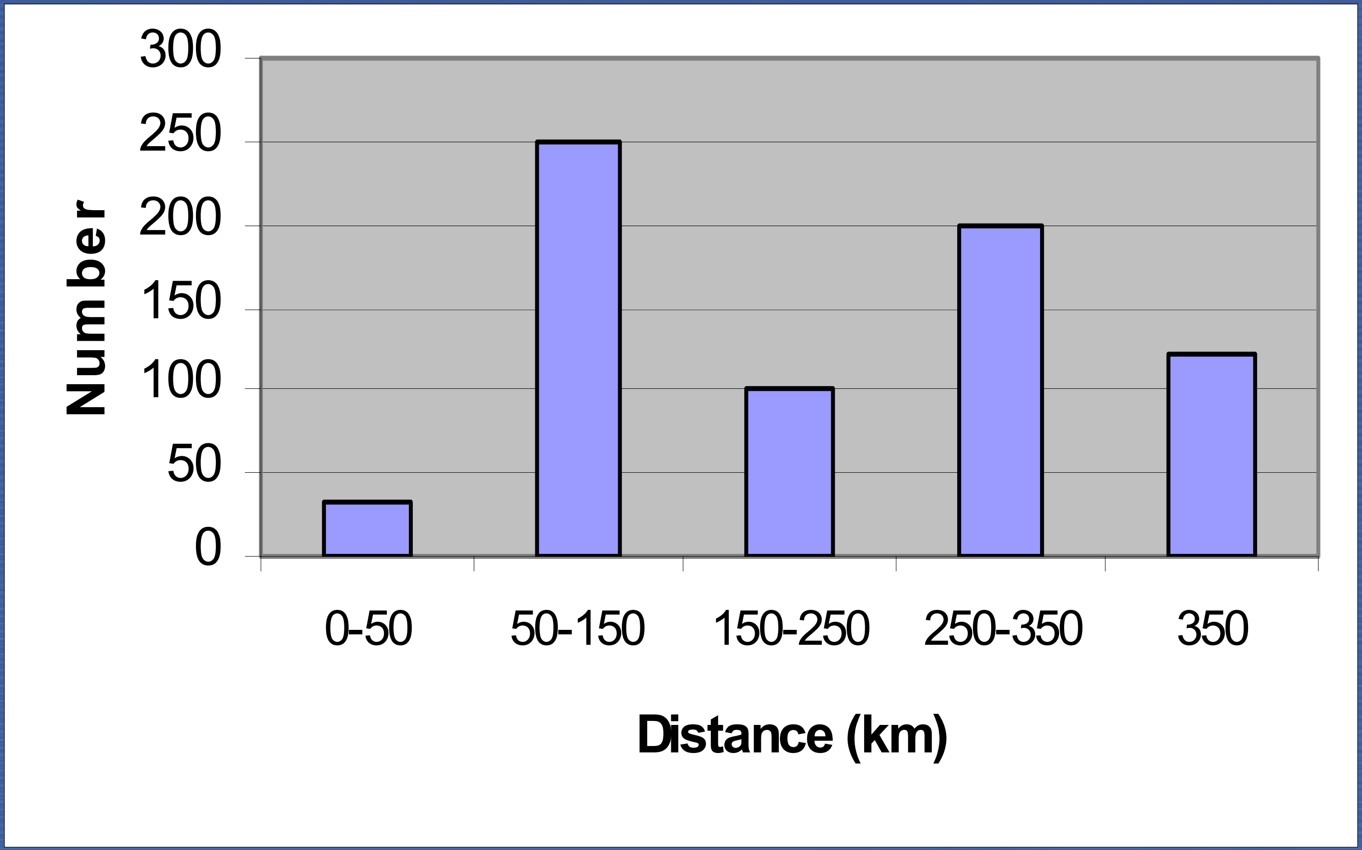
# Belarus: Thyroid Cancer occurred among population at over 300 km from Chernobyl NPP




Among those 0-18 years old at time of Chernobyl accident

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# Criteria developed after emergency can do more harm than good

- Not based on radiation protection principles
- Based on criteria developed during emergency and associated with:
  - Mistrust
  - Emotions
  - Political pressure

**Example: Belarusian action levels for Cs content in milk after Chernobyl accident**

| | | | | | | |
|---|---|---|---|---|---|---|
| Year of approval | 1986 | 1988 | 1990 | 1992 | 1996 | 1998 |
| Action levels, Bq/l | 370 | 370 | 185 | 111 | 111 | 100 |

# International criteria is not complete
# Example: No criteria for decontamination

Thousands may come - no criteria:

- Increased perception of risk
- Poor allocation of resources
- Inappropriate placement into the registry for long term medical follow up

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# Medical community

- Often first to identify radiological emergency
  - Sometime takes several visits
- Reluctant to treat contaminated patients
- Not aware of need for specialized treatment
- Do not understand risk
- Have given inappropriate advice
  - e. g. for pregnant women

# International criteria is not complete Example:

- Does not cover:
  - protection of foetus
  - counselling of pregnant women
  - plain language explanation of radiation health effects and risks

**Thousands of unjustified abortions (no detectable effects expected) after Chernobyl accident**

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# Actions are taken by decision makers and public

They:

- are not experts
- do not understand basis for recommendations (e.g. Sv, averted dose, etc)
- experts can not explain


**Therefore could not make informed decisions**

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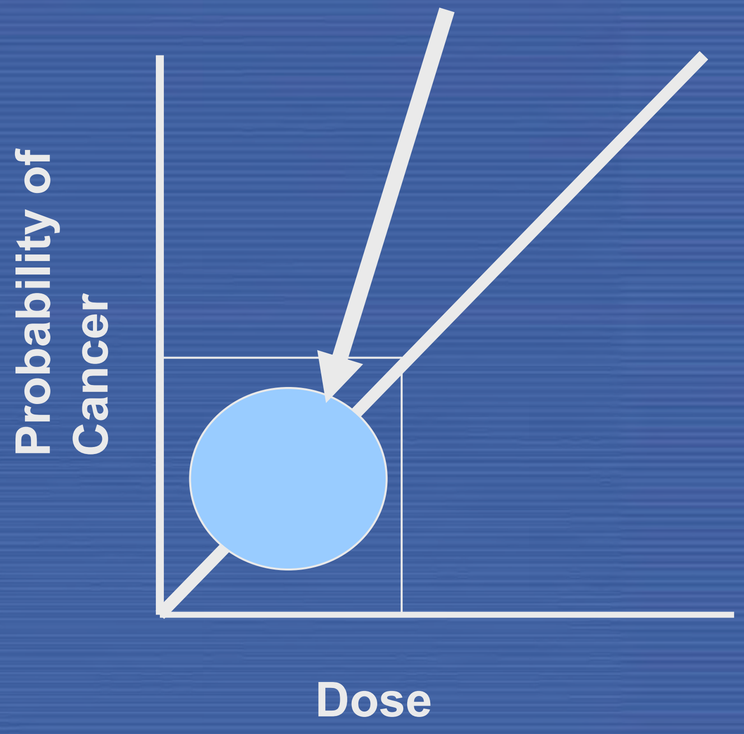
# Big problem: There will be people using the LNT model during emergency to project deaths

Chernobyl: using LNT "experts" estimated 50000 deaths among pubic – but in fact will not see any

LNT is intended for radiation protection only (regulation)

What is the public think?

Below – 100 mSy (10 rem) Even in thousand – have not see any excess

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# Big lesson: International criteria is:

**Not compete – dose not cover:**

- Faculty conditions
- Individual decontamination
- Immediate medical treatment and follow-up
- Medical consultation, e.g.  pregnant women
- Resumption of normal activity
- All pathways and radionuclides
- Protection of trade etc….

**Not useable by decision makers or responders – no understandable explanation**

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# TECDOC objectives

- Expand existing criteria for taking protective and other actions
  - Address lessons
  - Address recently published requirements
  - Address range of conditions
  - Provide basis for operational criteria
- Propose common language explanation to allow decision makers and public make informed decisions

# Basic scheme

- **Effect** → Generic Reference Levels (GRLs)
  - **E.g. – Gy**
  - **Preparedness**
- **GRLs** → Operational Intervention Levels (OILs)
  - **E.g. Sv/h**
  - **Actions/decisions**
- **OILs** → Plain language
- **Plain language** → Public Actions

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# Basic Scheme for GRL s

| HEALTH EFFECTS | RESPONSE ACTIONS | MEDICAL ACTIONS |
|---|---|---|
| Severe deterministic effects possible | Precautionary actions to prevent | Treat |
| High individual risk or detectable increase in cancer in large populations<br><br>Detectable effects from foetal exposure | Justified urgent protective actions<br><br>Justified longer term protective actions | Evaluate for possible follow-up Counselling |
| May be safe – areas at this level – no known effects<br><br>Known to be safe – many areas at this level – no effects | Return to normal – no intrusive actions | No actions – reassure |

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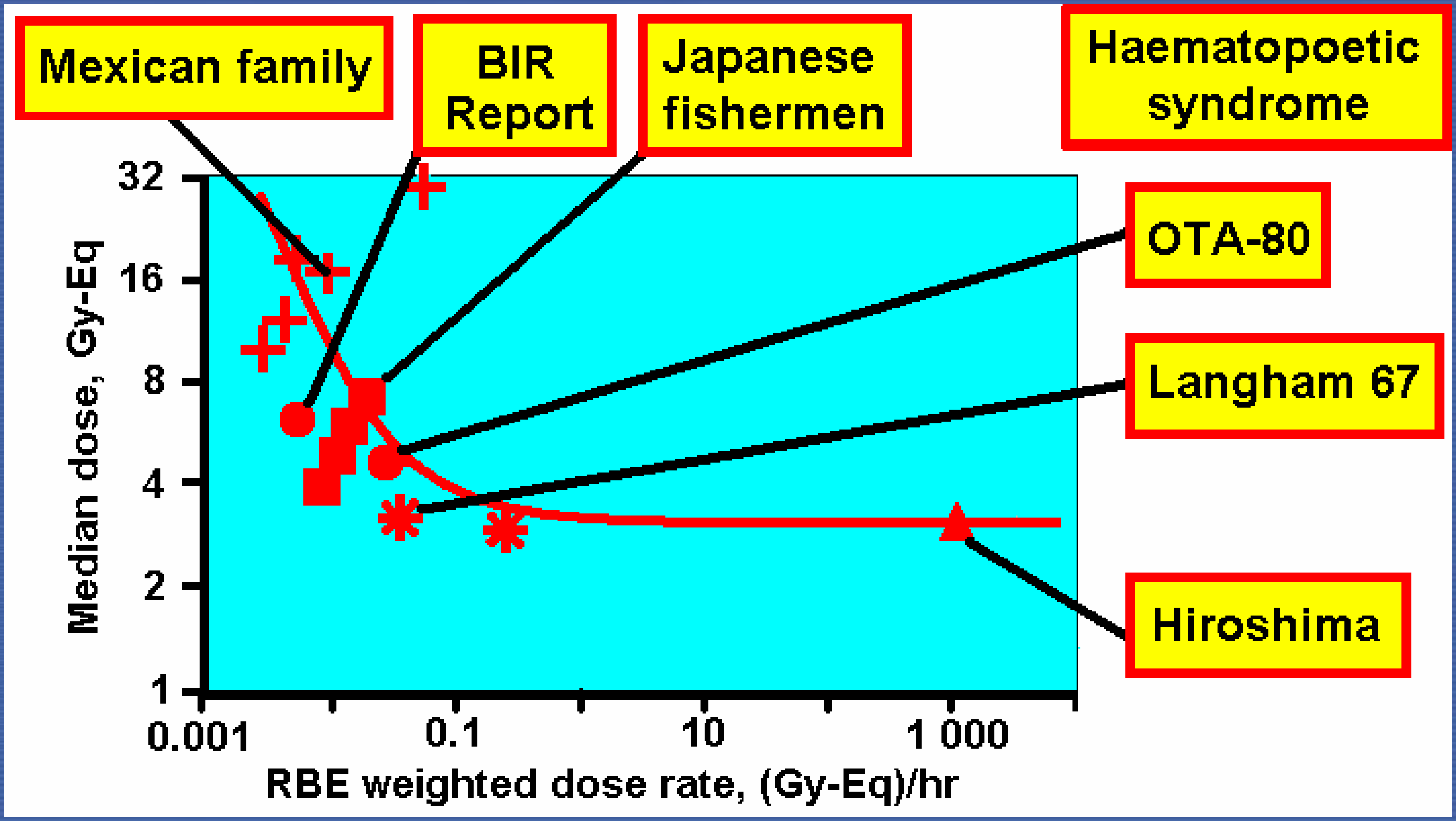
# Effects of external dose rate

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# GRLs - severe deterministic effects - external exposure

| Critical organ | GRL, Gy-Eq |
|---|---|
| **Whole body exposure to a distant source** | |
| Lens of the eye and testes | 1 |
| Embryo reduction in IQ | 0.1 |
| **Contact with an adjacent source (e.g. by carrying)** | |
| Soft tissue necrosis | 25 |
| **Large area of the skin (e.g. from contamination )** | |
| Skin - Moist desquamation | 10 |

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# GRLs - severe deterministic effects - intake

| Organs | GRL, Gy-Eq | Conditions |
|---|---|---|
| Red marrow | 0.2 | Intake of nuclides with Z>89 |
| | 2 | Intake of nuclides with Z<90 |
| Lung regions | 30 | Inhalation |
| Colon | 20 | Intakes |
| Thyroid | 2 | Intakes |

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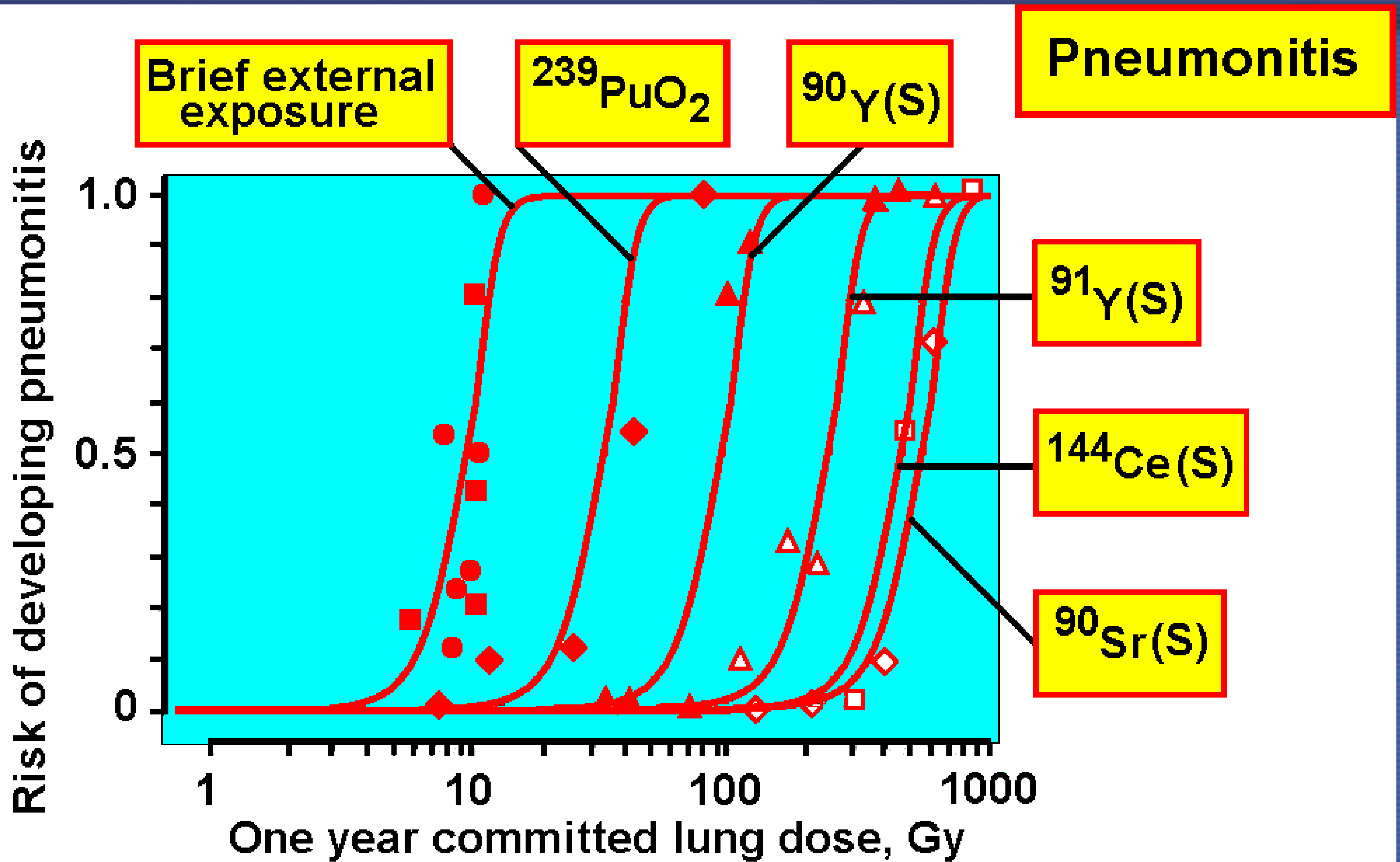
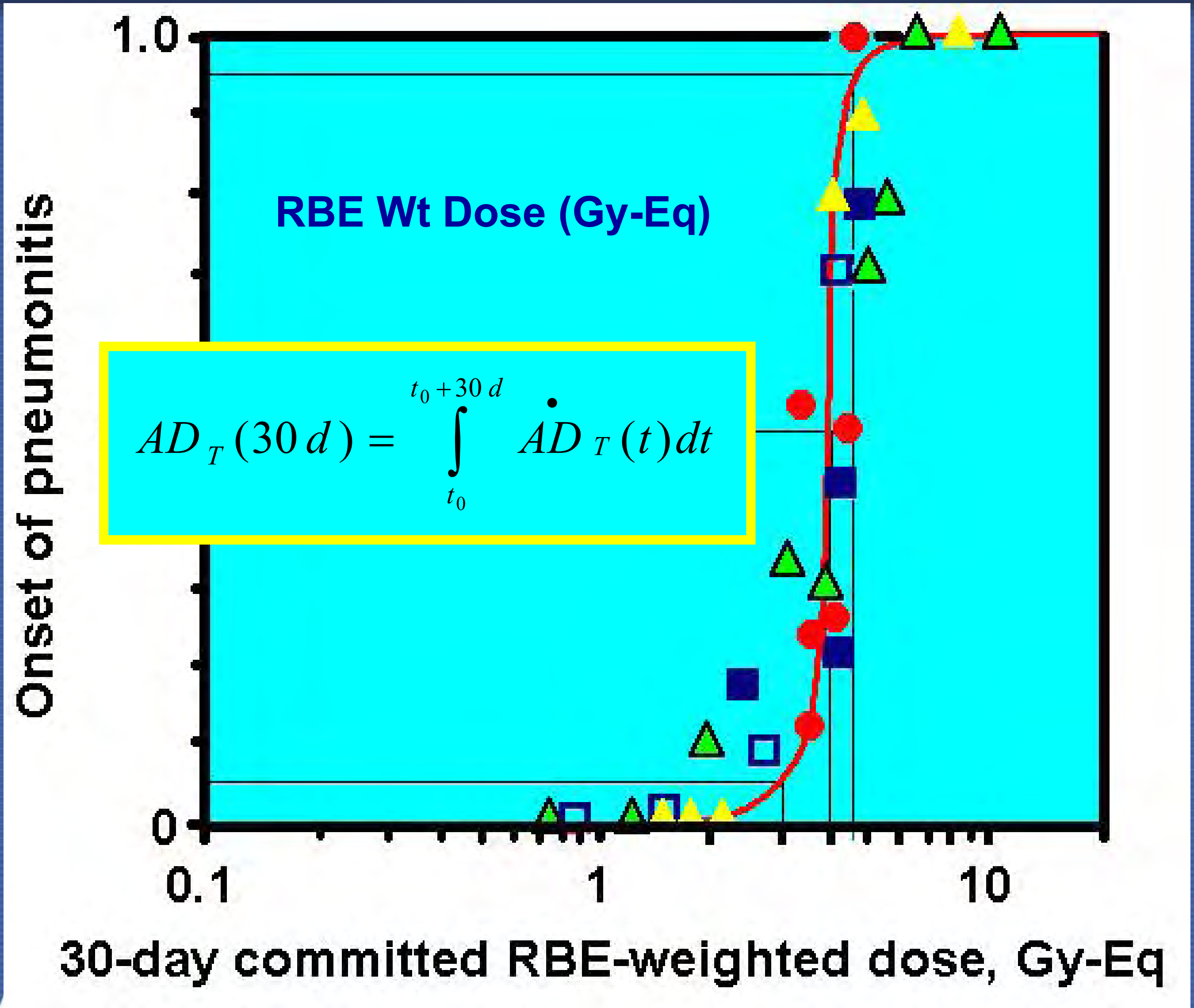
# Risk - internal exposure (absorbed dose)



# RBE-weighted dose as basis for criteria – to normalizing criteria




$$AD_T(30\,d) = \int_{t_0}^{t_0+30\,d} \dot{AD}_T(t)\,dt$$

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# GRLs to reduce and treat stochastic effects

**Actions to early detect and effectively treat radiation-induced cancers and other health effects (possible detectable effects)**

$E_T$: 0.1 Sv in weeks – month

$H_{Thyroid}$: 50 mSv

$H_{Foetus}$: 0.1 Sv in months

**Urgent protective actions (Basically existing guidance)**

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# GRLs to reduce and treat stochastic effects

| Longer term protective actions (Basically existing guidance) |
|---|
| Discontinue disruptive protective and other actions (clean-up criteria)<br><br>$E_T$:10 mSv per annum<br>$H_{\text{Any other organ}}$: 0.1 Sv per annum |

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# Summary

- Past emergencies showed existing international guidance is:
  - Incomplete
  - Does not provide a basis for informed decisions by public
- IAEA has underway to address these shortcomings

# Thank you

Thomas McKenna
International Atomic Energy Agency
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IAEA

# Public Perception of Risks, Rehabilitation Measures and Long-Term Health Implications of Nuclear Accidents

**Shunichi Yamashita, MD**

**World Health Organization**

**yamashitas@who.int**

# WHO-SMHF Declaration in Moscow, May 31, 2001

. . . . . . . . .

With the introduction of the new concept of "environmentally sound sustainable development" and from the viewpoint of "protecting the human environment", we are required to review the consequences of this accident, to further clarify both radiation-induced and non-radiation-related late health effects and to assess and understand them for the future welfare of society.

. . . . . . . . .

The international community is invited to participate in the effort to maintain the long-term follow-up of irradiated victims, to support field oriented radiation research and to improve the health care of children and others affected by the Chernobyl accident.

# Nuclear Security = IAEA
# Life Safety = WHO

**Human Security and Safety**

Environmental Factors

Human Body

Sensing

Guidance, Recommendation, Intervention
for Prevention, Diagnosis and Treatment

Monitoring

**High Technology and Health Promotion**

# Questions and Answers

**Questions;**

1. **What is the real problem around Chernobyl?**
2. **What is the target population secured?**
3. **What is the target disease?**

**What is the *STRATEGY for RECOVERY***
**around Chernobyl**
**at the standpoint of *PUBLIC HEALTH*?**

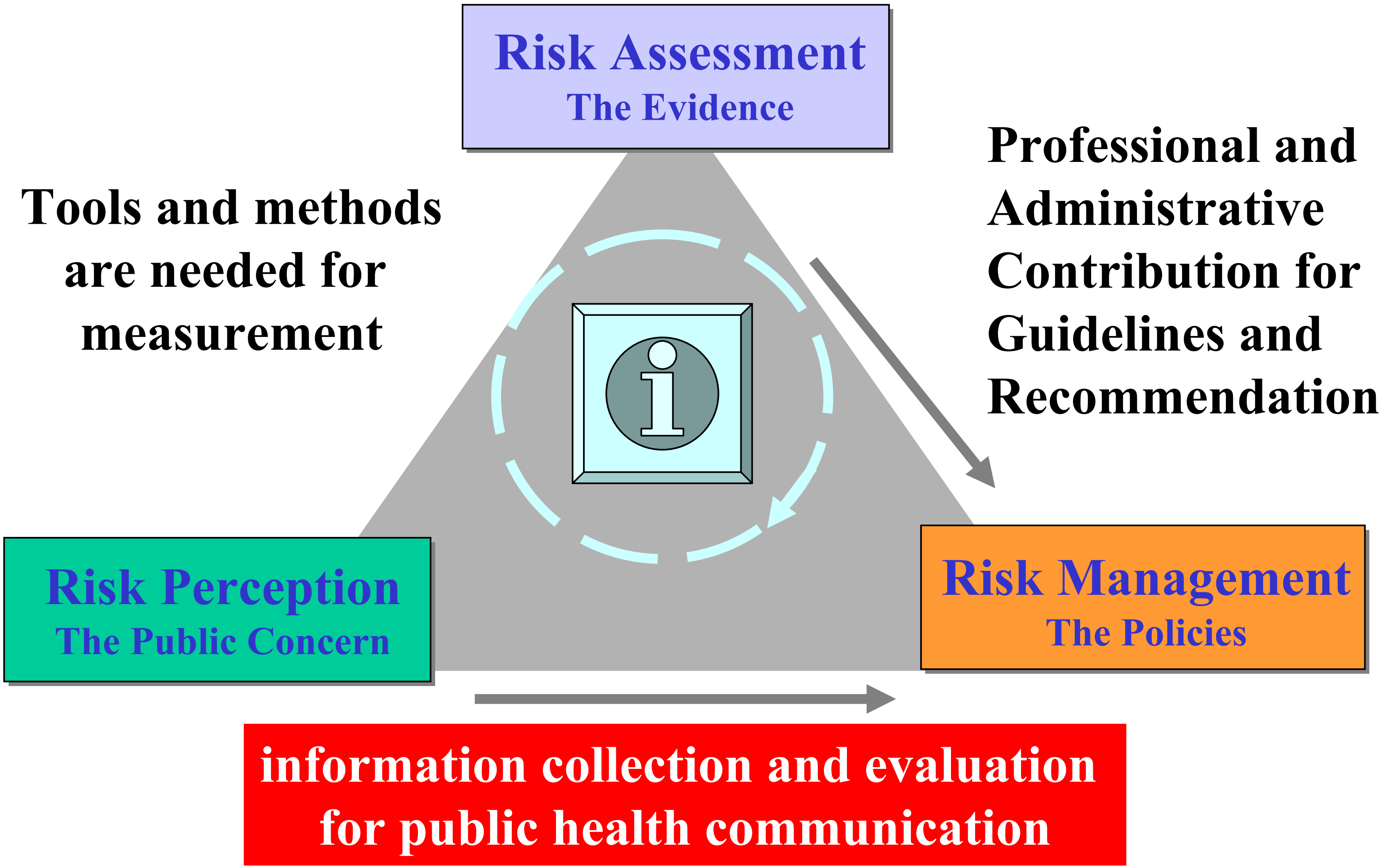
# Chernobyl-related Late Health Effects

1. Radiation-induced
2. Non-radiation-related

# Elements of Risk Perception

- Extent of health risk
- Probability of occurrence
- Uncertainty
- Ubiquity
- Pattern of exposure
- Delayed effect
- Inequity and injustice
- Poverty and stress
- Voluntary vs. involuntary exposure

# Managing Environmental Risks

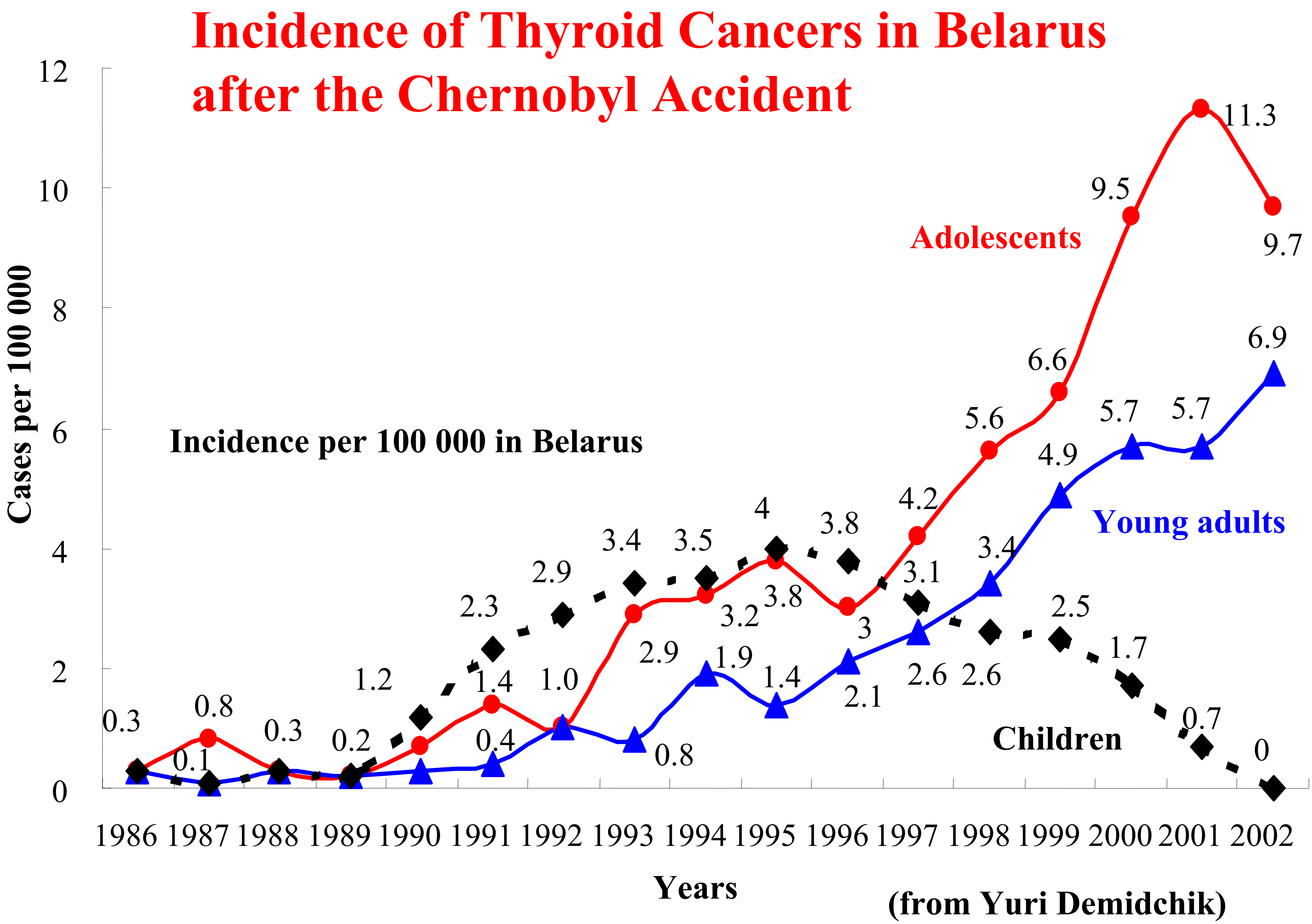


# Health Care and Research through WHO Radiation Projects around Chernobyl

**Information and communication**

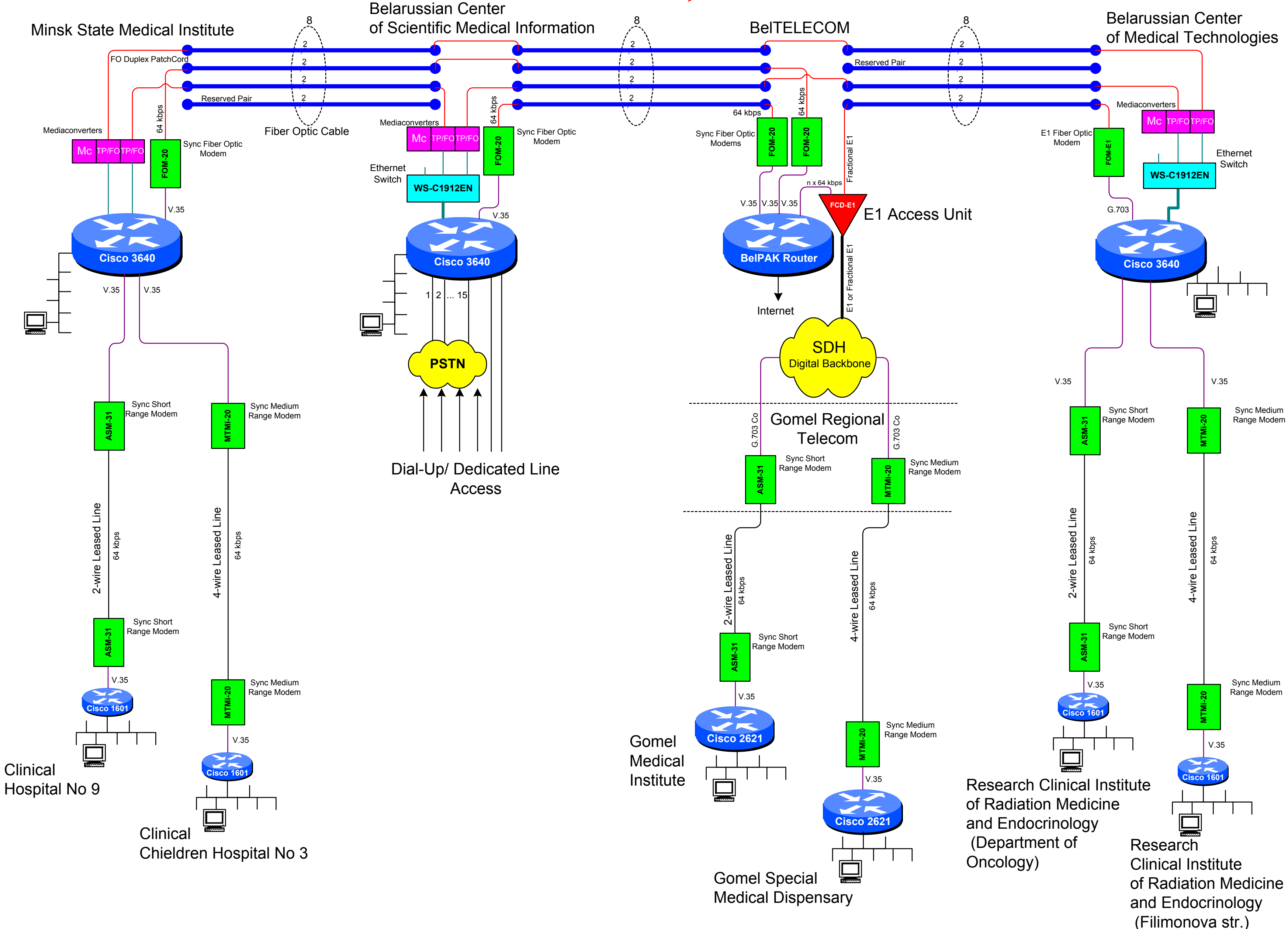
**Health care programs and medical monitoring**

**Future research and follow-up studies**

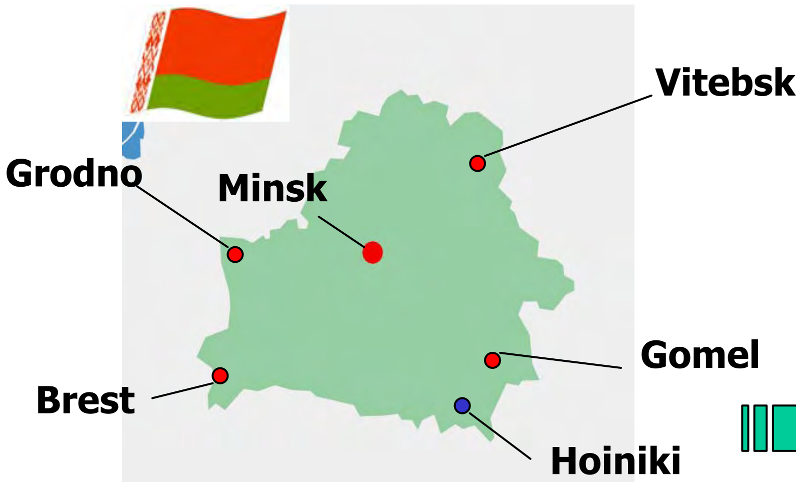


Incidence of Thyroid Cancers in Belarus
after the Chernobyl Accident
Cases per 100 000
Incidence per 100 000 in Belarus
Adolescents
Young adults
Children
Years
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002
0 2 4 6 8 10 12
(from Yuri Demidchik)

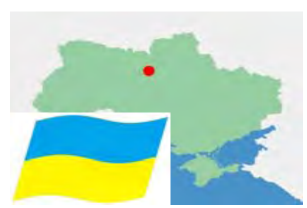
# Establishment of Infrastructure of Telemedicine in Minsk and Gomel, Belarus



# Future Development of Telemedicine within and beyond Belarus




Development of Telemedicine within Belarus



Long-term health monitoring center and databank will be supported

Telemedicine from Belarus to Ukraine and Russia for Chernobyl Medical Assistance

# Chernobyl Tissue Bank

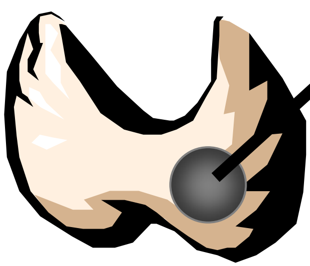
## International Cooperative Project

(EU, NCI, WHO, SMHF)

http://www.chernobyltissuebank.com

DNA and RNA
Extraction and Gene Bank

Training from 3NIS centers

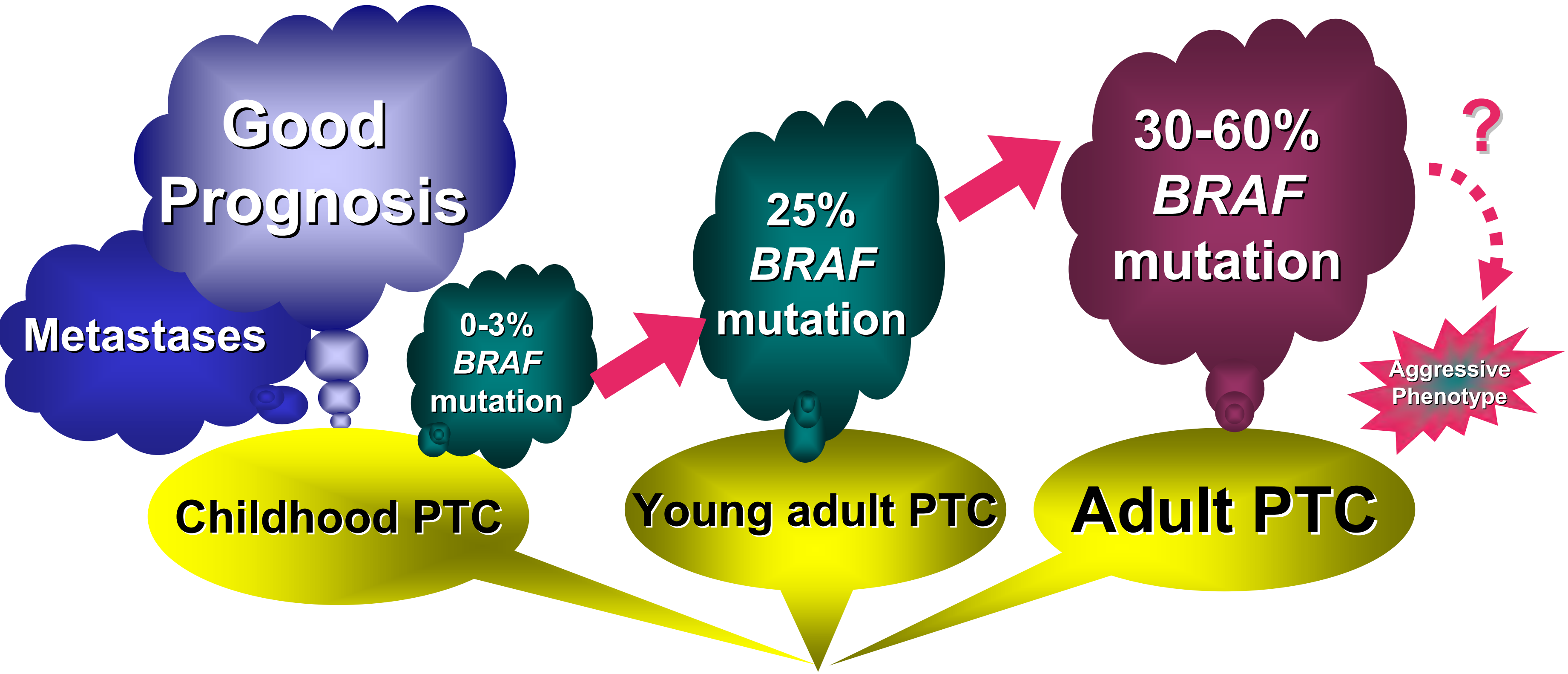


Operated thyroid tumor tissues with surrounding normal areas
in Belarus, Russia and Ukraine

Scientific Project Panel and Pathology Panel Meetings

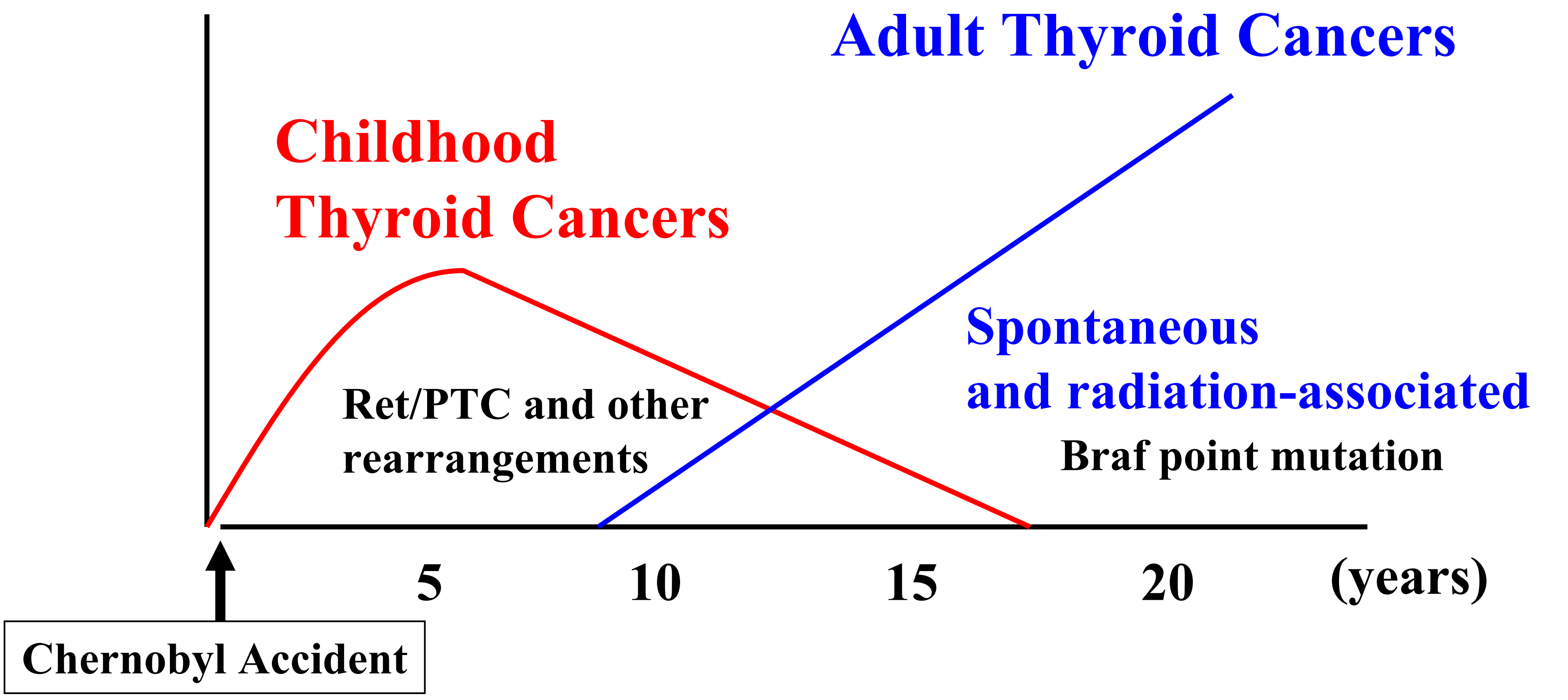
Research Protocol Application and Joint Work with 3NIS

# Age dependent changes of *BRAF* mutation in Papillary Thyroid Cancer (PTC)




Genetic background of childhood PTCs is different from adult PTCs

# Latency of Occurrence of Papillary Thyroid Cancers after the Chernobyl Accident



# WHO Strategy of Recovery for Chernobyl Health Issues

1. Strengthen infrastructure of medical diagnosis and treatment
2. Improvement of public health communication
3. Promotion of research on radiation effects on human health
4. Development of long-term follow-up mechanism in each health sector.

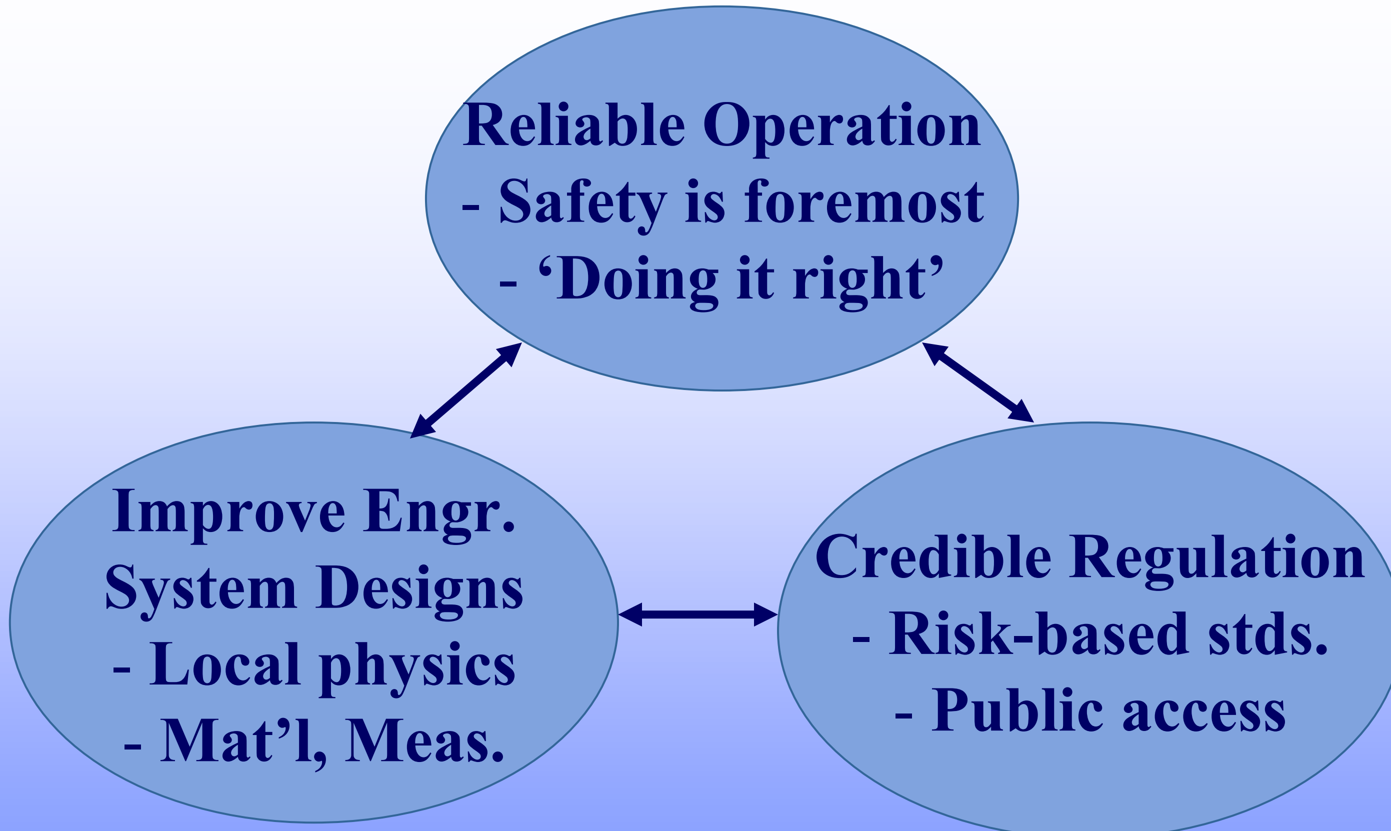
# NEW REACTOR TECHNOLOGY: SAFETY IMPROVEMENTS IN NUCLEAR POWER SYSTEMS

**M. Corradini, Nuclear Engr & Engr Physics**
**Director - Wisconsin Institute of Nuclear Systems**
**University of Wisconsin-Madison**

# Concept of Engineering Safety

- Engineers consider safety integral to system design
- Engineering systems have a number of safety levels:
  - Engineering system should imbed safety in the design
  - System operation strives for high reliability
  - An engineering system designs for off-normal events
  - Robust engineering systems consider rare events
- Nuclear power safety => Avoid, minimize & mitigate the release of radioactivity: Defense-in-depth
  - Reliable operation, anticipate accidents, continual improvements in operator and systems performance

# Nuclear Energy: Defense-in-Depth




**Provide key info and enough time to make correct decisions**

# Nuclear Power Plant Safety

- There has been an impeccable safety record for nuclear power in the U.S. (no loss of life from commercial operation)
- Current LWR design demonstrates a high degree of safety to remove decay heat & minimize radioactivity release (e.g, TMI)
- Chernobyl accident was a terrible accident (negligent actions with a flawed engineering design: redesigned and retrained)
- More than two decades, safety focus is on best-estimates for Design-base events and Risk-informed estimates with PRA for events that may be judged beyond the design base
- **This talk focuses on advanced reactors:**
    - **Design-base events & associated safety issues**
    - **Beyond the design-base events and risk issues**
    - **Key safety issues that are related to advanced reactors**

# Evolution of Nuclear Power Systems

**Generation I**

Early Prototype Reactors

- Shippingport
- Dresden,Fermi-I
- Magnox

**Generation II**

Commercial Power Reactors

- LWR: PWR/BWR
- CANDU
- VVER/RBMK

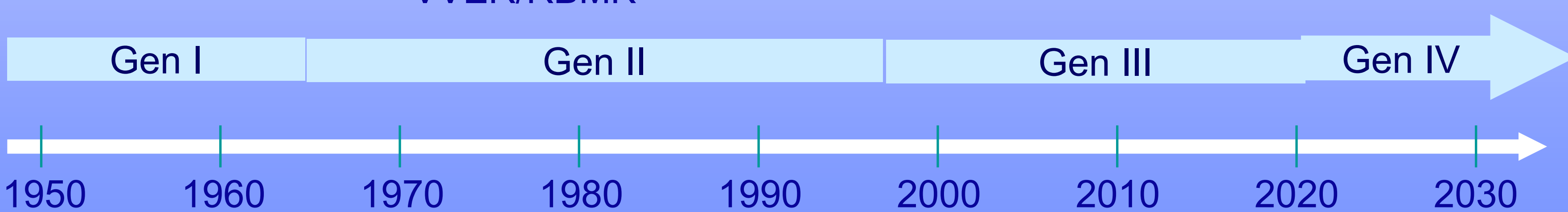
**Generation III**

Advanced LWRs

- System 80+
- ABWR
- AP600
- SBWR

**Generation IV**

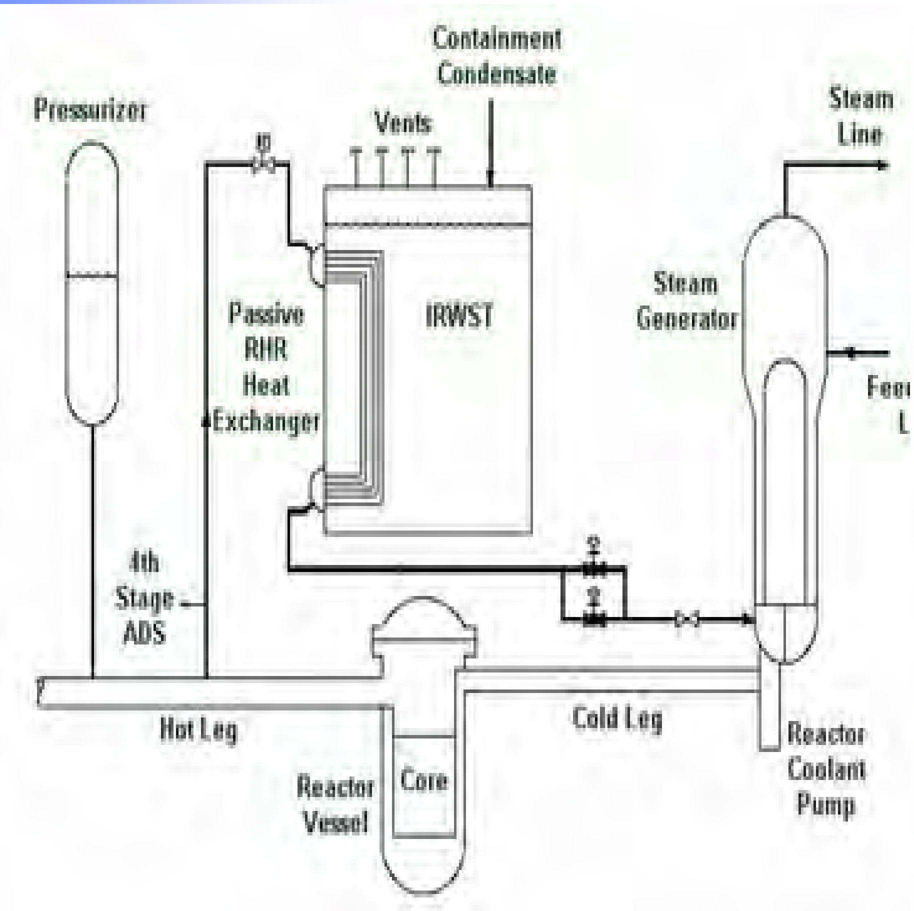
- Enhanced Safety
- Minimized Wastes
- Proliferation Resistance
- Highly economical

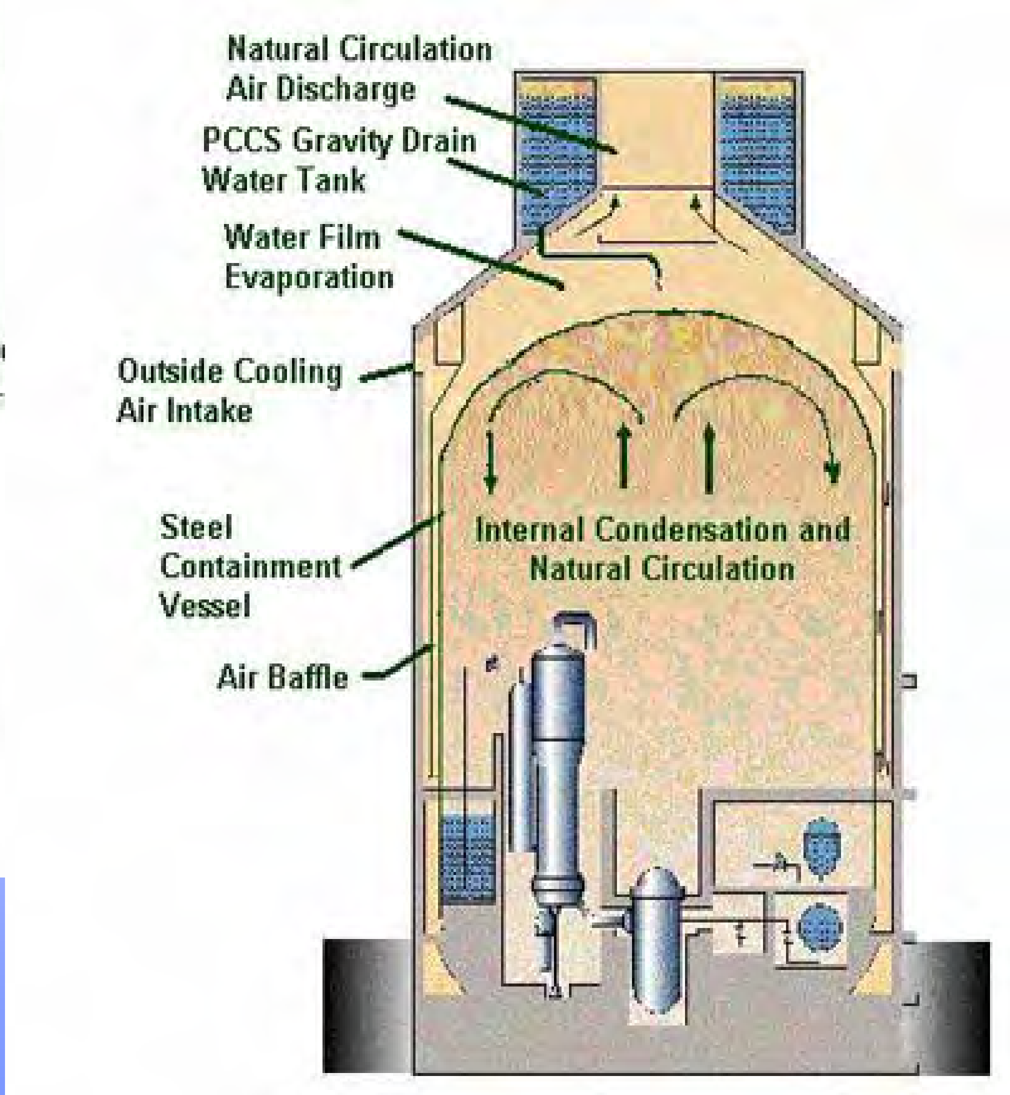


# Advanced Nuclear Reactor Systems

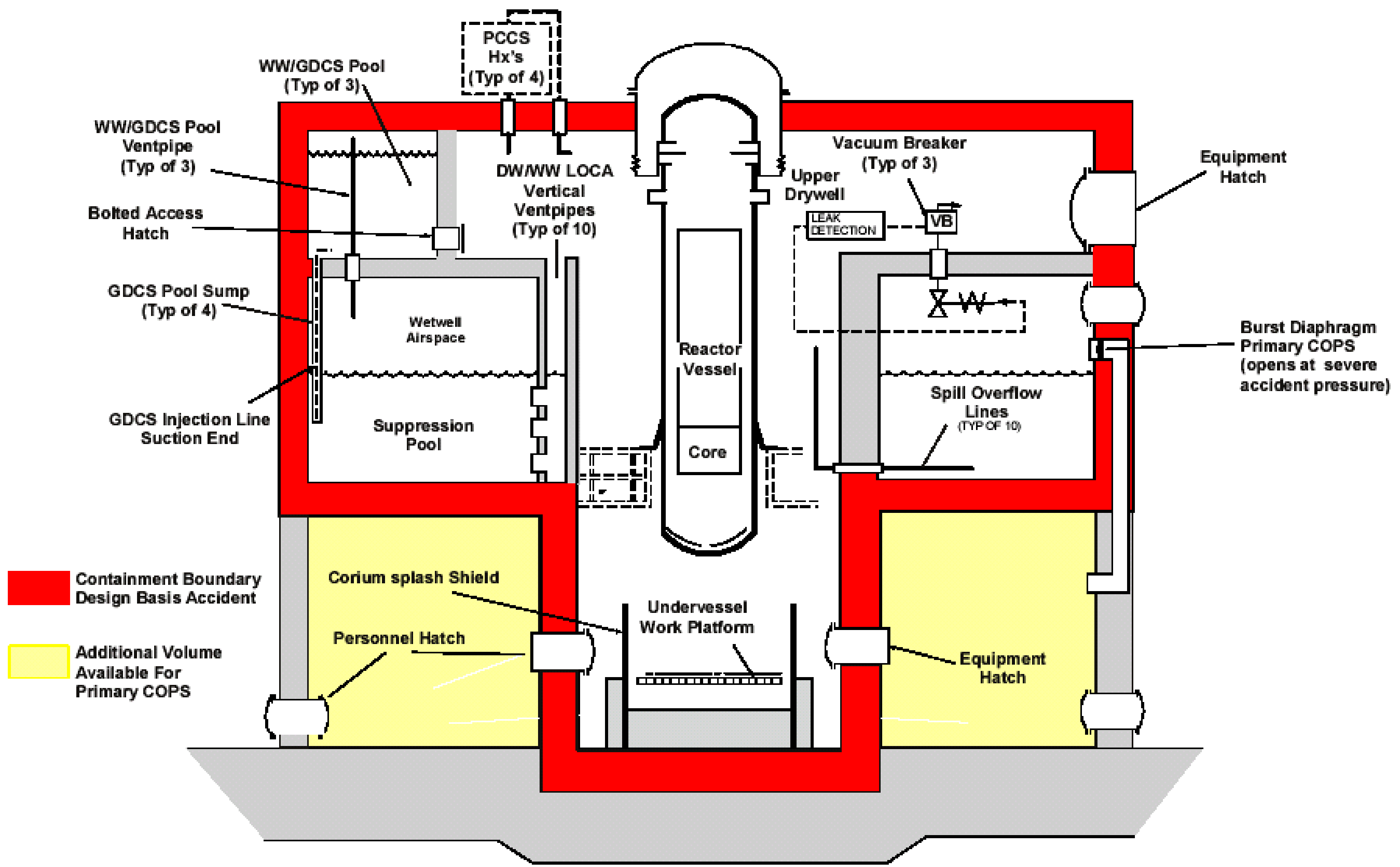
- **Safety: meet and exceed current nuclear power plant reliability, occupational radiation exposure and risk of accident consequences**
- **Sustainability: minimize waste streams during fuel processing and spent fuel recycling and/or disposal**
- **Optimize physical protection of facility and non-proliferation risks**
- **Economics: reduce the total cost of electricity to remain competitive with other baseload power technologies (e.g., fossil fuels)**

# Advanced LWR: AP-1000



# Advanced LWR: ESBWR

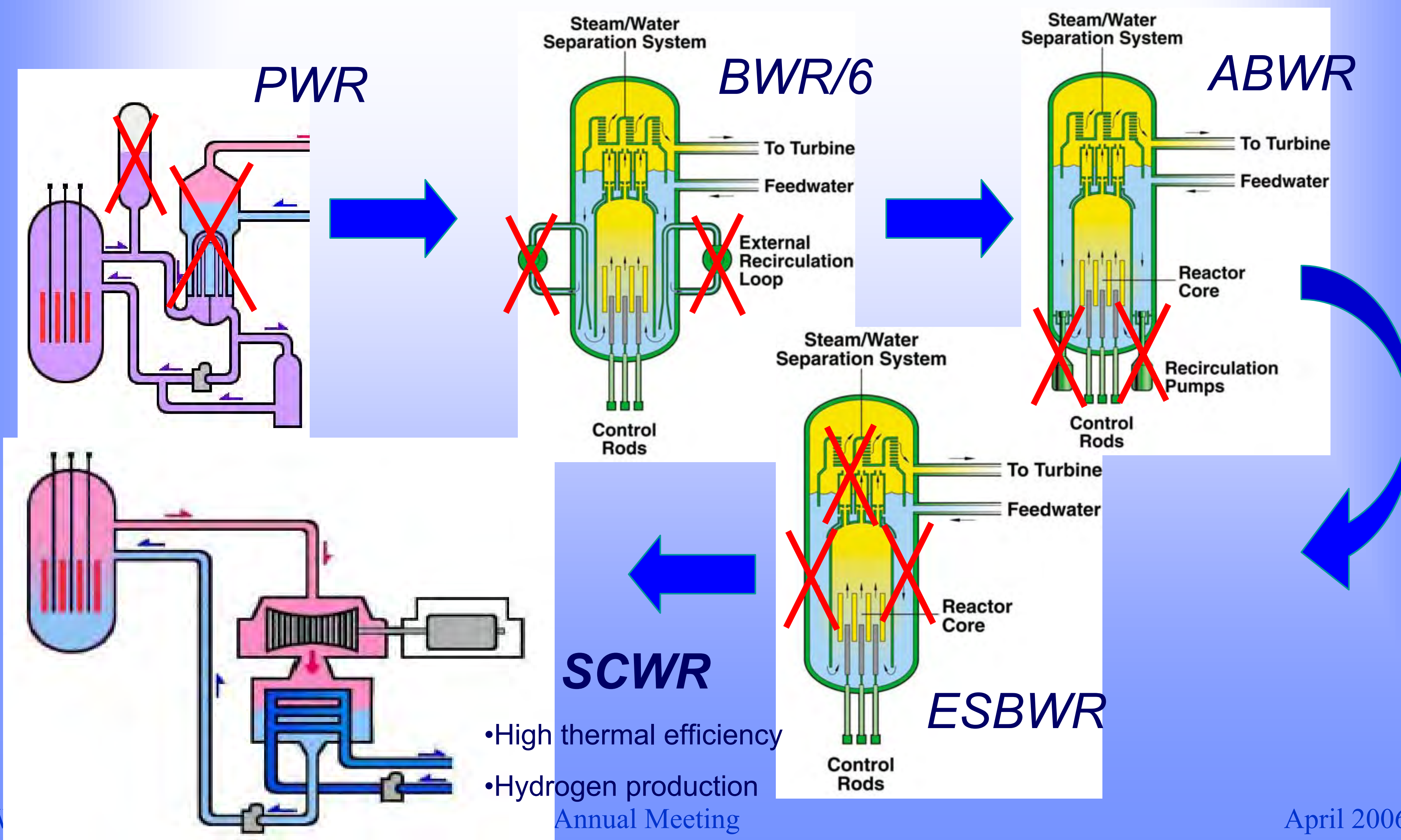


# Advanced Nuclear Reactor Systems

- Safety: meet and exceed current nuclear power plant reliability, occupational radiation exposure and risk of accident consequences
- Economics: reduce the total cost of electricity to remain competitive with other baseload power technologies (e.g., fossil fuels)
- Sustainability: minimize waste streams during fuel processing and spent fuel recycling and/or disposal
- Optimize physical protection of facility and non-proliferation risks

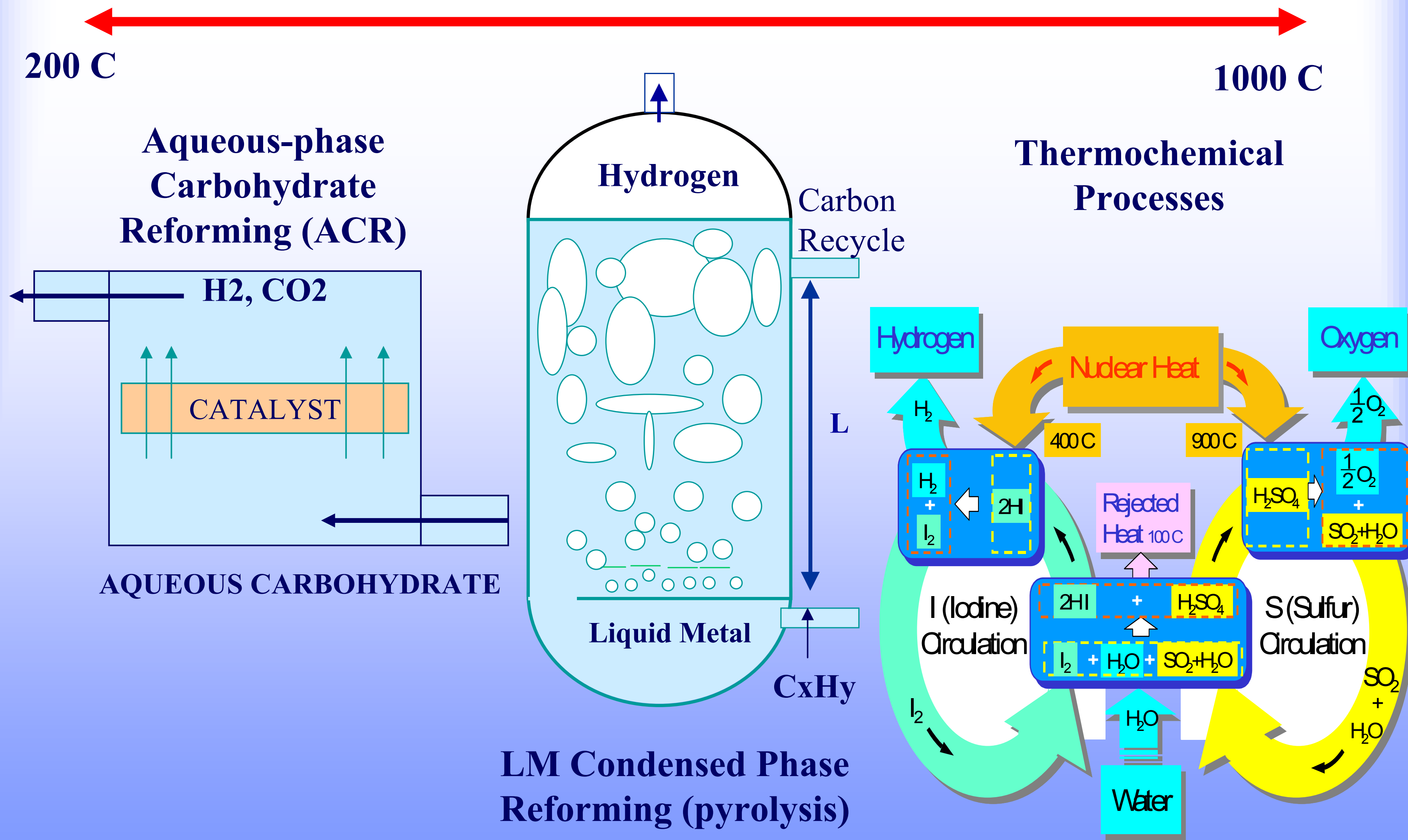
# SCWR: Gen-IV LWR

***The next logical step in path toward simplification***




- High thermal efficiency
- Hydrogen production

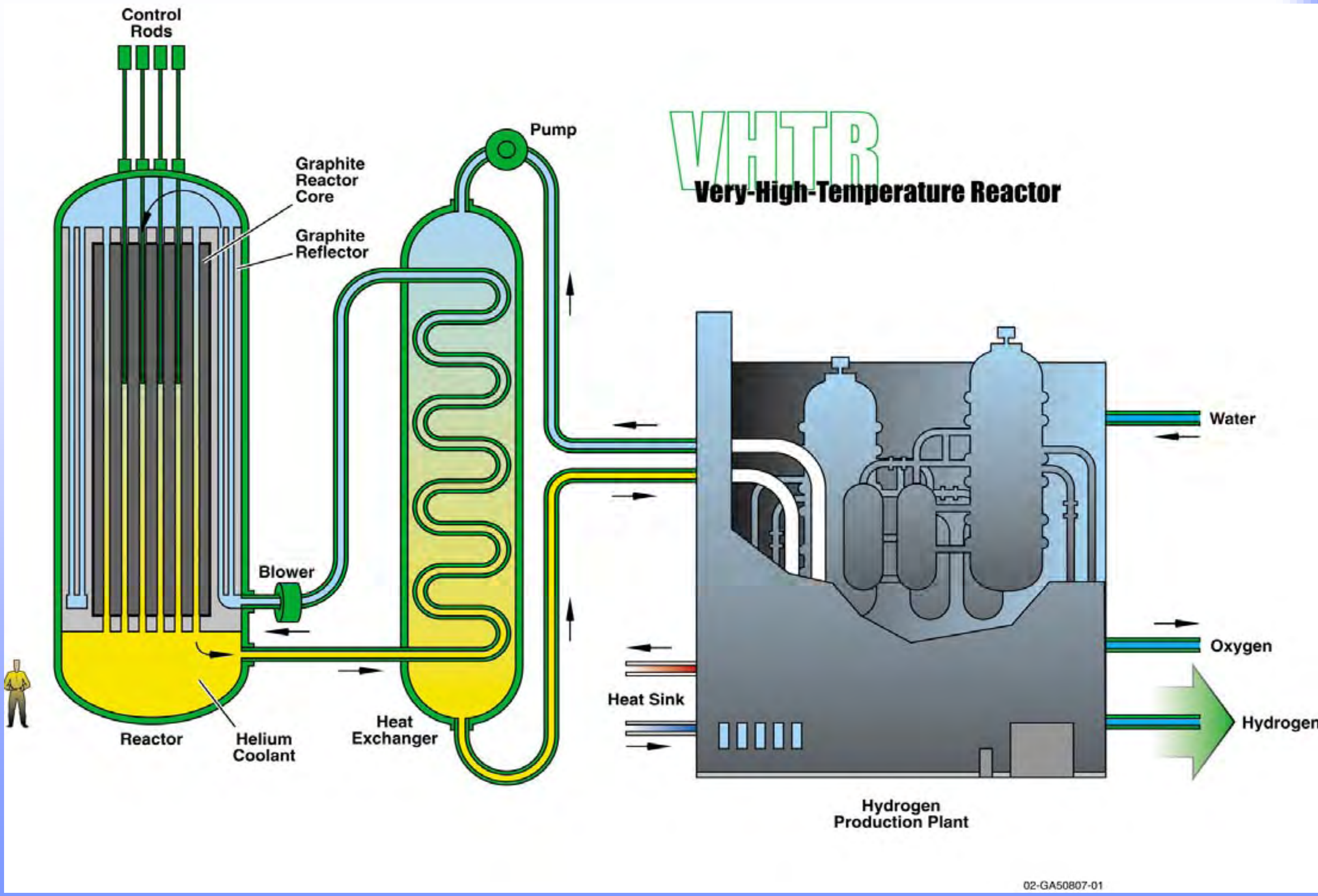
# Process Heat for Hydrogen Production



# Very-High-Temperature Reactor (VHTR)

- Characteristics
  - Helium coolant
  - 1000°C outlet temp.
  - 600 MWth
  - Water-cracking cycle

- Key Benefit
  - High thermal efficiency
  - Hydrogen production by water-cracking



# Advanced Nuclear Reactor Systems

- Safety: meet and exceed current nuclear power plant reliability, occupational radiation exposure and risk of accident consequences
- Economics: reduce the total cost of electricity to remain competitive with other baseload power technologies (e.g., fossil fuels)
- Sustainability: minimize waste streams during fuel processing and spent fuel recycling and/or disposal
- Optimize physical protection of facility and non-proliferation risks

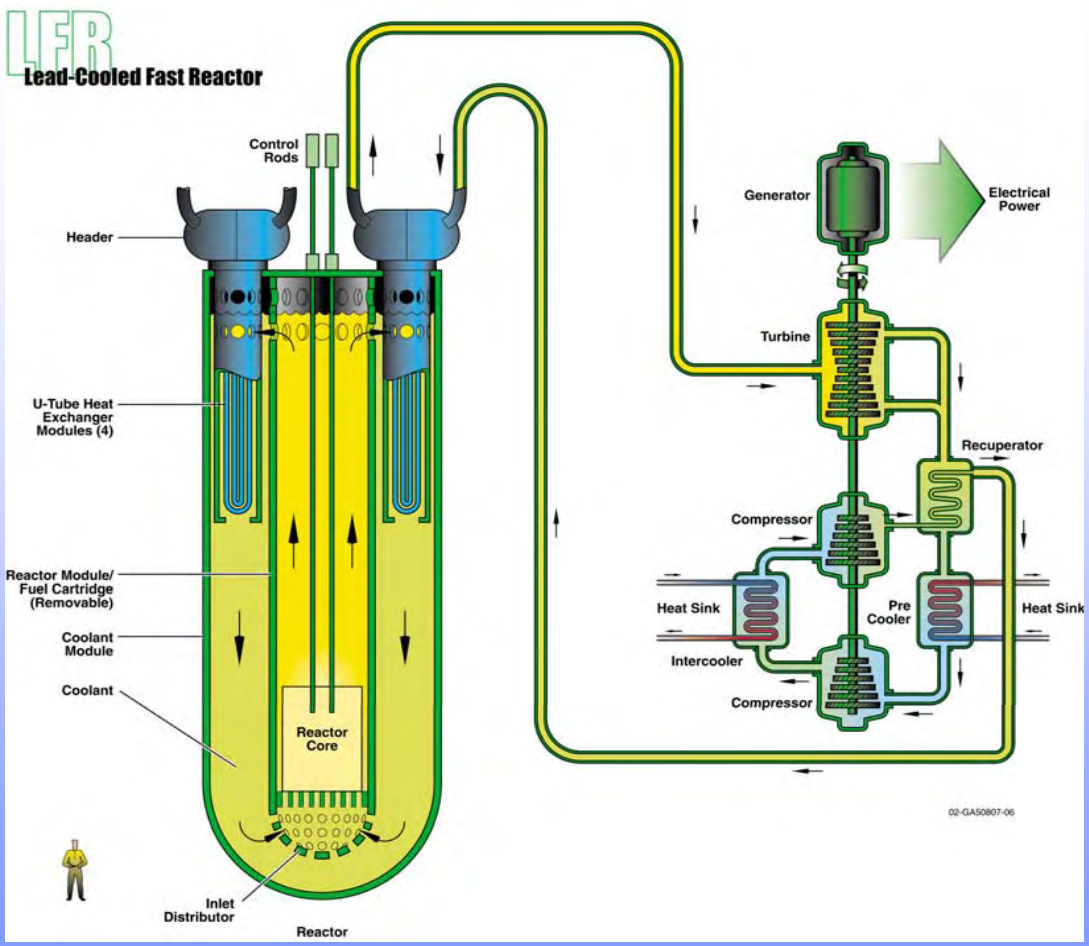
# Liquid-Metal Cooled Fast Reactor (LMR)

***Characteristics***

- ***Na, Pb or Pb/Bi coolant***
- ***550°C to 800°C outlet temperature***
- ***120–400 MWe***

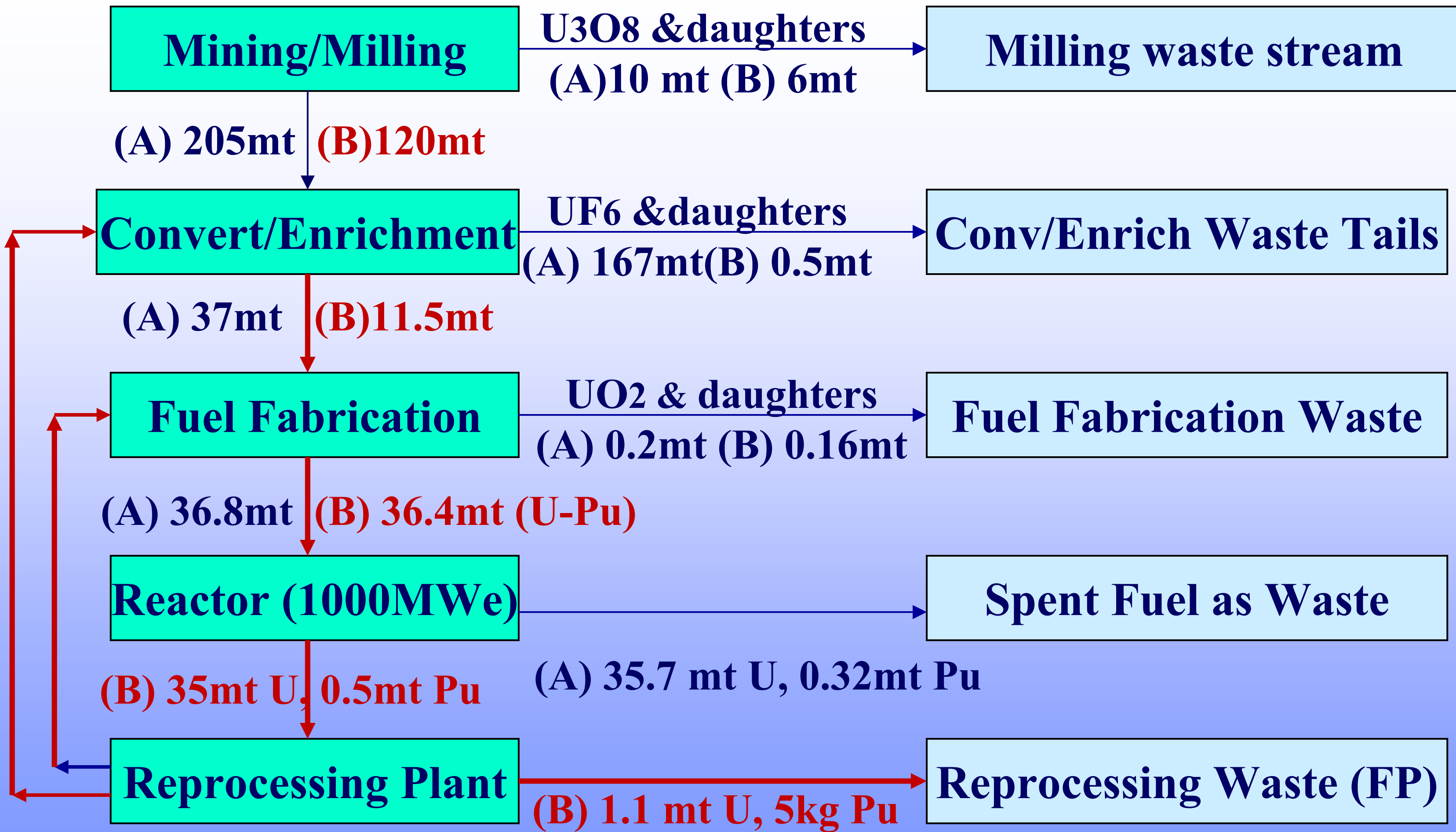
***Key Benefit***

- ***Waste minimization and efficient use of uranium resources***



# Nuclear Power Fuel Cycle

**[1GWe-yr – (A) Once Through (B) With Recycle; 3.3%U235, 30GWD/mt]**



# Advanced Reactors Regulatory Issues

## Based on SECY-05-0130, NRC SRM 9-12-05, ACRS Ltr. 9-21-05

- ‘Technology Neutral Regulatory Framework’ is currently under development by the USNRC staff with ACRS input.
- NUREG-0880 Reactor Safety Goals are to be used as overall guidance (qualitative goals and quantitative health objectives).
- In the interim surrogate regulatory guidance follows approach for ALWR’s: i.e., DBA analyses and CDF & LER goals
  - DBA: Design Basis Accidents - Power-cooling mismatch events
  - CDF: Core Damage Frequency << 1/10,000 (PRA analyses)
  - LER: Large Early Radioactivity Release < 1/10 (w core damage)
- Usage of PIRT (Phenomena Ident. & Rank. Table) as a way to determine key issues needed for modeling and testing

# Overview of PIRT Approach

1. Gather information and select Figures of Merit
2. Identify Scenario(s) to be Addressed for Review
3. Develop/Define Event Tree and the Phases for Scenarios
4. Identify Systems & Components Active During Scenario (by Phase)
5. Rank Systems & Components Active During Scenario (by Phase)
6. Identify Key Phenomena for Reactor System and Rank (by Phase & Component )
7. Identify the Key Issues for Phenomena
8. Compile Results and Document

PIRT Iterative Ranking Process

# ACR-700 Example: Severe Accident Panel

| SA Member | SA Scenario | SA Activity |
|---|---|---|
| M. Corradini | Single Channel | Evt.Tree, PIRT |
| S. Levy | Single Channel | Scenario, PIRT |
| R. Henry | Whole Core | Evt. Tree, PIRT |
| K. Vierow | Whole Core | Scenario, PIRT |
| D. Powers | Fission Prod. | Phen., PIRT |

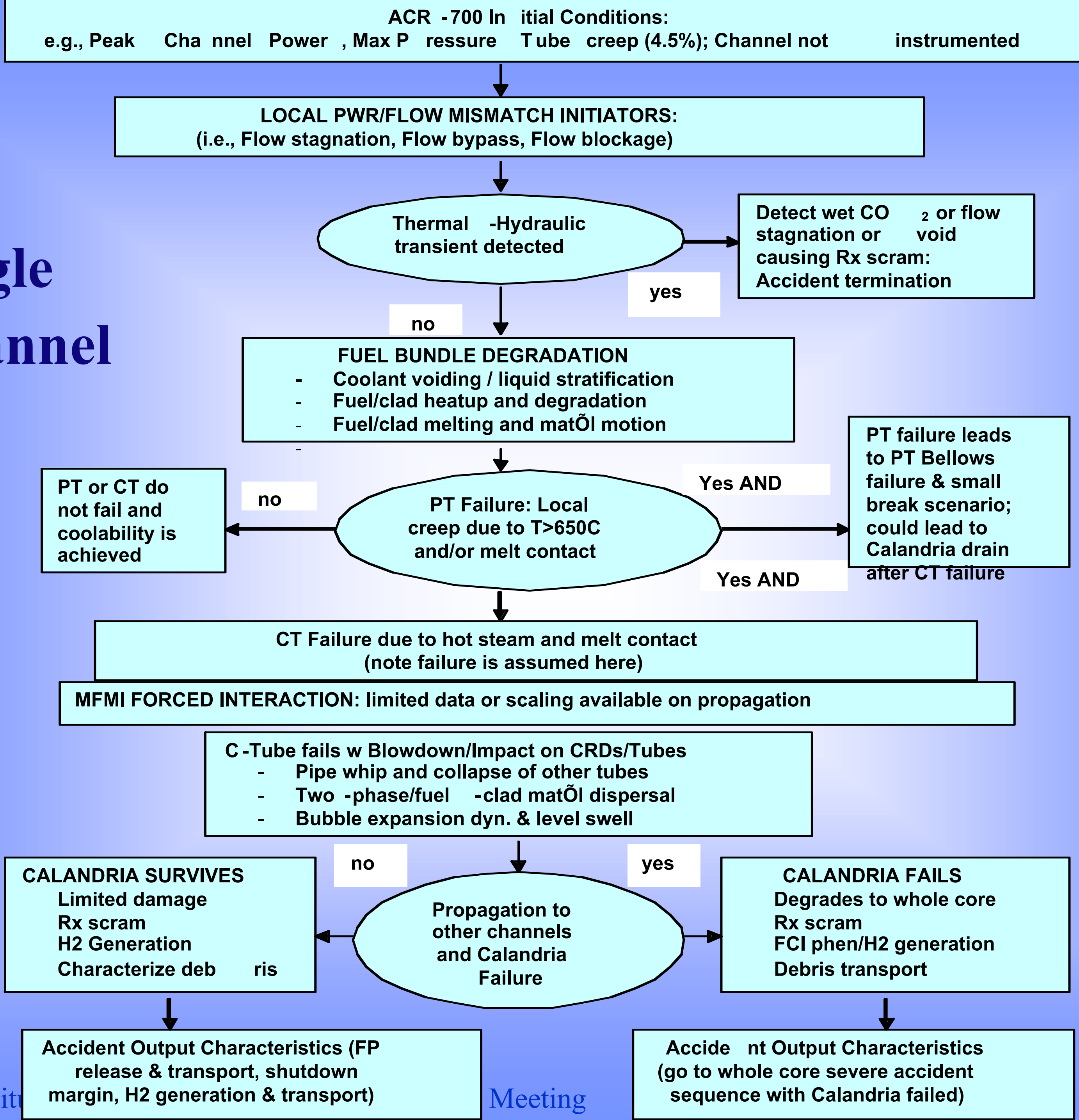
# SEVERE ACCIDENT FIGURES of MERIT

- Single channel events with limited core damage that do not propagate and degrade to a whole core accident

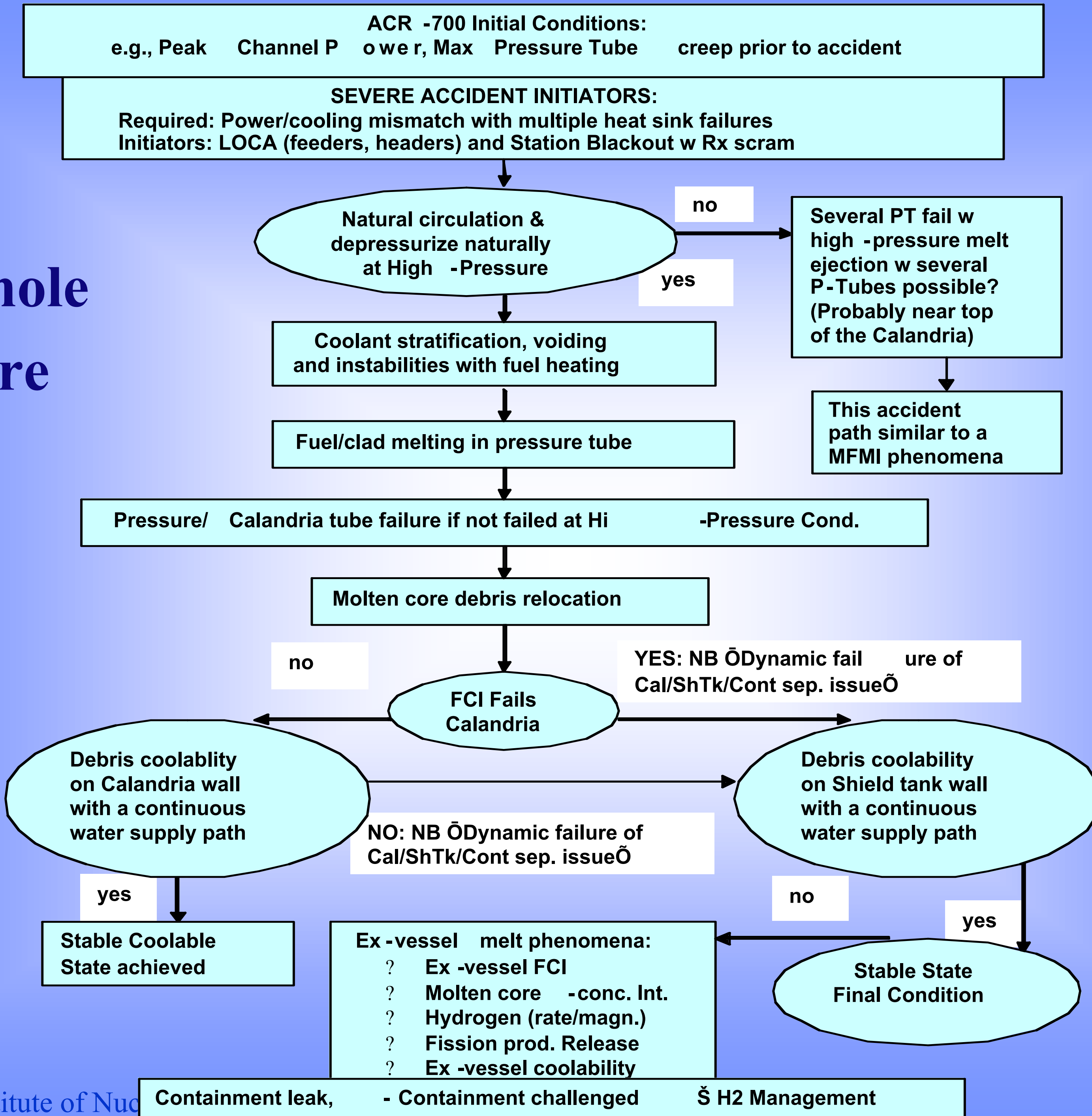
- Whole core accidents that achieve core debris coolability (in-vessel or ex-vessel)

- Prevent the release of radioactivity from containment from these (other) scenarios

# Single Channel



# Whole Core


ACR -700 Initial Conditions:
e.g., Peak Channel P o we r, Max Pressure Tube creep prior to accident
SEVERE ACCIDENT INITIATORS:
Required: Power/cooling mismatch with multiple heat sink failures
Initiators: LOCA (feeders, headers) and Station Blackout w Rx scram
Natural circulation & depressurize naturally at High -Pressure
no
yes
Several PT fail w high -pressure melt ejection w several P-Tubes possible? (Probably near top of the Calandria)
This accident path similar to a MFMI phenomena
Coolant stratification, voiding and instabilities with fuel heating
Fuel/clad melting in pressure tube
Pressure/ Calandria tube failure if not failed at Hi -Pressure Cond.
Molten core debris relocation
no
YES: NB ŌDynamic fail ure of Cal/ShTk/Cont sep. issueÕ
FCI Fails Calandria
Debris coolablity on Calandria wall with a continuous water supply path
Debris coolability on Shield tank wall with a continuous water supply path
NO: NB ŌDynamic failure of Cal/ShTk/Cont sep. issueÕ
yes
Stable Coolable State achieved
no
yes
Ex -vessel melt phenomena:
? Ex -vessel FCI
? Molten core -conc. Int.
? Hydrogen (rate/magn.)
? Fission prod. Release
? Ex -vessel coolability
Stable State Final Condition
Containment leak, - Containment challenged Š H2 Management

# PIRT: Single Channel Accident Key Phenomena

| Issue (Phenomena, process, geometry condition) | Importance for ACR-700 | Rationale | Level of Knowledge | Rationale | Status of Severe Accident Modeling |
|---|---|---|---|---|---|
| Melt progression through pressure tube and calandria | High | Initial and long-term progression will fail pressure tube and calandria tube allowing fuel relocation downward amongst other tubes | Low | Extended melt progression information is probably not well-characterized in comparison with data base for melt progression in LWRs | Modification needed for SA codes to model this unique configuration |
| Pressurized expulsion of melt from the pressure tube into calandria | High | This is the key phenomena that may take a single channel event and propagate to whole core event | Low | This is an active area of experimental research by AECL to consider forced FCI interaction mode with chemical augmentation | AECL has stand-alone parametric unqualified model; may need a mechanistic model to provide scaling of loads and energetics. |
| Dry Core Melt Progression | High | High zirconium content in the molten material that is produced and moves due to slumping may directly cause Calandria and Shield tank failure | Low | LWR core melt contains a much lower amount of unoxidixed Zr compared to what may be in ACR-700 | Needs discussion |
| Flow paths, flow splits and flow instabilities during severe accident progression | High | Flow paths dictate the ability to remove heat and to carry fission products through the reactor coolant system and into containment or, in the case of bypass accident sequences, to environment | Low | Complicated geometry of CANDU system leads to uncertain flow splits in parallel flow piping, with possible instabilities and additional PT failures and complex flow patterns to consider | Modifications to current severe accident computer models will be necessary to account for complex flow paths |

# PIRT: Whole Core Accident Key Phenomena

| Issue (Phenomena, process, geometry condition) | Importance for ACR-700 | Rationale | Level of Knowledge | Rationale | Status of Severe Accident Modeling |
|---|---|---|---|---|---|
| Melt progression through pressure tube and calandria | High | Initial and long-term progression will fail pressure tube and calandria tube allowing fuel relocation downward amongst other tubes | Low | Extended melt progression information is probably not well-characterized in comparison with data base for melt progression in LWRs | Modification needed for SA codes to model this unique configuration |
| Creep of pressure tubes during whole core degradation | High | Pressure tube creep affects cooling and can bring Zr tubes into contact with calandria tube | Low | Limited data base on heat transfer from creeping tubes during whole core degradation | Major modifications |

# ACR 700 Key Issues and Approach

- Severe Accident PIRT process concluded with identification of key phenomena of high priority
  - Core melt progression with neutronic feedbacks
  - Pressurized expulsion of melt w PT/CT failure
  - Pressure tube creep rupture during whole core event
  - Flow paths, flow splits, flow instabilities in accident
  - Dry-core melt progression and debris coolability
- Future safety research needs to address modeling and experimental knowledge base needed to meet goal
- *Focus on passive safety and longer time for response*

# Advanced Reactor Safety Research

- Current NRC's advanced reactor research applies principally to certain reactors: AP1000, ACR-700, ESBWR, PBMR, GT-MHR and IRIS. There are several key research areas:
  - Neutral regulatory framework (regulatory decision-making based on the risk-informed, performance-based principles)
  - Improved techniques for accident analysis (e.g., PRA methods and assessments, human factors, and instrumentation and control)
  - System models (e.g., TH analysis, nuclear, severe accident and source term analysis)
  - Advanced fuels analysis and associated testing
  - Materials analysis (e.g., graphite behavior and high-temperature metal performance)
  - Structural analysis (e.g., containment/confinement performance and external challenges)
  - Consequence analysis (e.g., dose calculations, and environmental impact studies)
  - Nuclear materials safety (e.g., enrichment, fabrication, and transport) and waste safety (including storage, transport, and disposal), and nuclear safeguards

# Reactor Safety Research Issue Matrix

| Research Area | Advanced Water Reac. | Gas Cooled Reactors | Liquid Metal Reactors | Simulation Issues |
|---|---|---|---|---|
| PRA analysis - assessment | Improve techniques to allow for technology neutral assessments, analysis & consequences | | | PRA techniques e.g., ROAAM, MELCOR |
| Reac. system analyses | P-TH transients<br>Core coolability | Mod. response temp & radiation | Failure P-P prop<br>Trans. O-P anal. | Neutronics-TH coupled anal. |
| Materials analysis | Hi-Temp Corros. & Mat'l Damage | Graphite prop.<br>Surf. Emissivity | Fatigue Failure<br>Fuel Parameters | Computational<br>Mat'ls & Props |
| Structural analysis | High-temp. creep behavior | Heat exchanger struct'l. integrity | Fuel and core support analysis | Fluid-Structure coupled analy. |
| Consequence analysis | Fission product release and transport is dependent upon failure mechanisms and local chemistry. | | | Fission product transport |

# Reactor Safety Research: ALWR's

Current NRC's advanced reactor research applies to certain water reactors: AP1000, ACR700, ESBWR and IRIS. Examples include:

- ◆ System power/temperature response to modifications in LWR operating conditions and geometry:
  - ☞ ESBWR: Condensation heat transfer and mixing PCCS
  - ☞ ACR700: Void and temperature coefficients in ACR geometry
  - ☞ IRIS: System TH analysis given design-basis accident initiators
  - ☞ SCWR: Heat transfer deterioration near pseudo-critical point
- ⇒ New initiatives in neutronics/thermal-hydraulics coupled models
- ◆ Debris coolability in-vessel (or ex-vessel) for specific designs
- ◆ Creep and creep-fatigue in design and safety computer models

# Reactor Safety Research: GCR’s

Current NRC's advanced reactor research applies to certain water reactors: PBMR and MGTHR. Examples include:

- ◆ T-H system analyses for LOF & LOP accidents with air ingress (this is the analogue to water reactor design basis and beyond)
- ◆ Graphite swelling from fluence & temperature variations in core:
- ⇒ Initiatives in coupled neutronics/heat-transfer effects
- ⇒ BES initiatives in first-principles materials properties
- ◆ Emissivity-by-design: passive surface cooling of RPV in accident
- => Exp’tl initiative with testing in stable surface props (temp. & rad.)
- ◆ Effect of mixed-oxides and actinides on neutronics safety parameters: delayed neutron fraction, Doppler feedback, thermal conductivity, etc. => Basic research on fuel properties

# Reactor Safety Research: LMR's

Current NRC's advanced reactor research applies to certain water reactors: SFR's and LFR's. Examples include:

- T-H system analyses for transient overpower and LOF/LOHS accidents as well as pin-to-pin propagation failures

⇒ New initiative in first-principles multi-dimensional fluid dynamics

⇒ Initiatives in coupled neutronics/heat-transfer effects

- Effect of mixed-oxides and actinides on neutronics safety parameters: delayed neutron fraction, doppler feedback, thermal conductivity etc.

=> NE initiative on fuel properties as a function of fissile composition as well as fission product and minor actinide content

# Hi-Performance Computing Focus

Consider now the common attributes from all of these examples for various advanced reactor designs and associated accident scenarios:

- As computer modeling capabilities become more sophisticated the tools used for design and safety will become “one and the same”.
- As these fields continue to merge => design-to-analysis capability will also lead to direct interface between CAD and high-fidelity coupled multi-physics capabilities (neutronics+TH+fuel performance+structural analysis+..)
- Imagine reactor system analysis with Monte Carlo: simplified temperature-dependent analysis with coupling to other physics (TH + Fuel + Structures)

# SA Event Scenario (example)

Table 2.1 Scenario and phase descriptions

(Single Channel Event Sequence: PT Strain Localization + Loss of Class III power )

| Phase | Timing | General Phase Boundaries | Significant Events |
|---|---|---|---|
| I | 0-30 sec. | **Fuel Channel Failure** | **Pressure Tube Failure**<br>1. Pressure Tube Failure (refer to event description). Non-uniform circumferential temperature distribution results in PT failure due to strain.<br>2. Pressurization of annulus between PT and CT up to the HTS pressure.<br>3. Water hammer pulse in annulus.<br>4. Subsequent bellows failure at both ends of the calandria tube<br>5. LOCA through both channel bellows<br>**Plant Response Prior to CT Failure**<br>6. No reactor trip, assuming affected channel is not instrumented<br>7. Nominal conditions maintained by Pressure and Inventory Control System<br>8. Reactor Power maintained by Reactor Regulating System<br>**Calandria Tube Failure**<br>9. Molten and solid fuel element material ejected to calandria tube<br>10. Transition to stratified flow pattern in calandria tube<br>11. Reduced cooling of top fuel elements<br>12. Melt relocation and contact with calandria channel<br>13. Calandria tube thinning at full pressure (Ref. 16, Figure 4-3)<br>14. Calandria tube failure<br>For complete flow blockage PT/CT failure would happen in 10-12 seconds. For partial flow blockage it could take 40-60 seconds (ref. 5, Tables 7.1-5 and 7.1-6).<br>**Plant Response after CT Failure**<br>15. HTS LOCA on the order of 100 kg/s<br>16. Reactor trip due to moderator high level, RCS (Reactor Cooling System) lower pressure, and pressurizer reduced level<br>17. Turbine trip (Timing per "LOCA due to 25% RIH (Reactor Header Inlet) Break with Subsequent Loss of Class IV Power" |

# Future Challenges for Nuclear Power Plant Development Research, and for Radiological Risk Assessment and Management

Dr. Ted Lazo

OECD Nuclear Energy Agency

# Looking to the Future

## Reactor Design is Evolving

– Generation III reactors will be built in the coming years (EPR, ABWR, AP1000, etc.)
– These will be followed by Generation IV reactors (after 2030)

## Radiation Protection is Evolving

– New challenges are emerging
– Ongoing challenges will need to be addressed in new and innovative ways

# Generation IV International Forum

- TECHNOLOGICAL PROJECT
  - Legal & organizational matters
    - agreements
    - Governance & policy statement
    - Valuation of the contributions
  - Technical studies
    - System Research Plans
      - Steering committee
    - R&D collaboration plans
      - Project Management Boards
      - Involvement of many Parties
        - » R&D organisms : CEA, DOE labs, EURATOM,JAEA, KAERI
        - » Industry : PBMR, BNFL…….
        - » Sub contractors : university…………


NEA : Technical Secretariat

# TECHNOLOGY ROAD MAP (Dec 2002) for Generation IV Nuclear Energy system

## SELECTED CRITERIA FOR THE GENERATION IV NUCLEAR ENERGY SYSTEMS (reactor + fuel cycle)

- Sustainable development
  - Waste management : to reduce waste volumes and radioactivity (actinide)
  - Resources utilization : to optimize
- Competitiveness
  - To decrease the construction costs and duration
- Safety / security
  - Passive safety : To integrate passive safety aspects within the initial design
- Non proliferation resistance / physical protection
  - To limit access to Plutonium production and to embed its further use
  - To improve the NPP robustness towards physical protection

# Very High Temperature Reactor System

## Pros and Cons

- **High temperature**
- **Cogeneration: electricity / $H_2$**
- **Other nuclear heat processes**

- **Open cycle: sustainability**

## Research Focus

- **Design Safety & system integration**
- **Computational methods**
- **Fuel and Fuel Cycle**
- **Materials & Components**
- **Hydrogen Production**
- **Helium Turbine and BOP**

# Molten Salt Reactor

## Pros and Cons

- **Close cycle**
- **High thermal power reactor with reduced volume**

- **Fuel salt chemistry (Fluoride based salts)**
- **Material corrosion**

## Research Focus

- **Liquid salt chemistry and properties**
- **Design and safety**
- **Fuel Cycle**
- **Reactor physics**
- **Materials Mechanics & Components**

# The Lead Fast Reactor System

## Pros and Cons

- **High boiling point**
- **Low neutron absorption**
- **Excellent shielding and heat transfer**
- **Chemically inert**
- **Retains fission products in accident conditions**

- **Materials performance**
- **SG and pump performance**
- **In-service inspection (visibility in lead)**

## Research Focus

- **Core and vessel design**
- **Coolant choice: Pb or Pb/Bi**
- **Materials performance**
- **Thermohydrolics and heat transfer**

# The Gas Fast Reactor

## Pros and Cons

- **Proven technology**
- **Links with VHTR work**
- **Early utilisation can be expected**

- **Large physical size**
- **High temperature, materials questions**
- **High fuel temperature**

## Research Focus

- **Direct or indirect cycle**
- **Dispersed or particle fuel**
- **Materials and thermohydrolics**
- **Power density (controllability)**
- **Post-accident decay heat removal strategy (natural convection or pump)**

# Sodium-cooled Fast Reactor Systems

## Pros and Cons

- **Proven technology and operating experiences**
- **Advantages in transmuting fission products**

- **Sodium interaction with water and sodium fire**
- **Public perception on Monju and Super Phenix**

## Research Focus

- **Economics enhancement :**
- **elimination of the intermediate loops, high burn-up fuels, etc**
- **In-service Inspection technology**
- **Passive safety systems research**

# Super-Critical Water-cooled Reactor Systems

## Pros and Cons

- **Utilizing LWR technologies and experiences**
- **Good economics due to high thermal efficiency**

- **Start-up operation (passage to super-critical state)**
- **Difficult to overcome the limits and image of LWRs in safety**

## Research Focus

- **Materials : supercritical water is very corrosive**
- **Thermal-hydraulic properties**

# Radiological Protection: Where Are We Now?

- There is broad agreement that the current system of radiological protection is not under-protecting the public, workers or the environment
- There are no new significant scientific studies that suggest that major change is needed
- However………

# Emerging and Ongoing Challenges to RP

- RP Science is increasingly identifying specific aspects of the current approach that may no longer be scientifically sound
- Extensive ICRP and BSS implementing experience shows some difficulties
- The ICRP is developing new recommendations
- Stakeholder involvement in decision-framing and decision-making processes is affecting the way that radiological risks are assessed and managed

# Challenges from RP Science

- Non-targeted effects (bystander effects, genomic instability) and adaptive response suggest that the LNT Hypothesis may not be appropriate in all circumstances.
- Different Situation, Different Dose Response?
  - High LET versus Low LET
  - High Dose Rate versus Low Dose Rate
  - Chronic Exposure versus Acute Exposure
- Certain individuals may be more radiosensitive than others

**These results raise several questions**

- Is it still valid to assess detriment using the Sievert?
- What if there is a "practical threshold"?
- What would we do to protect "radiosensitive" individuals?

# Experience has taught us…

- RP decisions are increasingly viewed as "judgemental, social choice" informed by RP science
- In this light, some of the central ICRP/BSS approaches present implementation problems
  - Practice/Intervention
    - "Double Standard" for protection
    - Focus on Averted Dose
  - Exclusion/Exemption
    - Reduces regulatory flexibility

**This raises several questions**

- How should emergencies and existing situations best be addressed?
- How should low-level contamination be handled?

# New ICRP Recommendations

- The ICRP has for some time broadly based its recommendations on consideration of
  - Responsibility: the Justification principle
  - Equity: the Limitation principle, and
  - Prudence (precaution) in the face of uncertainty: the Optimisation principle
- Through approximately 100 years of development, radiological protection has pragmatically and continually adjusted to appropriately address new and arising issues
- Recent drafts of new recommendations retain these three principles, but their interpretation and application has significantly evolved

**This raises several questions**

How should Constrained Optimisation be understood and applied?

How should Exemption and Exclusion be understood and applied?

# Interacting with Stakeholders

- Radiological risk assessment and management has moved from "good science" to "social judgement informed by good scientific knowledge", influenced by stakeholder involvement.
- Broad stakeholder involvement is generally not necessary, but for some situations it is the only way forward.
- Social evolution, scientific advancement and implementation experience suggest that:
  - Prevailing circumstances will be strongly taken into account, perhaps leading to specific, local solutions
  - Local stakeholders will inevitably become more influential in radiological risk assessment and management
  - The balance between internationally harmonised approaches and local specificity must be a central issue in the future development of radiological protection principles.

**This raises several questions**

- How will Stakeholder Involvement affect RP decision making?
- How will Stakeholder Involvement affect RP "structures?

# Conclusions

## Generation IV Reactors

- The Generation IV International Forum is developing new nuclear energy systems that have been selected within the Technology Road-Map (Dec 2002) to meet a range of user needs and criteria (i.e. size, fuel cycle)
- Key issues to be solved include design and safety, fuel cycle, materials and components, nuclear process heat
- Eight countries have already signed the Framework Agreement, and others are expected to follow.

## Radiation Protection

- There continues to be a broad consensus that the standard of radiological protection across OECD member countries is very high, and indeed, that the current system of radiological protection provides a solid basis for protection across the entire world
- Over the past 15 years, a series of events and changes have somewhat shifted the focus of radiological protection, and will affect the future path taken by the profession in addressing radiological protection situations.
- Social evolution, scientific advancement and implementation experience have all taught us invaluable lessons that can be used to guide the policy, regulation and application of radiological protection in a cohesive and integrated manner.

# Moving to a Low-Carbon Energy Future:
## Perspectives on Nuclear and Alternative Power Sources

A talk to the Forty-Second Annual Meeting of the NCRP

2006 April 04

M. Granger Morgan
Department of
Engineering and Public Policy
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Pittsburgh, PA 15213
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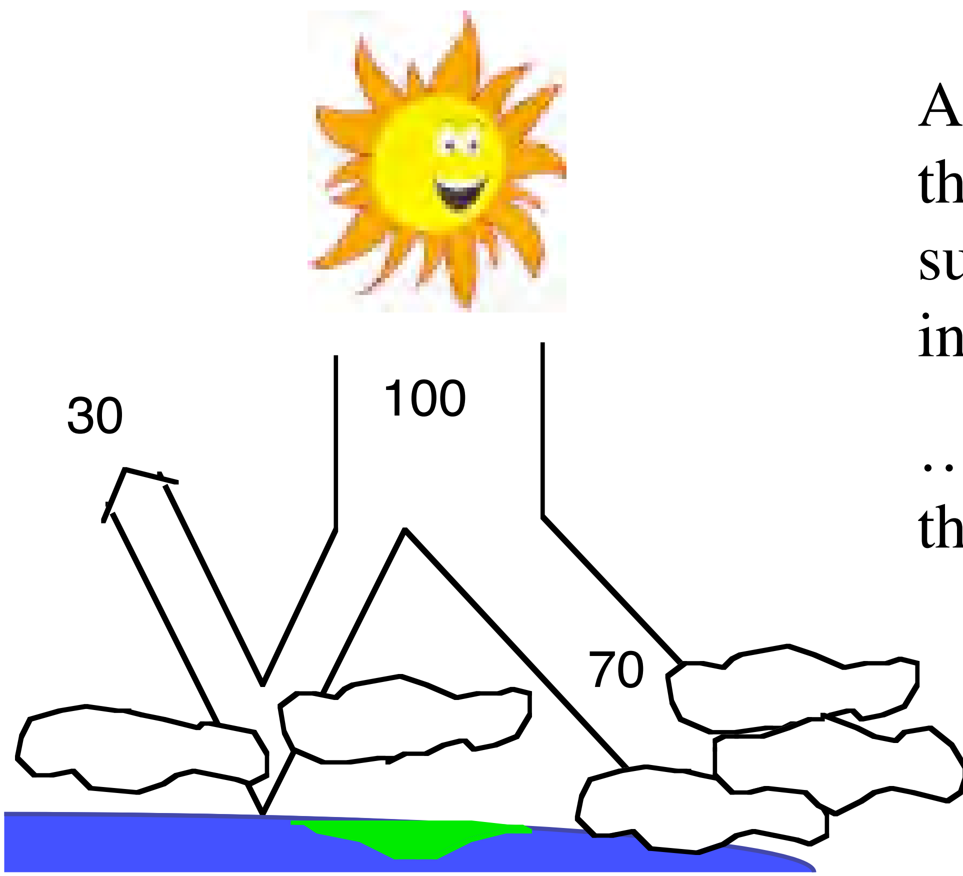
# In this talk I will:

- Say a few words about climate science and the impacts of climate change to motivate the need to decarbonize the energy system.
- Talk some about the technical alternatives we have available, their likely costs, and their respective strengths and limitations.
- Conclude with some comments on regulatory and policy needs if we are going to decarbonize the energy system in a timely and cost-effective manner.

# Sun-earth system

## A quick review




About 30% of the light energy that comes to the earth from the sun is immediately reflected back into space…

…and about 70% is absorbed by the atmosphere and the ground.

# But…

…while the atmosphere is transparent to visual light, it is opaque to heat (infrared).

So heat energy gets trapped.

This is termed the "greenhouse effect."

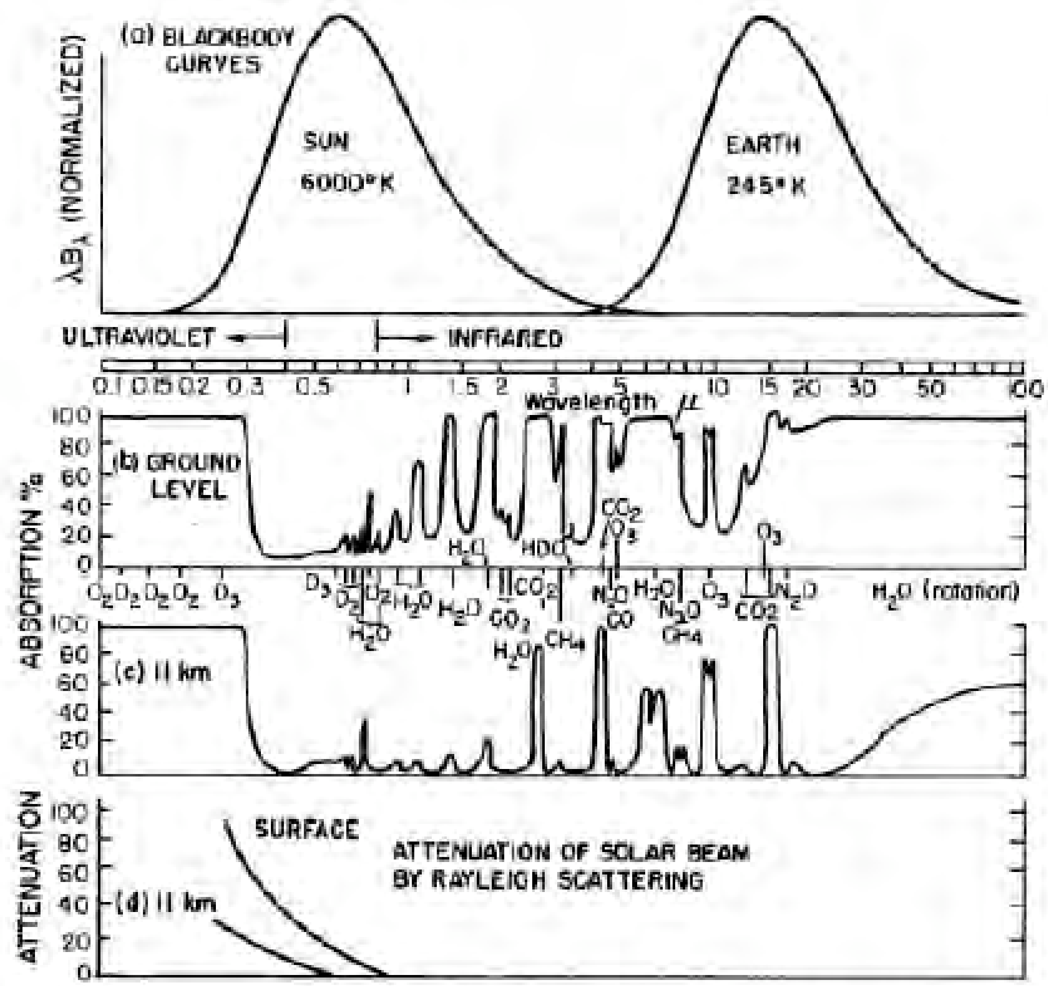
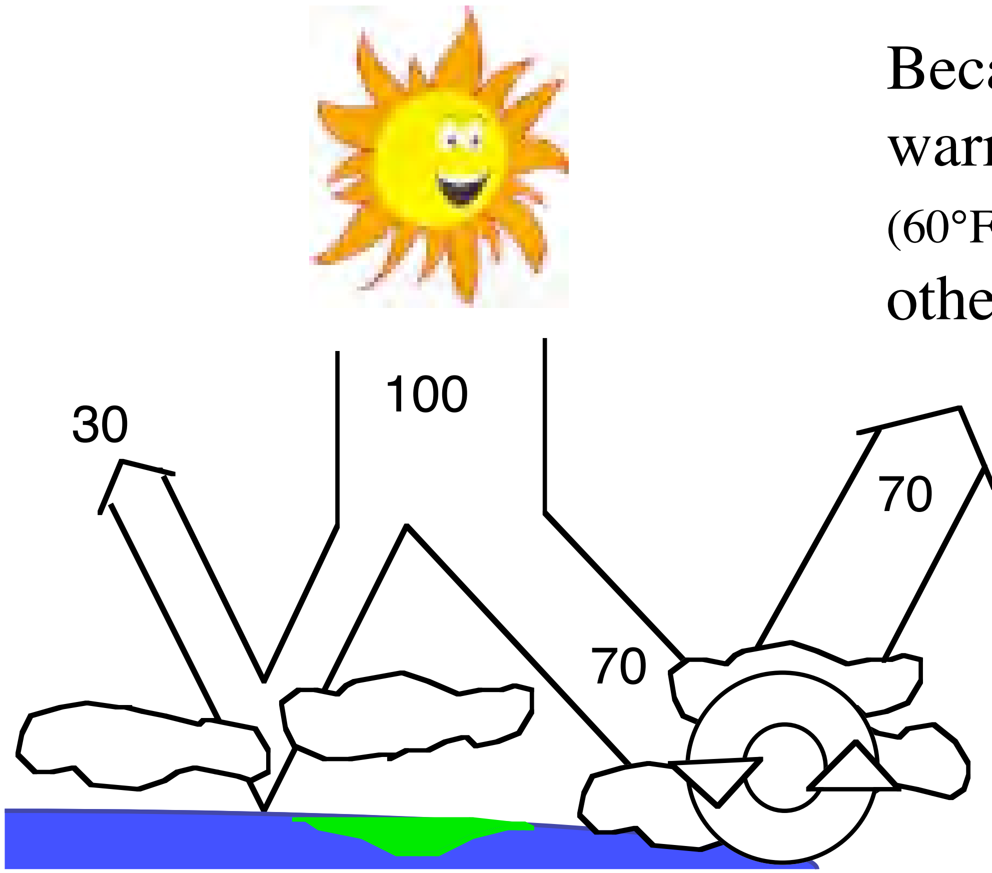



Fig. 1. (a) Blackbody emission for 6000°K and 245°K, being approximate emission spectra of the sun and earth, respectively (since inward and outward radiation must balance, the curves have been drawn with equal areas—though in fact 40% of solar radiation is reflected unchanged). (b) atmospheric absorption spectrum for a solar beam reaching the ground; (c) the same for a beam reaching the tropopause in temperate latitudes; (d) attenuation of the solar beam by Rayleigh scattering at the ground and at the temperate tropopause.

Source: Friskin, EOS, 1971.

# Sun-earth system…(Cont.)

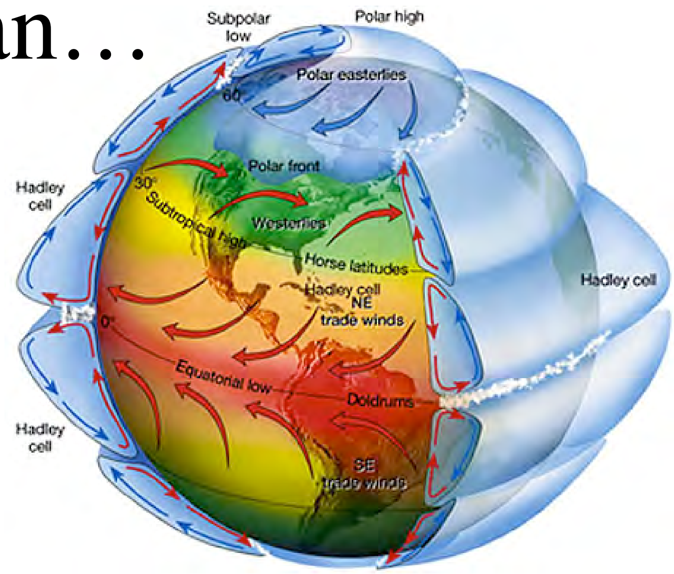



Because of this "greenhouse" warming the earth is 33°C (60°F) warmer than it would otherwise be.

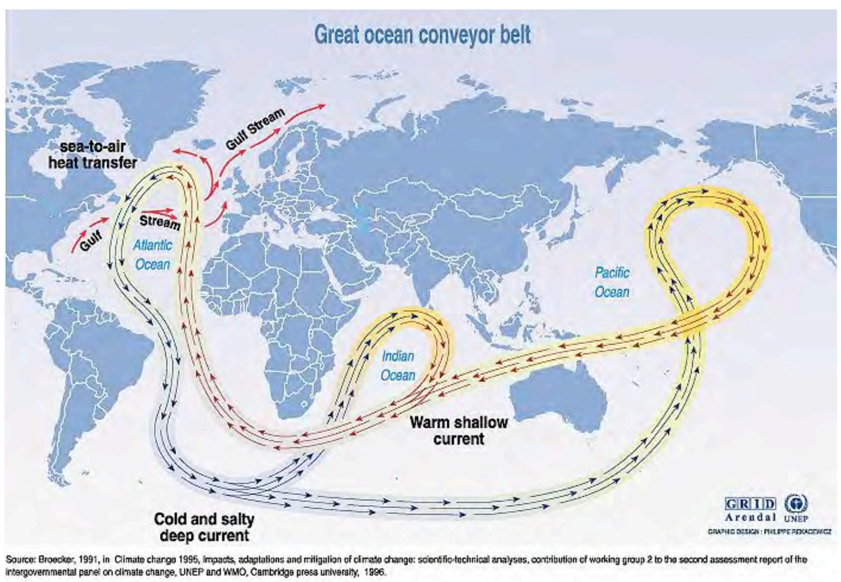
At that warmer temperature an equilibrium is reached and the same amount of energy is radiated back to space from the top of the atmosphere.

# The atmosphere and ocean…

…move energy from the equatorial region toward the poles - about half of the energy is carried by the atmosphere half by currents in the ocean.



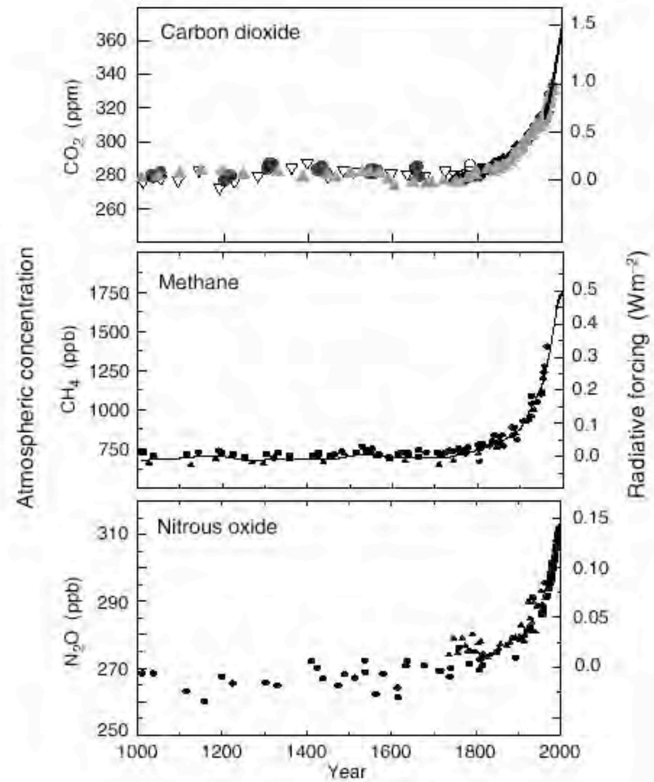

Source: NASA



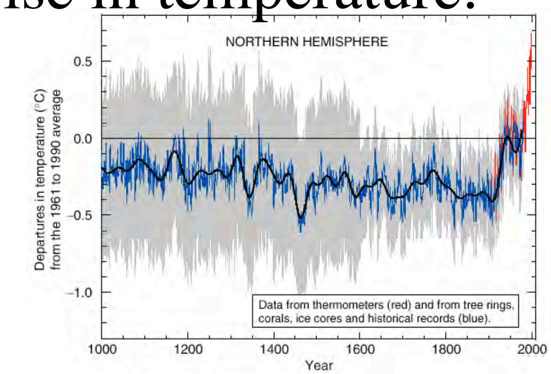

Source: UNEP

# Consequences of burning fossil fuel

When coal, oil and gas are burned, carbon dioxide ($CO_2$) is created.  Much of it remains in the atmosphere for ≥100 yrs. Since the beginning of the industrial revolution, atmospheric concentration has risen by about 30%. The same is true for other "greenhouse" gases such as methane.



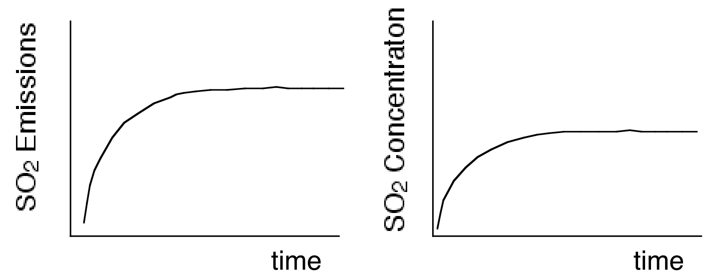

This is contributing to a rise in temperature:




Source: IPCC WG1 2001.

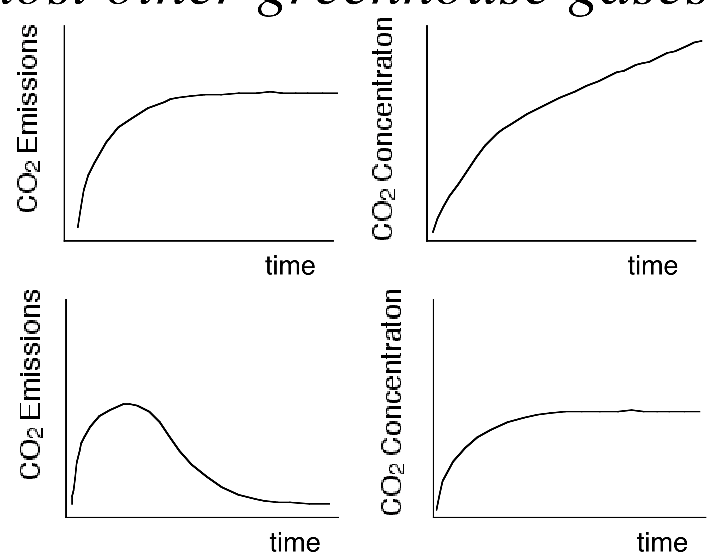
# GHGs are not like conventional pollutants

Conventional pollutants like $SO_2$ or $NO_x$ have a residence time in the atmosphere of just a few hours or days. Thus, stabilizing emissions of such pollutants results in stabilizing their concentration.




*This is not true of carbon dioxide or most other greenhouse gases*.

Because $CO_2$ lasts ~100 years in the atmosphere, stabilizing atmospheric *concentrations* of $CO_2$ will require reductions in current emissions *by at least 90%*.



# Warming from human GHG releases

The earth has already warmed by about 0.6°C (1.1°F), and will experience an average warming of between 1.4 and 5.8°C (2.5 to 10.4°F) over the coming century (IPCC, 2001).

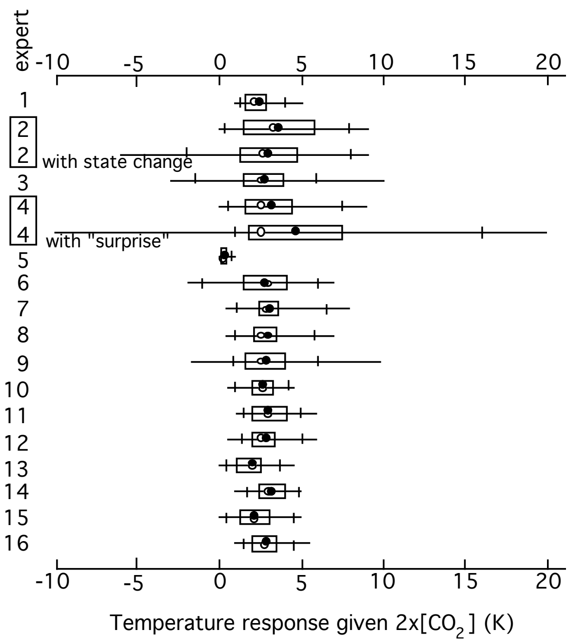
The impacts of such warming on the economies of developed countries will likely be just a few percent of GDP or less, although parts will be harder hit. The impacts on the economies of some developing countries will likely be *much* larger.

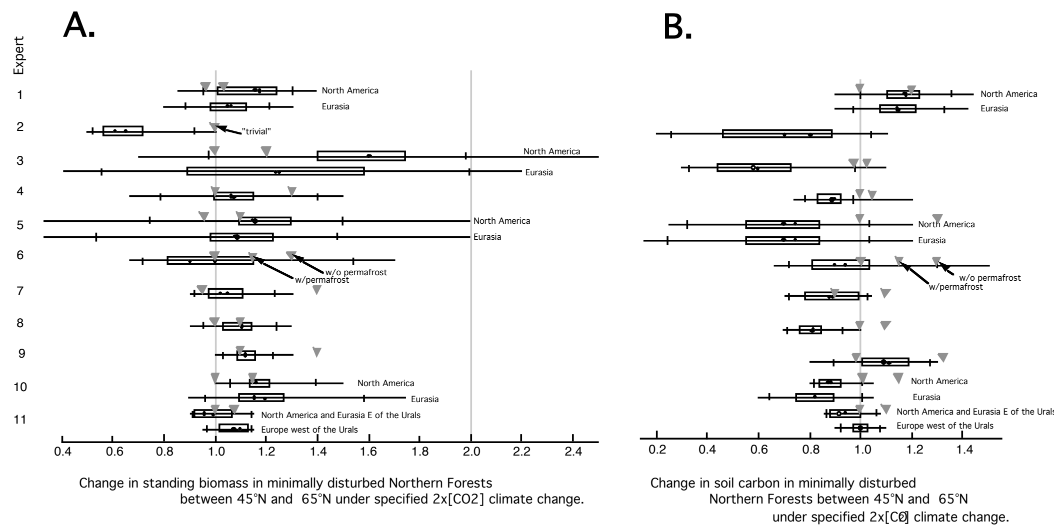
The impacts on many natural ecosystems will be enormous, since unlike us, trees, alpine meadows, polar bears, and coral reefs have a limited ability to adapt or move.

For details see: www.ipcc.ch
and www.usgcrp.gov/usgcrp/assessments.htm.

# Uncertainty

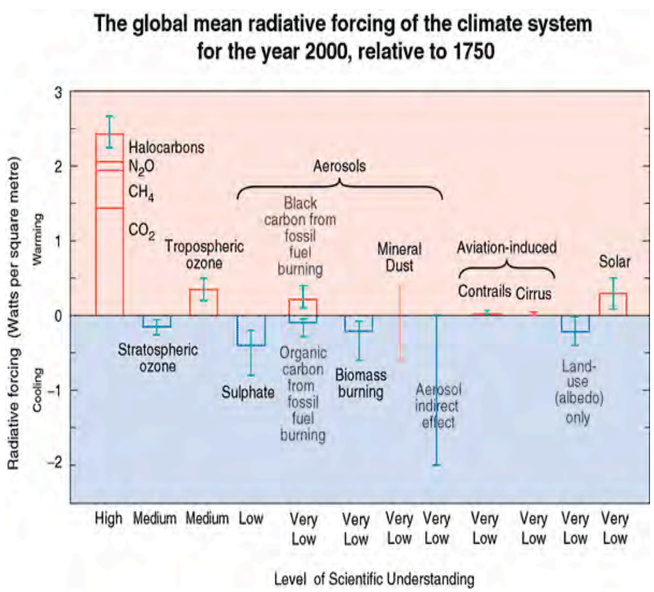
There is essentially no uncertainty about whether the climate is changing as a result of anthropogenic GHG emissions. There is considerable uncertainty about many of the details.

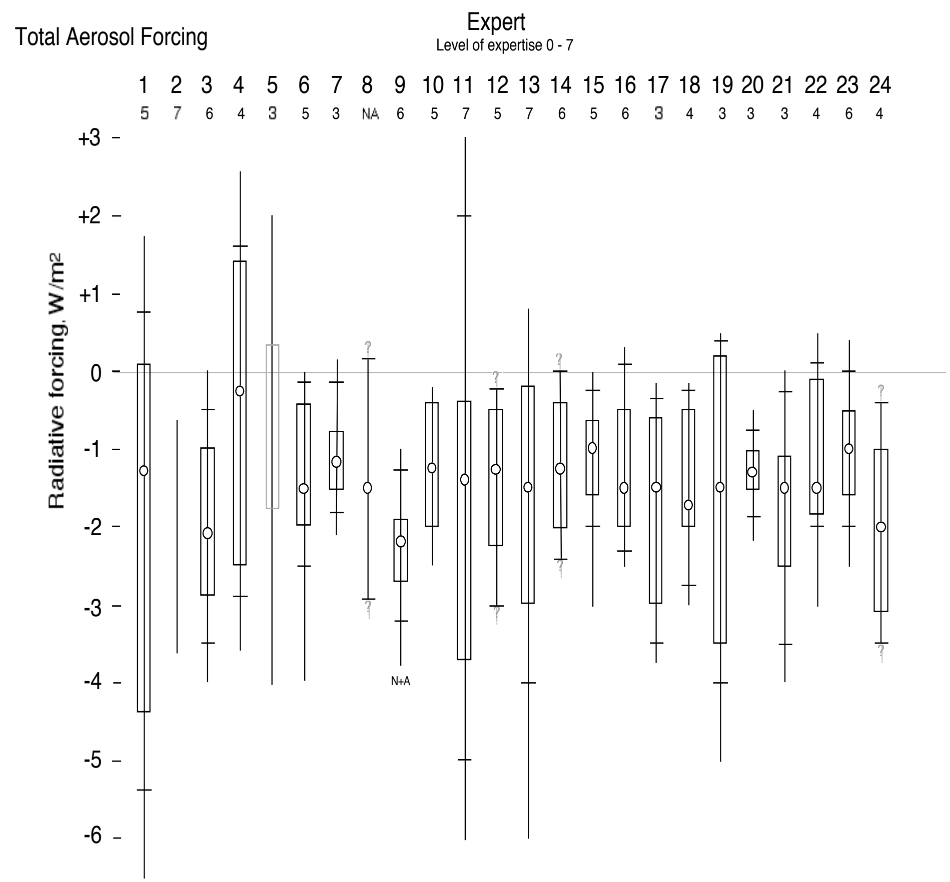



Sources: Morgan and Keith, *ES&T*, 1995; Morgan et al., 2001

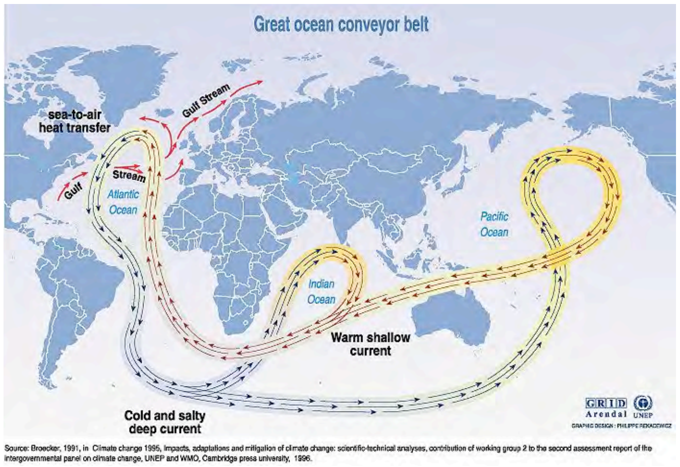
# Comparison with IPCC consensus results



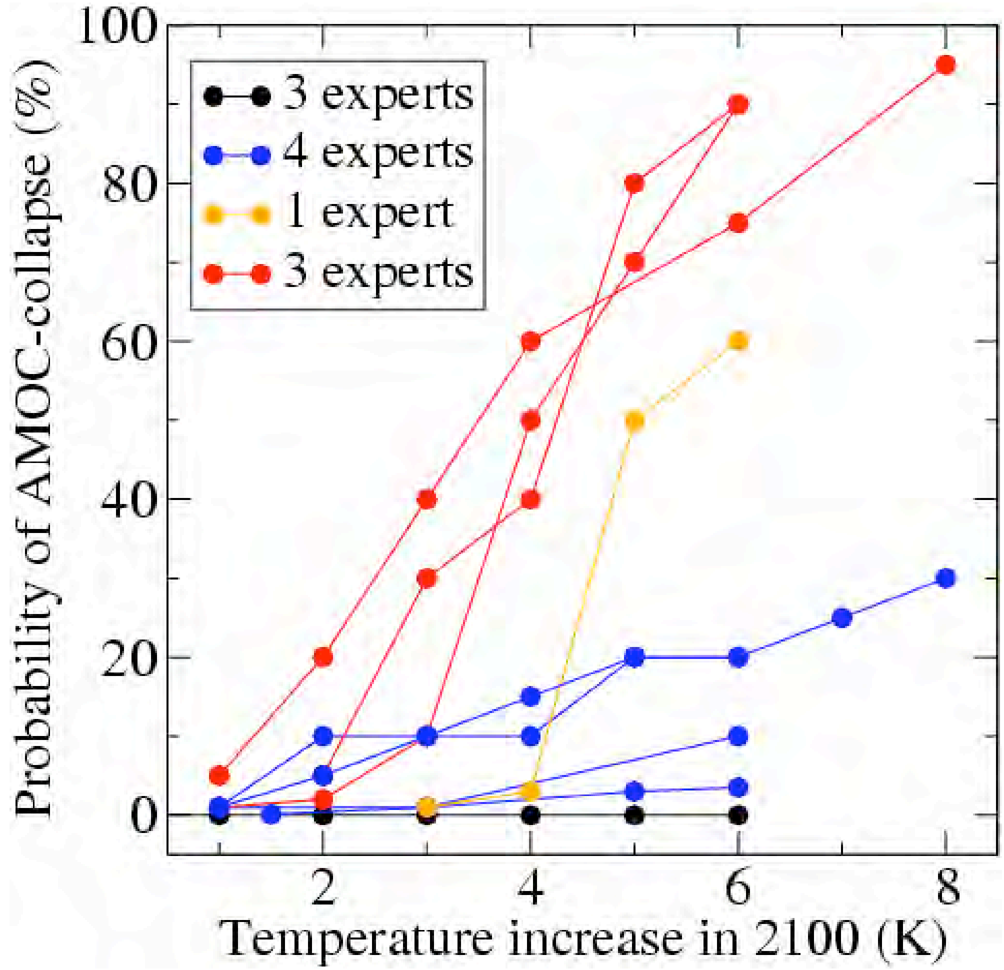




Sources: IPCC TAR WG1
Morgan et al., *Climatic Change*, in press.

# Collapse of the THC



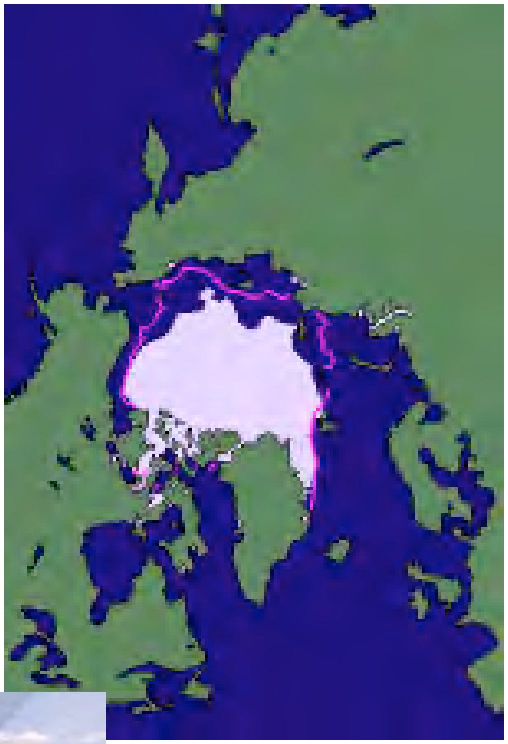

Source: UNEP at
http://www.grida.no/climate/vital/32.htm

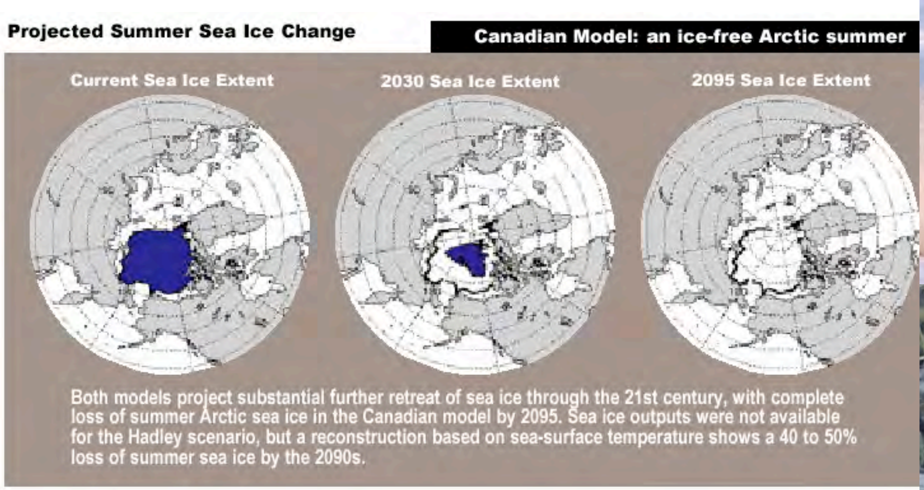


# Warming will be…

…greatest at the poles. The extent of summer polar sea ice is already decreasing.

Some models suggest the Arctic Ocean will be ice free by 2100.



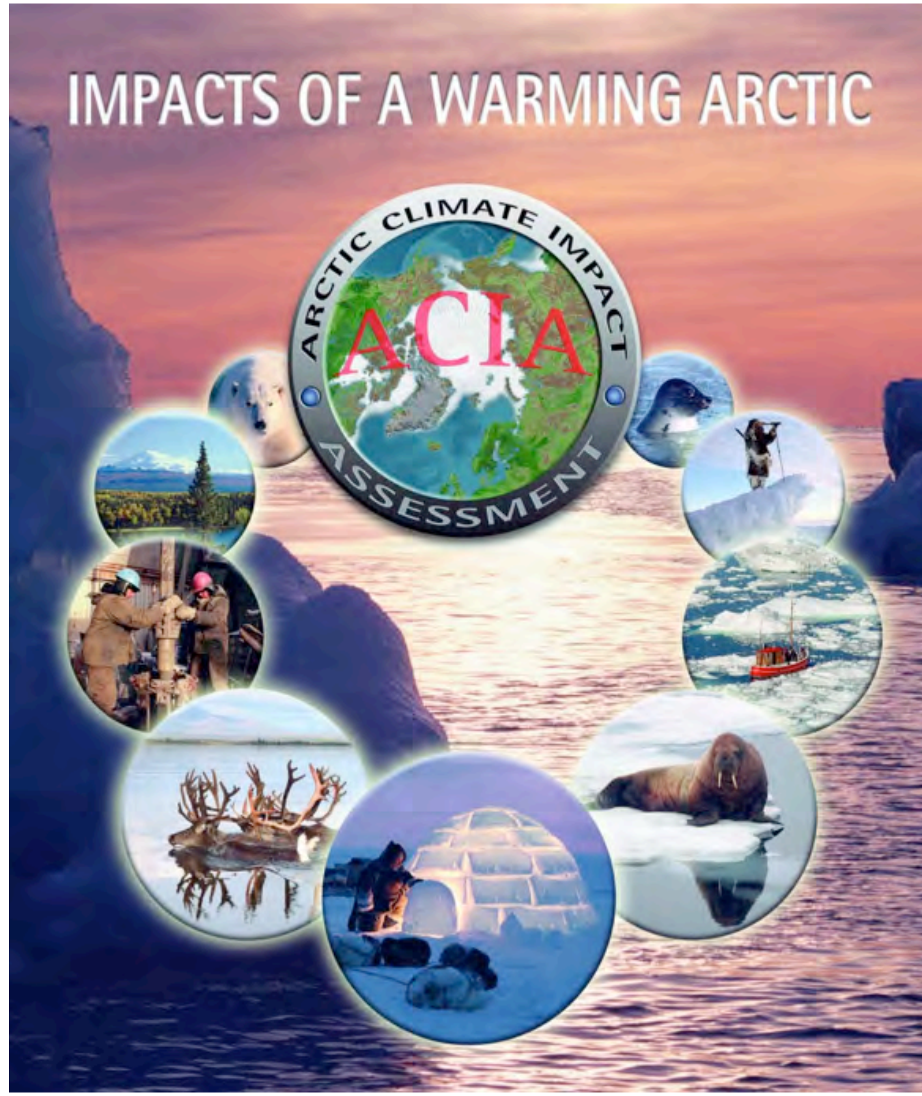



Sources: U.S. National Assessment, Polar Bear International and NOAA

# The Arctic Impact study…

…was commissioned by the Arctic Council, an international organization of eight Arctic countries and six organizations representing indigenous Arctic peoples.

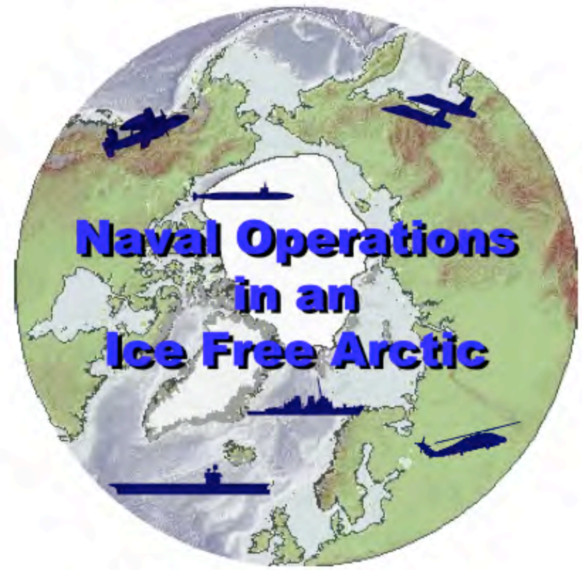
Published in 2004.




See: http://www.usgcrp.gov/usgcrp/Library/nationalassessment/newsletter/2000.Fall/arcticassess.html

# And lest you think this is only…

…the concern of climate scientists and environmentalists:




Naval Operations
in an Ice-free Arctic
Symposium
17-18 April 2001

**Final Report**

OFFICE OF NAVAL RESEARCH,
NAVAL ICE CENTER,
OCEANOGRAPHER OF THE NAVY,
AND THE ARCTIC RESEARCH COMMISSION

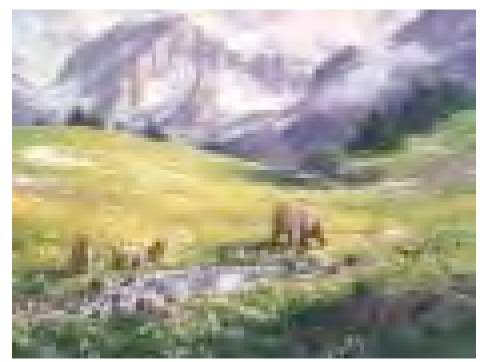
*Prepared by:*
*Whitney, Bradley & Brown, Inc.*

# While the Arctic is vulnerable, so too are…

Small island states and costal estuaries

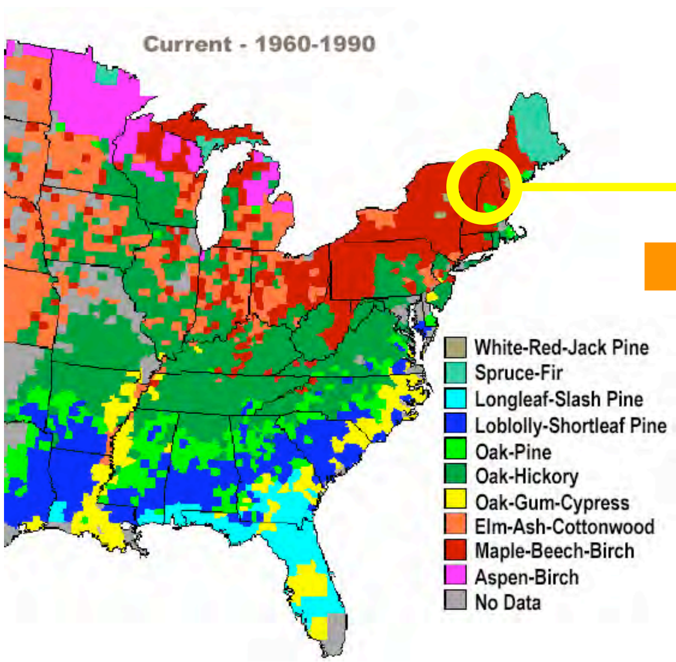
Mangroves

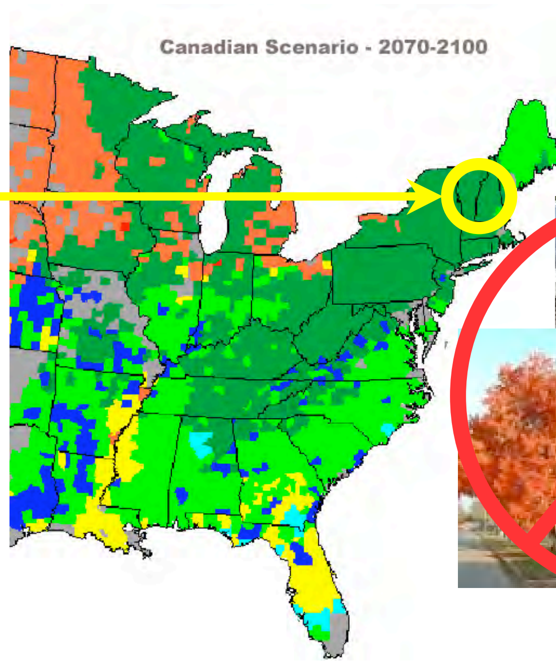
Alpine meadows



Coral reefs

# …as well as continental ecosystems that many of us hold dear.



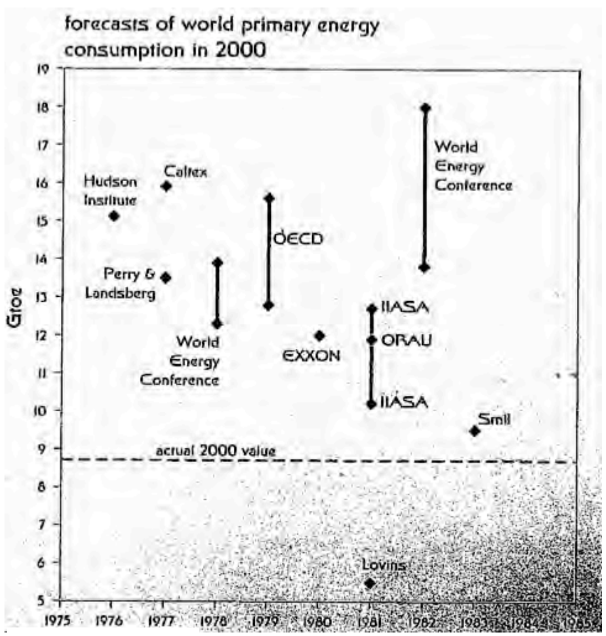

Sources: U.S.National Assessment

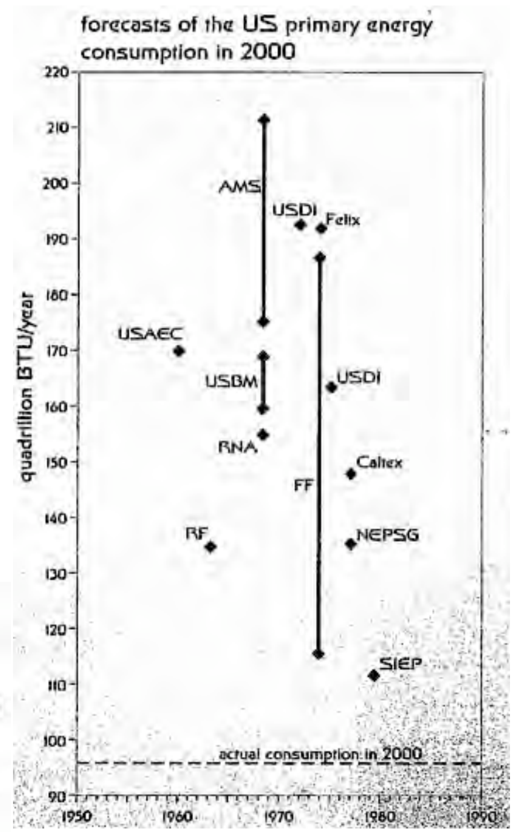
# In this talk I will:

- Say a few words about climate science and the impacts of climate change to motivate the need to decarbonize the energy system.
- Talk some about the technical alternatives we have available, their likely costs, and their respective strengths and limitations.
- Conclude with some comments on regulatory and policy needs if we are going to decarbonize the energy system in a timely and cost-effective manner.

# That we will need significant amounts of energy…

…in the decades to come, seems clear. Beyond that, as Vaclav Smil has clearly shown, we should be dubious about all quantitative forecasts and predictions.

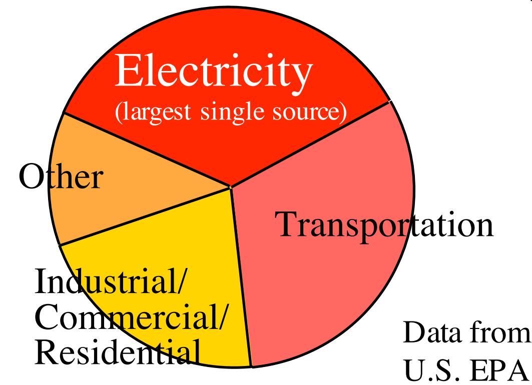



| | |
|---|---|
| AMS | A.M. Strout |
| FF | Ford Foundation |
| USBM | US Bureau of Mines |
| RNA | Robert Nathan Associates |
| SIEP | Stanford International Energy Program |
| USAEC | US Atomic Energy Commission |
| USDI | US Department of the Interior |
| NEPSG | Nuclear Energy Policy Study Group |
| RF | Resources for the Future |

Source: Vaclav Smil, *Energy at the Cross Roads*, MIT,2005.

# $CO_2$ Control Options:




**For Electricity:**

- Today
  - Conservation
  - Fuel switching
  - DG w/CHP
  - Nuclear
  - Wind
  - Biomass
- In 5 - 10 years
  - Coal w/carbon capture and geo. sequestration
- In 50 years
  - Solar photovoltaics?
  - Others?

**For Cars:**

- Today
  - Tighter CAFE standards
  - Hybrids
  - Biomass fuel
- In 5 - 10 years
  - Plug (i.e. grid charging) hybrids
  - Fuel cells
- In 50 years
  - Hydrogen

# As the French have clearly shown…

…despite its various issues, nuclear power is capable of serving a nation's electricity needs without $CO_2$ emissions. About 88% of EDF's electricity is generated in 58 nuclear power plants at 19 different sites.


Source: www.edf.fr/12025m/txt/Homefr/EDFEnergies/Nuclearpower.html

# But, before it can play…

…an expanded role in the U.S. I believe that following issues must be better resolved:

- Disposition of spent fuel
- Cost
- Liability/safety

And internationally:

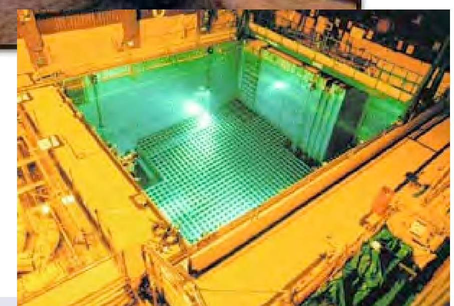
- Internationalization of the back end of the fuel cycle.

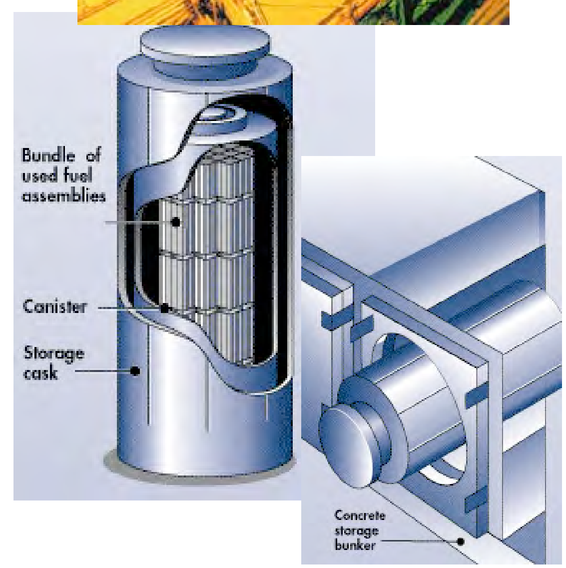
# Waste storage

In my view, we will not resolve this issue in the U.S. until we acknowledge that there is no technical way to assure that a waste site will be secure for 10's of thousands of years.

We need to recognize this explicitly and move on to secure, monitored, retrievable storage.

Storing spent fuel at reactor sites in a world with terrorism strikes me as just asking for trouble.  I had hoped that the Bush Administration would break the log jam using this argument to but so far they have not.






Figures from NRC and DoE

# Cost


If we made 747s one at a time on a custom basis, we would not be able to afford many of them either.

Clearly, until we can achieve some economies of scale, U.S. nuclear power will be too expensive, and the financial risks too great for most power companies. The Nuclear Regulatory Commission has recently approved an 1100 MW standardized design which is meant to lower costs and increase safety. Additional efforts to address issue of cost show some promise, but we have a very long way to go.

# Cost…(Cont.)

The 2003 MIT study argues that costs can be brought down, but also makes it clear that decarbonizing the world in the next 50 years will almost certainly require more than nuclear power.

**Global Growth Scenario**

| REGION | PROJECTED 2050 GWe CAPACITY | NUCLEAR ELECTRICITY MARKET SHARE 2000 | NUCLEAR ELECTRICITY MARKET SHARE 2050 |
|---|---|---|---|
| **Total World** | **1,000** | **17%** | **19%** |
| Developed world | 625 | 23% | 29% |
| U.S. | 300 | | |
| Europe & Canada | 210 | | |
| Developed East Asia | 115 | | |
| FSU | 50 | 16% | 23% |
| Developing world | 325 | 2% | 11% |
| China, India, Pakistan | 200 | | |
| Indonesia, Brazil, Mexico | 75 | | |
| Other developing countries | 50 | | |

Projected capacity comes from the global electricity demand scenario in Appendix 2, which entails growth in global electricity consumption from 13.6 to 38.7 trillion kWhrs from 2000 to 2050 (2.1% annual growth). The market share in 2050 is predicated on 85% capacity factor for nuclear power reactors. Note that China, India, and Pakistan are nuclear weapons capable states. Other developing countries includes as leading contributors Iran, South Africa, Egypt, Thailand, Philippines, and Vietnam.

**The Future of Nuclear Power**

AN INTERDISCIPLINARY MIT STUDY

**Comparative Power Costs**

| CASE (Year 2002 $) | REAL LEVELIZED COST Cents/kWe-hr |
|---|---|
| Nuclear (LWR) | 6.7 |
| + Reduce construction cost 25% | 5.5 |
| + Reduce construction time 5 to 4 years | 5.3 |
| + Further reduce O&M to 13 mills/kWe-hr | 5.1 |
| + Reduce cost of capital to gas/coal | 4.2 |
| Pulverized Coal | 4.2 |
| CCGT[a] (low gas prices, $3.77/MCF) | 3.8 |
| CCGT (moderate gas prices, $4.42/MCF) | 4.1 |
| CCGT (high gas prices, $6.72/MCF) | 5.6 |

a. Gas costs reflect real, levelized acquisition cost per thousand cubic feet (MCF) over the economic life of the project.

Available on line at:
http://web.mit.edu/nuclearpower/.

# Internationalize the back end of the fuel cycle

If nuclear power is to be a major part of the world's strategy for decarbonizing the energy system, than we must address the problem of proliferation that is posed by the back end of the fuel cycle.

I am not worried about countries like India, China and Brazil but many other developing states pose grave concerns.

Folks like Chauncey Starr and Wolf Hafele have proposed internationalizing the back end of the fuel cycle.

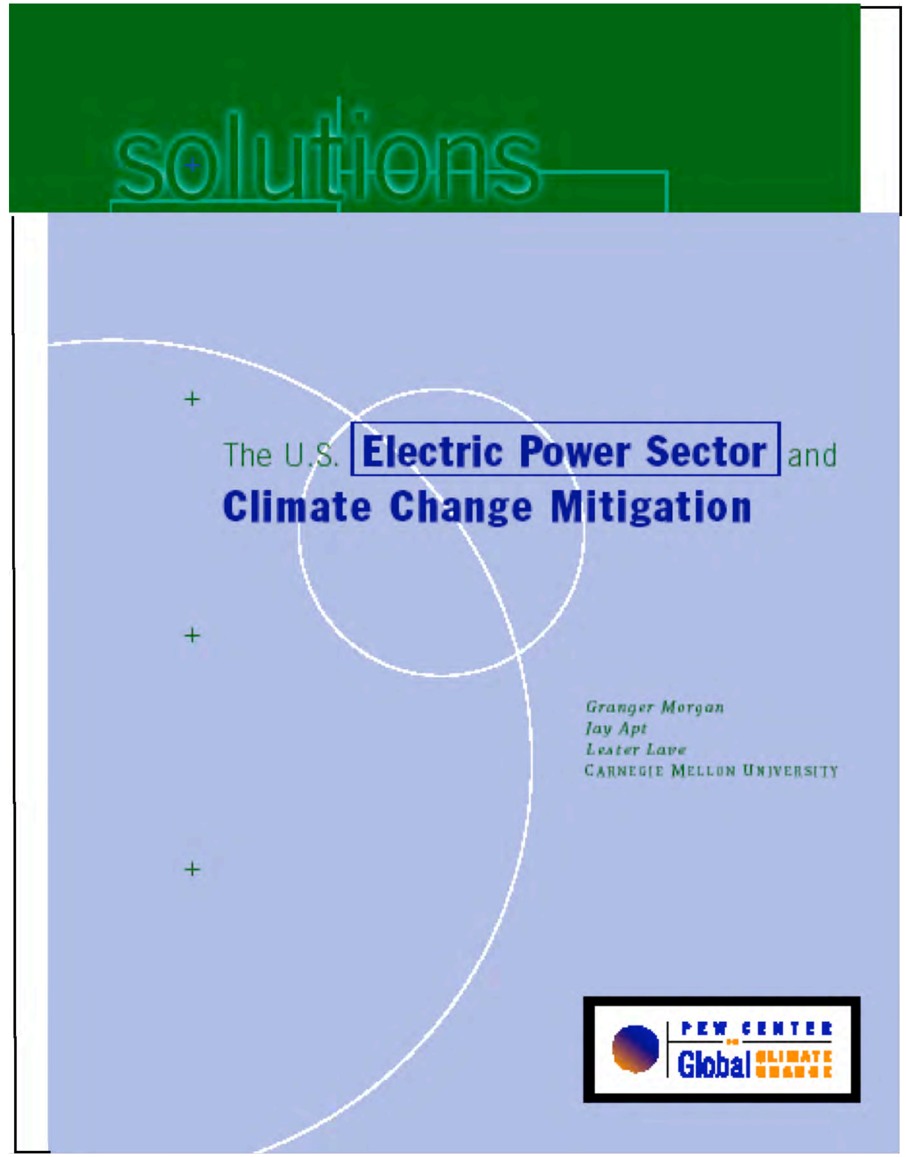
# Internationalize…(Cont.)

Details of an international spent fuel management system, such as how it would be administered, how it would be paid for, how many storage facilities would be developed, as well as the key issue of enforcement mechanisms, all need to be worked out through international negotiation which should start *now*.

The key point would be to create an international norm that *all* nations that employ nuclear power agree to place their spent fuel under a well monitored common system of international control.

# My colleagues…

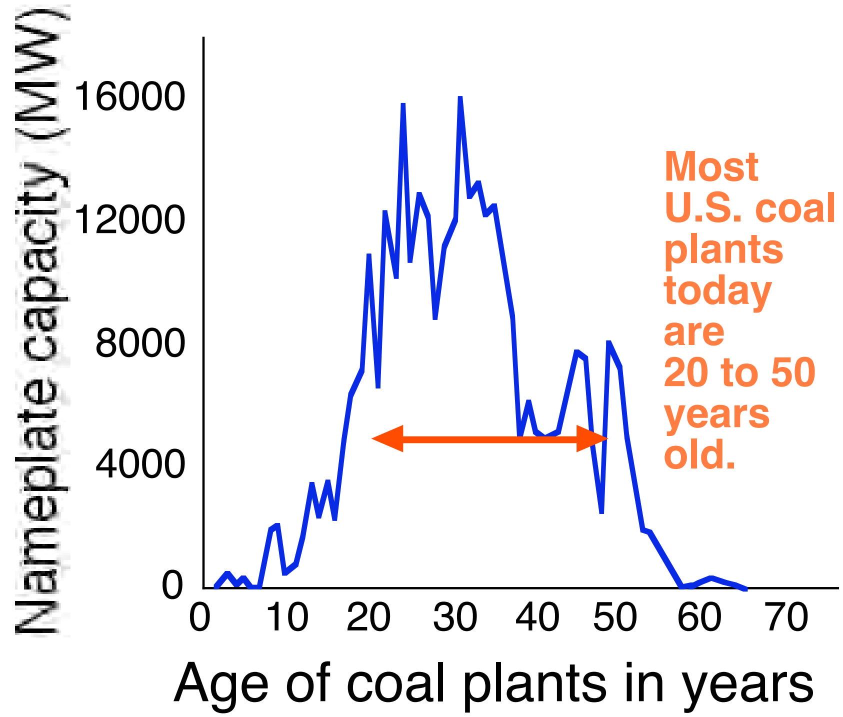
…and I recently produced a report for the Pew Center on Climate Change which addresses the problems of the U.S. electricity industry and climate change.




Available at: http://wpweb2k.tepper.cmu.edu/ceic/publications.htm
Or at: http://www.pewclimate.org/global-warming-in-depth/all_reports/electricity/index.cfm

# The U.S. makes just over half of its electricity from coal

Coal 51.2%
Nuclear 19.9%
Gas 16.6%
Hydro 7.2%
Oil 3.1%
Geothermal 0.34%
Wind 0.28%
Solar 0.01%

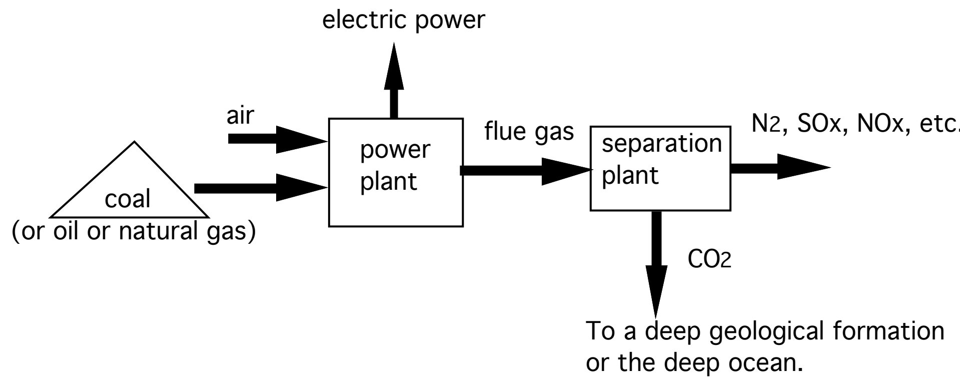



Many coal plants are old and will soon need to be replaced.

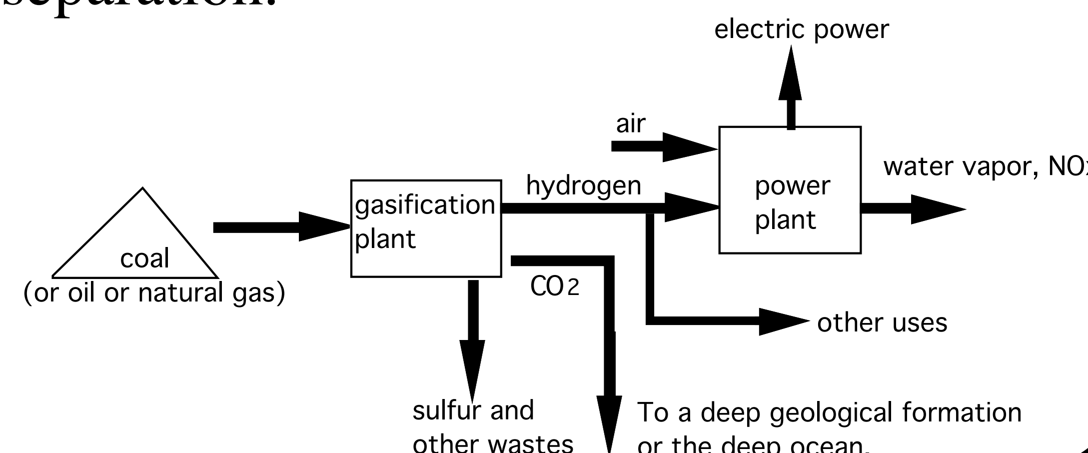
# $CO_2$ Capture and Sequestration (CCS)

There are several strategies.
The two closest to commercial use are:

1. Post-combustion separation after combustion in air.

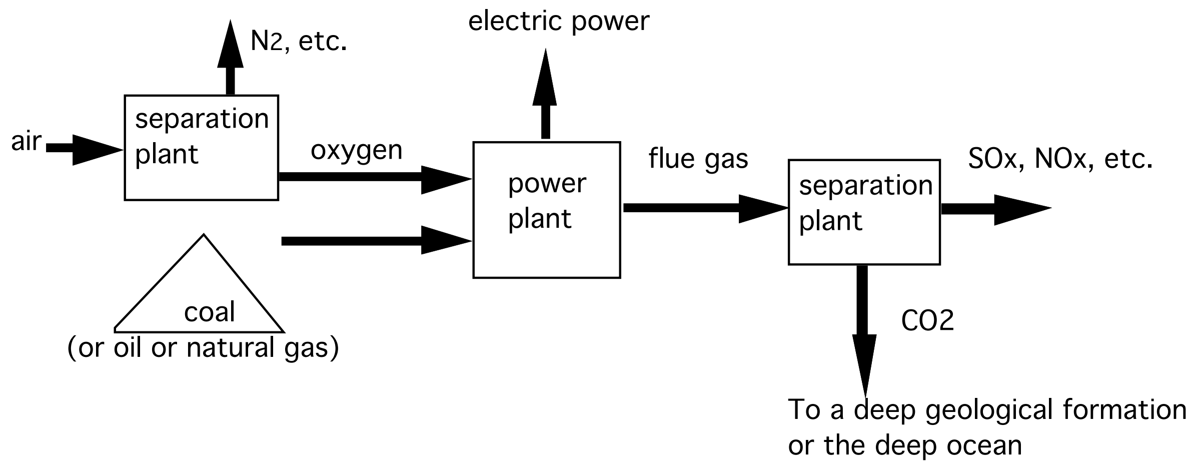



2. Pre-combustion separation.



# CCS…(cont.)

3. Combustion in oxygen.




Of course, there are many permutations on these basic designs.

# There are two IGCC plants now operating in the U.S.

The Wabash Valley Plant in Indiana, 262 Mwe. Repowered an existing old coal unit.

The Tampa Electric Polk Station, 262 Mwe. A new plant.

For details on both plants see: http://www.fe.doe.gov/programs/powersystems/gasification/gasificationpioneer.html

# Four other examples of existing facilities


Source: DoE

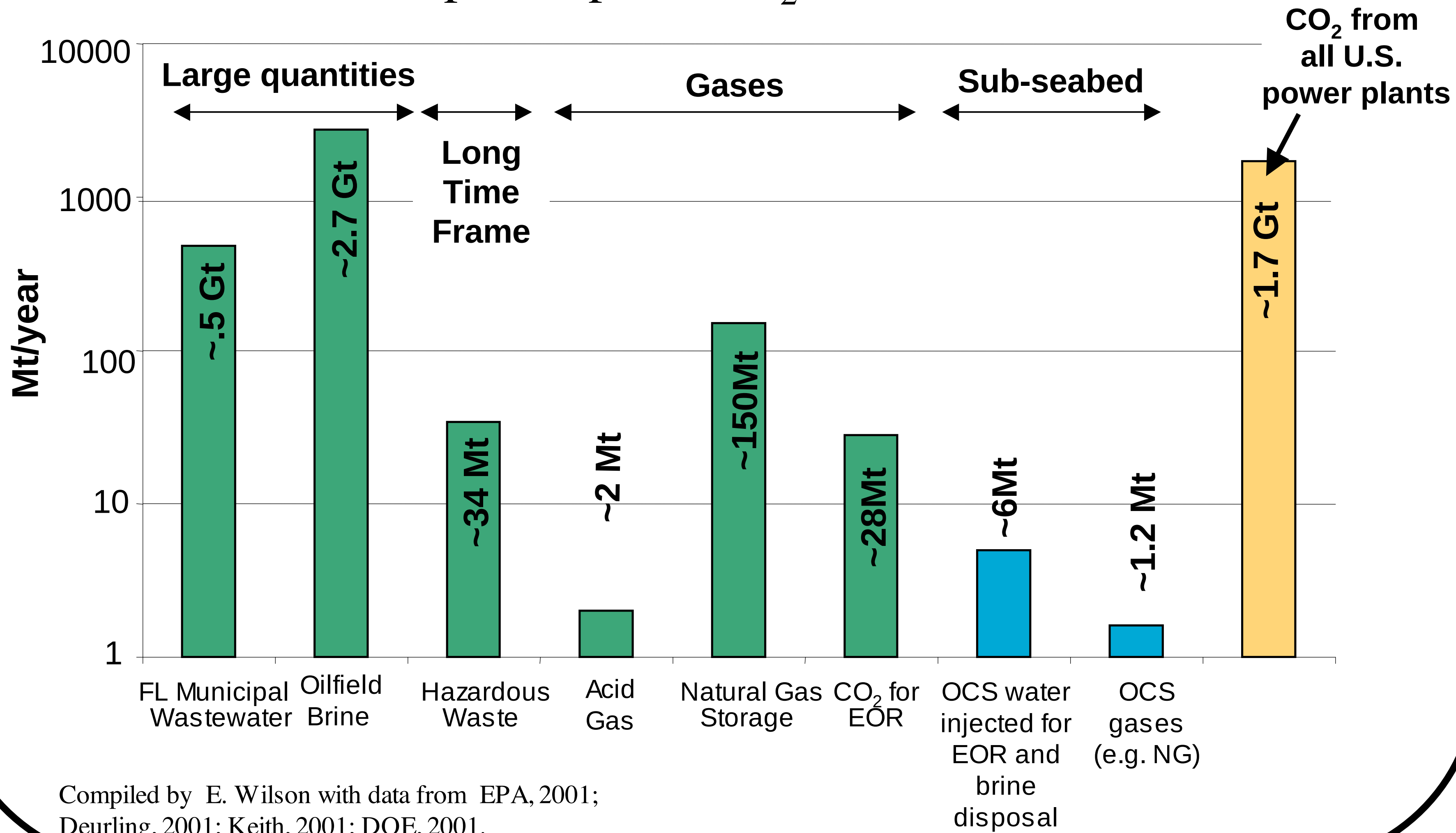

Source: Statoil


Source: AES Shady Point, Inc.


Source: BP

# The U.S. already injects lots of fluid

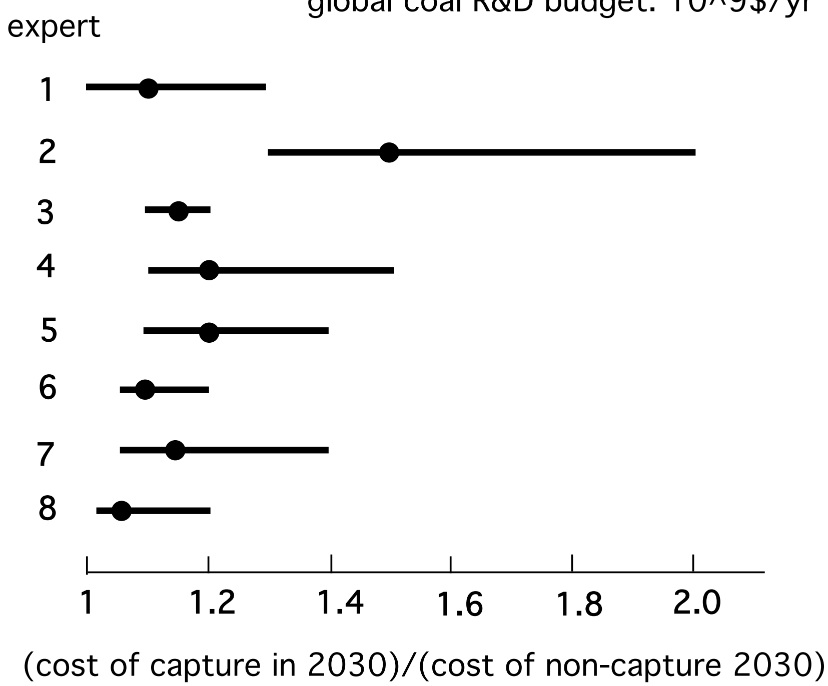
The mass of current U.S. fluid injections is greater than the mass of current power plant $CO_2$ emissions.

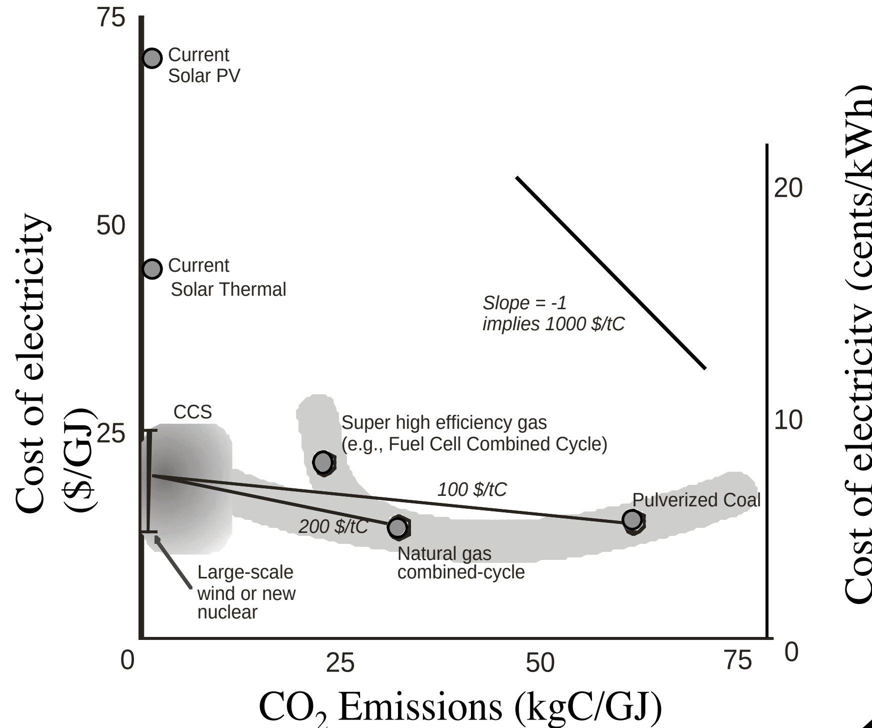



Compiled by E. Wilson with data from EPA, 2001; Deurling, 2001; Keith, 2001; DOE, 2001.

# Costs can be made manageable

carbon valued @ 50$/TC
global coal R&D budget: 10^9$/yr




Sources: Morgan & Keith; Keith.

# But we still need:

1. Adequate risk assessment and adaptive performance-based regulations. The Florida experience shows that the current approach to regulation is not adequate for $CO_2$. EPA and DoE need to talk more with each other to assure that the right science is now getting done.

## Regulating *the* UNDERGROUND INJECTION *of* $CO_2$

**Florida's batties over injecting wastewater deep underground offer a lesson for any future U.S. regulation of the underground disposal and sequestration of $CO_2$.**

When the U.S. finally gets serious about climate change, it will have to reduce emissions of $CO_2$ by more than a factor of two during this century in order to do its part in stabilizing atmospheric concentrations (*1*). $CO_2$ capture and disposal is among the most important supply-side technologies for managing the carbon problem. This technology could enable continued access to fossil energy while virtually eliminating emissions by capturing $CO_2$ from power plants and "storing," "sequestering" or "disposing" of it in deep geological formations (*2–5*). Surprisingly, all the hardware required to capture $CO_2$, transport it long distances, and inject it deep underground is currently commercially available. A successful technology, however, is more than just hardware; it comprises a network of institutions, financial systems, and regulations that is able to achieve broad public understanding and acceptance.

Disposal of fluids by injection deep underground is not new. Every year, the U.S. disposes of more fluids by deep-well injection than the mass of all the $CO_2$ now being released from the country's electric power plants (*6*). Regulations for disposal of $CO_2$ will not be written on a clean sheet; rather, they will be grafted on top of the substantial body of regulations and institutions that now manage underground disposal.

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*UNIVERSITY OF MINNESOTA*

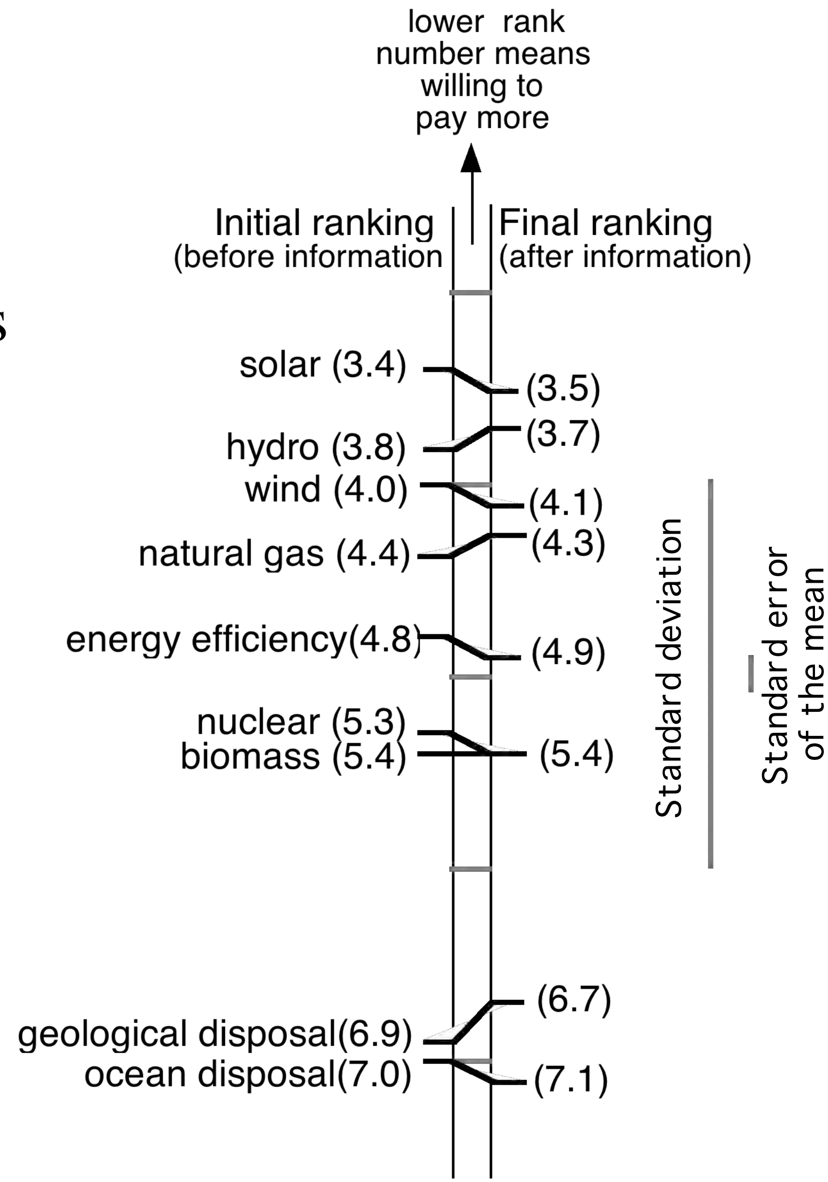


DECEMBER 15, 2005 / ENVIRONMENTAL SCIENCE & TECHNOLOGY ■ 499A

*ES&T*, December 2005

# Still need…(Cont.)

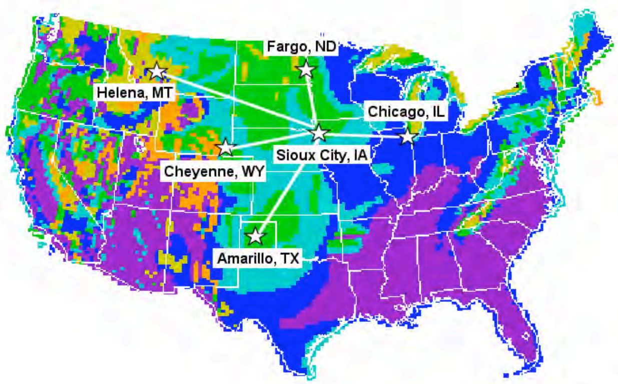
2. Much more attention to issues of public communication and public perceptions.



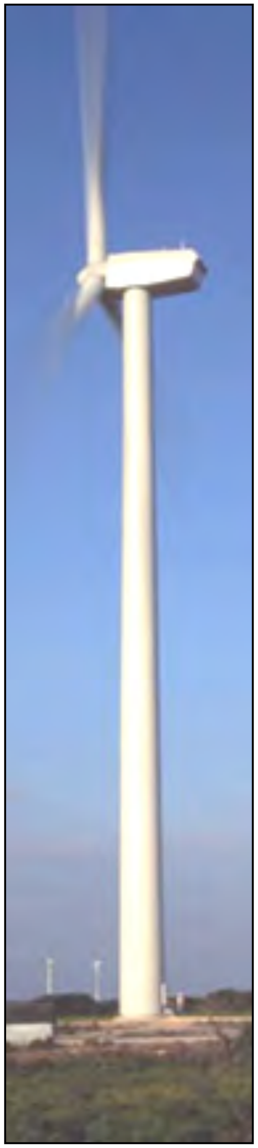
# Wind

Costs are becoming quite competitive. The big problem is intermittency, especially as capacity grows. Four recent studies from our group:

1. Use uncorrelated wind field on a continental scale.



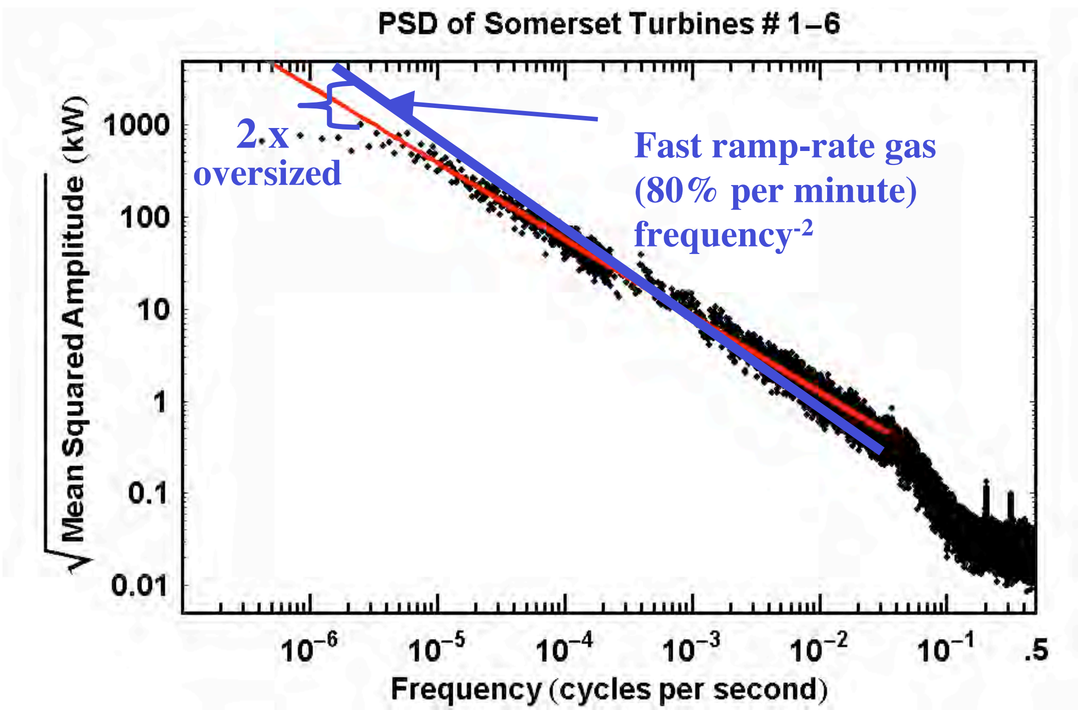

2. Wind in Texas under RPI - Apt et al. find given the high cost of new transmission, it would have been cheaper to use coal w/CCS.



# Four recent studies…(Cont.)

3. Matching ramp rates

Jay Apt has been doing power spectrum analysis of 1 sec resolution output from wind farms. Finds a perfect -5/3 Kolmogorov turbulence spectrum. To avoid "flicker" will need faster ramp rates than gas turbines can provide.



# Four recent studies…(Cont.)

4. Climate weather impacts.

PNAS

## The influence of large-scale wind power on global climate

David W. Keith*[†], Joseph F. DeCarolis[‡], David C. Denkenberger[§], Donald H. Lenschow[¶], Sergey L. Malyshev[‖], Stephen Pacala[‖], and Philip J. Rasch[¶]

*Departments of Chemical and Petroleum Engineering and Economics, University of Calgary, 2500 University Drive NW, Calgary, AB, Canada T2N 1N4; [‡]Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, PA 15213; Departments of [§]Mechanical and Aerospace Engineering and [‖]Ecology and Evolutionary Biology, Princeton University, Princeton, NJ 08544; and [¶]National Center for Atmospheric Research, P.O. Box 3000, Boulder, CO 80307

Communicated by Stephen H. Schneider, Stanford University, Stanford, CA, September 19, 2004 (received for review April 16, 2004)

Large-scale use of wind power can alter local and global climate by extracting kinetic energy and altering turbulent transport in the atmospheric boundary layer. We report climate-model simulations that address the possible climatic impacts of wind power at regional to global scales by using two general circulation models and several parameterizations of the interaction of wind turbines with the boundary layer. We find that very large amounts of wind power can produce nonnegligible climatic change at continental scales. Although large-scale effects are observed, wind power has a negligible effect on global-mean surface temperature, and it would deliver enormous global benefits by reducing emissions of $CO_2$ and air pollutants. Our results may enable a comparison between the climate impacts due to wind power and the reduction in climatic impacts achieved by the substitution of wind for fossil fuels.

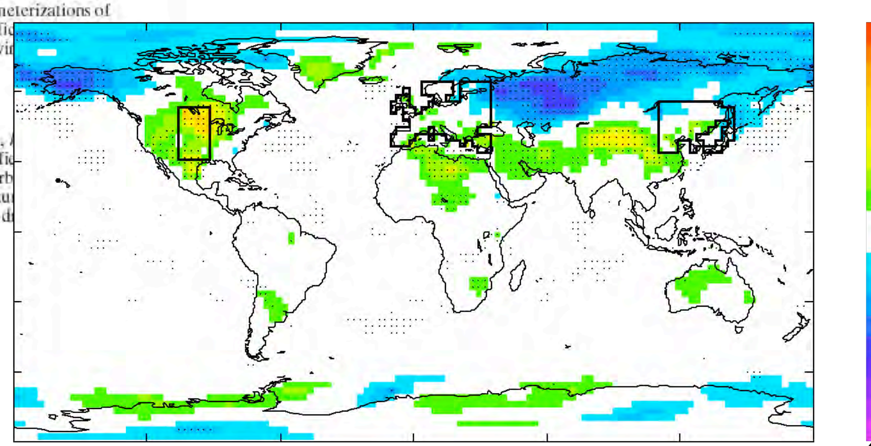
Global wind-power capacity is growing by ~8 GW·yr$^{-1}$, making wind the fastest growing nonfossil source of primary energy (1). The cost of electricity from wind power is now ~40 dollars per

experiment, the drag coefficients were perturbed uniformly over an area defined by one of three wind-farm arrays, denoted A, B, and C (outlined in black in Figs. 1, 5*A*, and 5*B*, respectively). The reason for choosing these arrays is discussed below.

We used two methods to parameterize the additional drag due to the turbines. The first method was a modification of the roughness length, $z_0$. In the boundary-layer parameterizations of the models (6, 7), $z_0$ determines the drag coeffic ultimately, the surface fluxes through the followi

$$C_D = f(Ri)\frac{k^2}{\ln(z_1/z_0)^2},$$

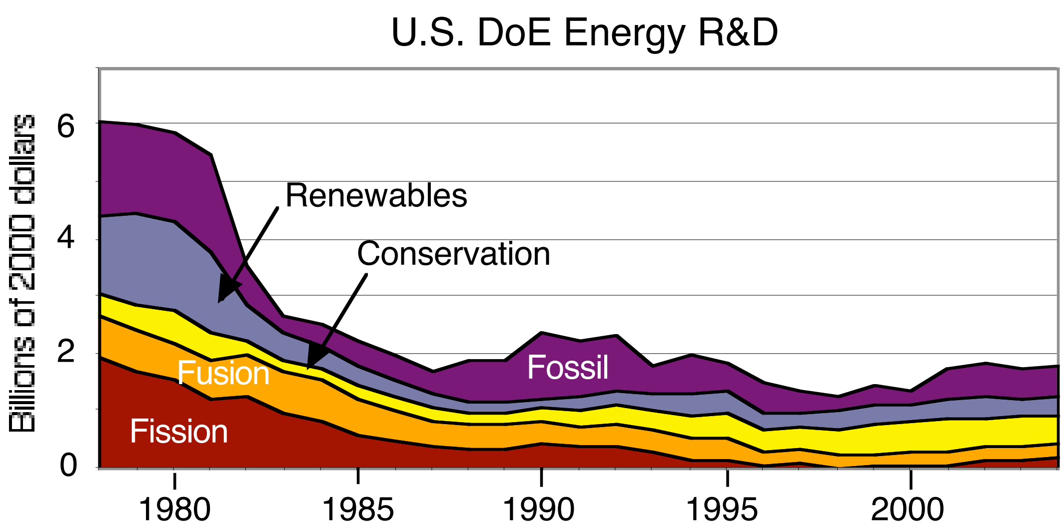
where $z_1$ is the height of the first-layer midpoint, von Karman constant, and $f$ is function that modifi of the influence of buoyancy on shear-driven turb which is parameterized by the Richardson nu simulate the effect of a uniform increase in d



# The importance of research

To do this the U.S. is going to need a dramatic expansion of investment in basic technology research.

Federal and state investments in energy R&D are not only low relative to the energy sector's economic, environmental, and national security importance, but are often directed at short-term or applied projects.




Source: Gallagher, K.S., Sagar, A., Segal, D., de Sa, P., and J.P. Holdren, "DOE Budget Authority for Energy Research, Development, & Demonstration," John F. Kennedy School of Government, Harvard University, 2004.

# There are basically three…

…technologies to switch the vehicle fleet to no net $CO_2$:

- Batteries charged from a generation source that does not emit $CO_2$;
- Hydrogen fuel cells for which the $H_2$ is isolated with an energy source that does not emit $CO_2$;
- Internal combustion engines fueled with ethanol made from cellulosic biomass.

Because time is short, I will do just one slide on each. My comments draw heavily on:

Lester Lave, W. Michael Griffin and Heather MacLean, "The Ethanol Answer to Carbon Emissions," *Issues in S&T*, Winter 2001.

# Batteries

Battery-powered cars are currently expensive and the associated heavy metals can pose health risks.

Today, to get even a 100-mile range, about 1,100 pounds of batteries are required for a two-passenger car. Making and recycling these batteries is expensive. Mining and smelting the heavy metals for the batteries, as well as making and recycling the batteries, potentially will discharge large quantities of heavy metals into the air, water, and landfills.

If the current U.S. fleet of ~200 million vehicles were run on current lead acid, nickel cadmium, or nickel metal hydride batteries, the amount of these metals discharged to the environment would increase by a factor of 20 to 1,000, raising serious public health concerns. Clearly, major breakthroughs are still needed in electrochemistry.

Despite problems, in my view, plug-hybrids hold great potential, at least as a transition technology.

# $H_2$ (w/fuel cells)

A great deal of attention has gone to fuel cells, which emit nothing but water vapor and are much more efficient than an internal combustion engine.

Unfortunately, the current reality is that fuel cells are extremely expensive, and cannot match the driving performance of current engines. Major technological breakthroughs are required to make fuel cells attractive for light-duty vehicles. I think much of the recent federal attention has been motivated by a desire to avoid doing things like tightening CAFE standards.

The environmental implications of fuel cells cannot be known until we know what materials and processes will be used in them, and how the hydrogen will be produced.

Given its low density, hydrogen is hard to store. There are also safety issues in that $H_2$ diffuses ~x10 more readily than $CH_4$, is explosive across ~x10 as wide a fuel-air mixture, and requires only about ~1/10th as much energy to ignite.

# Cellulosic Ethanol

Making ethanol from corn is a politically inspired subsidy to farms - but is *not* a realistic major long-term solution.

However, there is now technology that can make ethanol from lignocellulosic feedstocks with prototype pilot and full-scale plants under development.

The principal energy crops would be grasses such as switchgrass, which is a native prairie grass, and hybrid trees such as poplars or willows. A well-planned and thoughtful bioethanol program could return much of U.S. land closer to its native state, enhancing the environment, as well as bringing the benefits of a renewable and sustainable fuel. There are, of course, important land-use issues and soil degradation issues that deserve serious attention.

Lave and his colleagues have does assessments that suggest that the entire U.S. fleet could be powered by cellulosic ethanol.

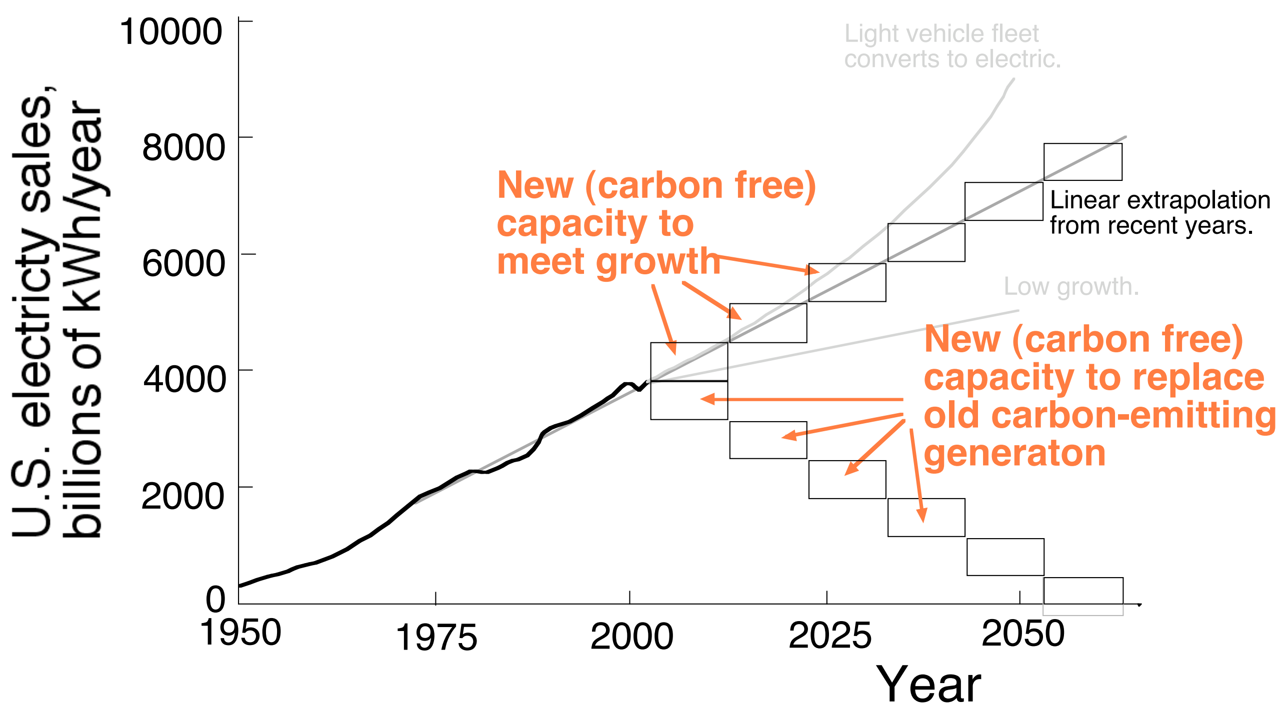
# In this talk I will:

- Say a few words about climate science and the impacts of climate change to motivate the need to decarbonize the energy system.
- Talk some about the technical alternatives we have available, their likely costs, and their respective strengths and limitations.
- Conclude with some comments on regulatory and policy needs if we are going to decarbonize the energy system in a timely and cost-effective manner.

# In our Pew Report, we asked…

…how fast could the U.S. electricity industry decarbonize?

Answer: About 50 years, if only zero carbon generation were installed and the current rate of construction were doubled. Perhaps faster with major conservation efforts.



# Many have argued…

…that *before* anything can be done about limiting climate change three things must happen:

1. Research must be conducted to eliminate all key uncertainties about the science;
2. All major nations must agree to control emissions of $CO_2$ and other greenhouse gases before any nation can be expected to impose significant controls, because otherwise there would be an unacceptable "free rider " problem; and
3. All major nations must agree on a "safe" target concentration of $CO_2$ which the world will then collectively achieve.

*I believe that all three of these claims are wrong and misguided.*

# It would be wonderful if we could have a "top down" target...

But, economic and ecological impacts differ all around the world, and different individuals and societies value them differently.

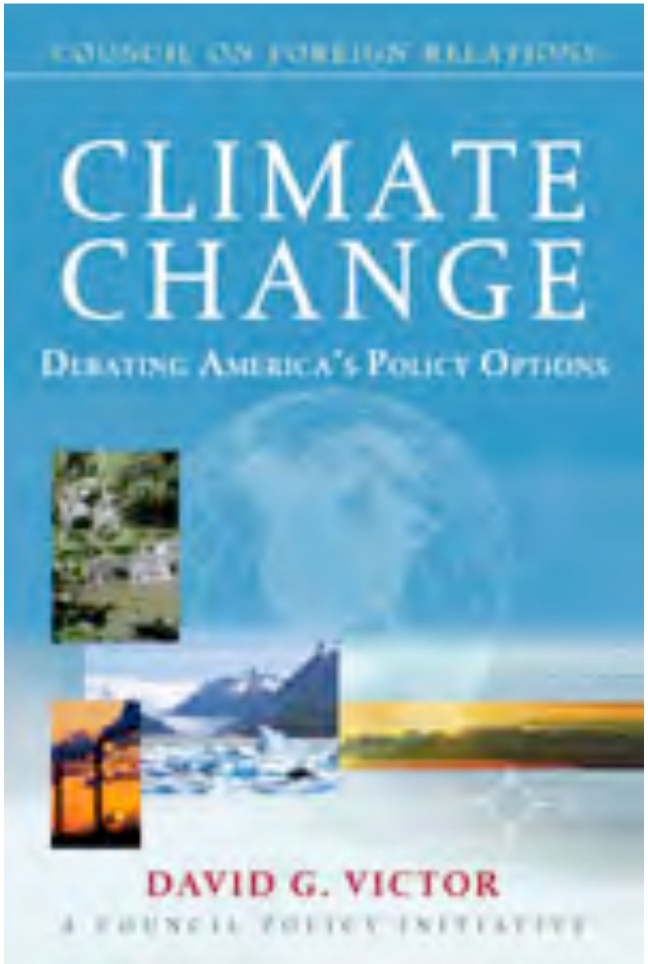
The consequences of this are clearly indicated in work my colleague Hadi Dowlatabadi (now at UBC) and I did several years ago using our Integrated Climate Assessment Model (ICAM).

# Carbon management from the bottom up

Five years ago in *Science** I argued that a more plausible alternative is a piece-meal build up from local and regional control regimes.

This is happening in the EU and in several U.S. states today.

A good recent argument for this approach is laid out in the third speech in David Victor's new book.




David G. Victor, *Climate Change: Debating America's Policy Options*, Council on Foreign Relations, 2004.

* M. Granger Morgan, "Managing Carbon from the Bottom Up," *Science*, *289*, p.2285, September 29, 2000.

# Regions are starting…

… to control emissions.

You may know about the $CO_2$ trading system being set up in the EU.

Some of you may not know that, while the U.S. Government has not undertaken any controls, originally nine but now seven states in the northeastern U.S., and the three western states (California, Oregon and Washington), are also undertaking regional controls, as are various cities.

**Seven Northeast States Launch Regional Greenhouse Gas Initiative**

**ALBANY, New York**, December 20, 2005 (ENS) - The governors of seven Northeast states announced their agreement today on the first mandatory cap-and-trade program to control carbon dioxide emissions in the United States. The regional climate change and energy program aims to reduce the heat-trapping greenhouse gas emissions responsible for global warming.

A memorandum of understanding detailing the program was released today and will be signed by Connecticut, Delaware, Maine, New Hampshire, New Jersey, New York, and Vermont.

Called the Regional Greenhouse Gas Initiative (RGGI), the program will reduce carbon dioxide pollution through a mandatory emissions cap on the electricity generating sector, coupled with a market-based trading program to achieve the lowest possible compliance costs.

Beginning in 2009, RGGI will stabilize carbon dioxide (CO2) emissions from power plants in the region at current levels through 2015, and reduce emissions by 10 percent from current levels by 2019. RGGI also aims to achieve reductions through energy efficiency and through greenhouse gas emission reduction projects outside of the power sector.

New York Governor George Pataki, a Republican, originated the RGGI proposal. "My goal in proposing the Regional Greenhouse Gas Initiative in 2003 was to bring states together to tackle a significant environmental challenge that we all face, knowing that a collaborative effort is the most effective policy," Pataki said today.

Source: Environmental News Service

# Why are they doing this?

I believe that the primary motivation is a concern about ecological impacts, and a belief that if someone doesn't take the lead and start doing something now, about limiting emissions, it will never happen.

If, as I have argued, $CO_2$ control occurs via "carbon management from the bottom up" not "from the top down" then resulting atmospheric concentrations will be the emergent consequence of the gradual coming together of a variety of politically motivated regulatory actions, *not* the consequence of a collective top-down global optimization.

# Some bottom lines

Increasing levels of greenhouse gases – and the climate change they are causing – are real *and they are a major problem*.

To stabilize concentrations, the world is going to have to reduce its emissions of $CO_2$ and other GHGs by *at least 90%*.

Over the coming decades there will have to be *enormous changes in the nature and operation of the global energy systems*.

A global system for control can be built up over time from separate regional efforts. A global agreement is not the necessary first step.

# Bottom lines…(Cont.)

Because the industrialized world:

- has far greater technical and economic capacity to limit emissions;
- has benefited far longer from unconstrained emissions; and
- has publics which are more likely to insist on addressing the problem of climate change in the near-term

they will be, and should be, the first to undertake major emissions control.

However, major industrializing states, such as China, India and Brazil will all have to undertake substantial reductions in a few decades as technology becomes more cost-effective, impacts become more serious, and global norms and regulations develop.

# Bottom lines…(Cont.)

The diplomatic community should start now to work on ways to facilitate carbon management from the bottom up and to develop positive (tech transfer) and negative ($CO_2$ boarder adjustment tariffs) to persuade developing countries to also move toward low carbon energy systems.

# Acknowledgments

Much of the research reported in this talk was supported by the US National Science Foundation under awards: DMS-9523602; SBR-9521914; and SES-034578; by EPRI, the Alfred P. Sloan Foundation and by the Pew Center for Global Climate Change.

The opinions expressed are my own.

# The Chernobyl Aftermath

## vis-à-vis

# the Nuclear Future:

# An International Perspective

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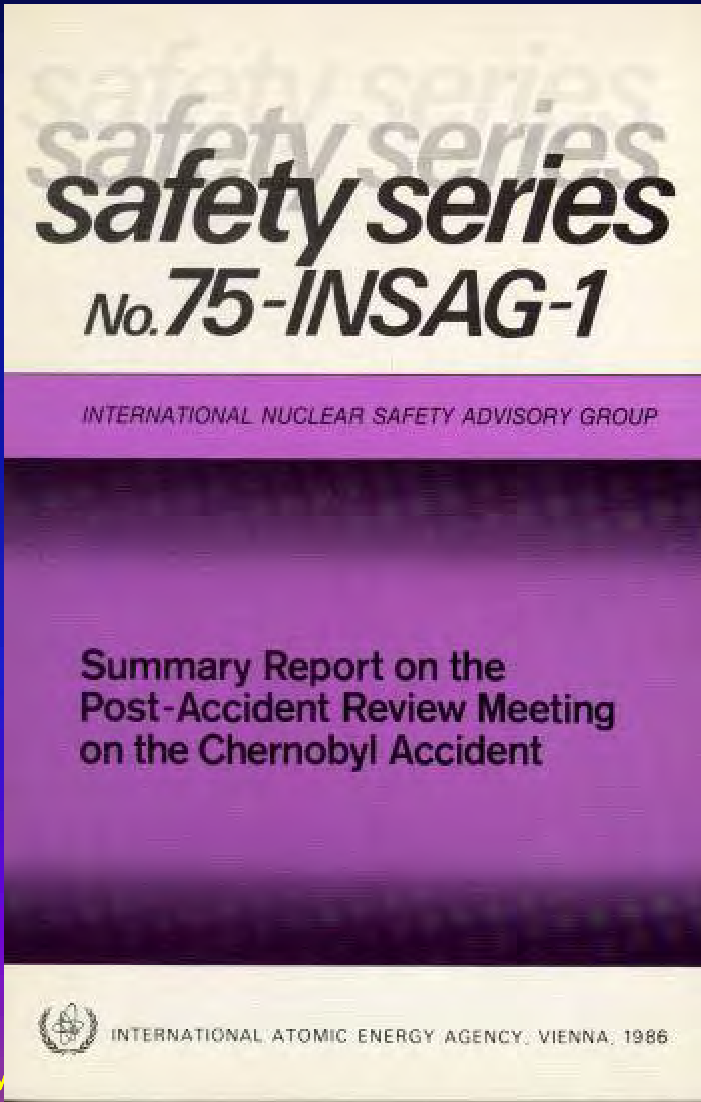
# The Chernobyl Saga:

## a long story of heroic achievements…

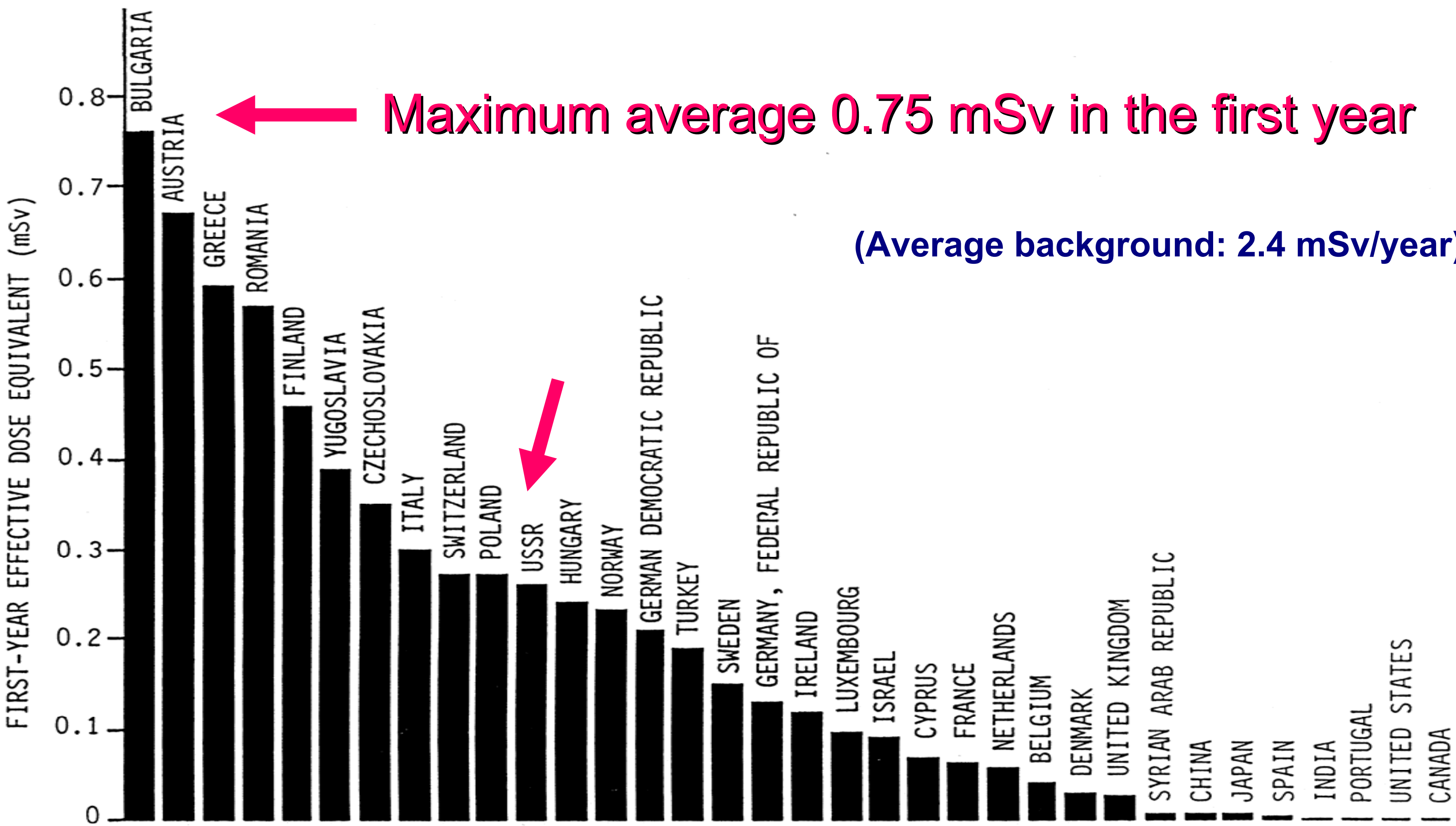
## but also a narrative of misunderstandings!

# IAEA's early conclusions (August 1986)

- 203 people with syndromes of radiation effects
- 29 deaths
- 135.000 evacuees: over next 70 years, the evacuees' spontaneous incidence of cancer will not be increased by more than about 0.6%
- There will be thyroid cancers: increase in mortality could reach 1%



# CHERNOBYL first-year average dose

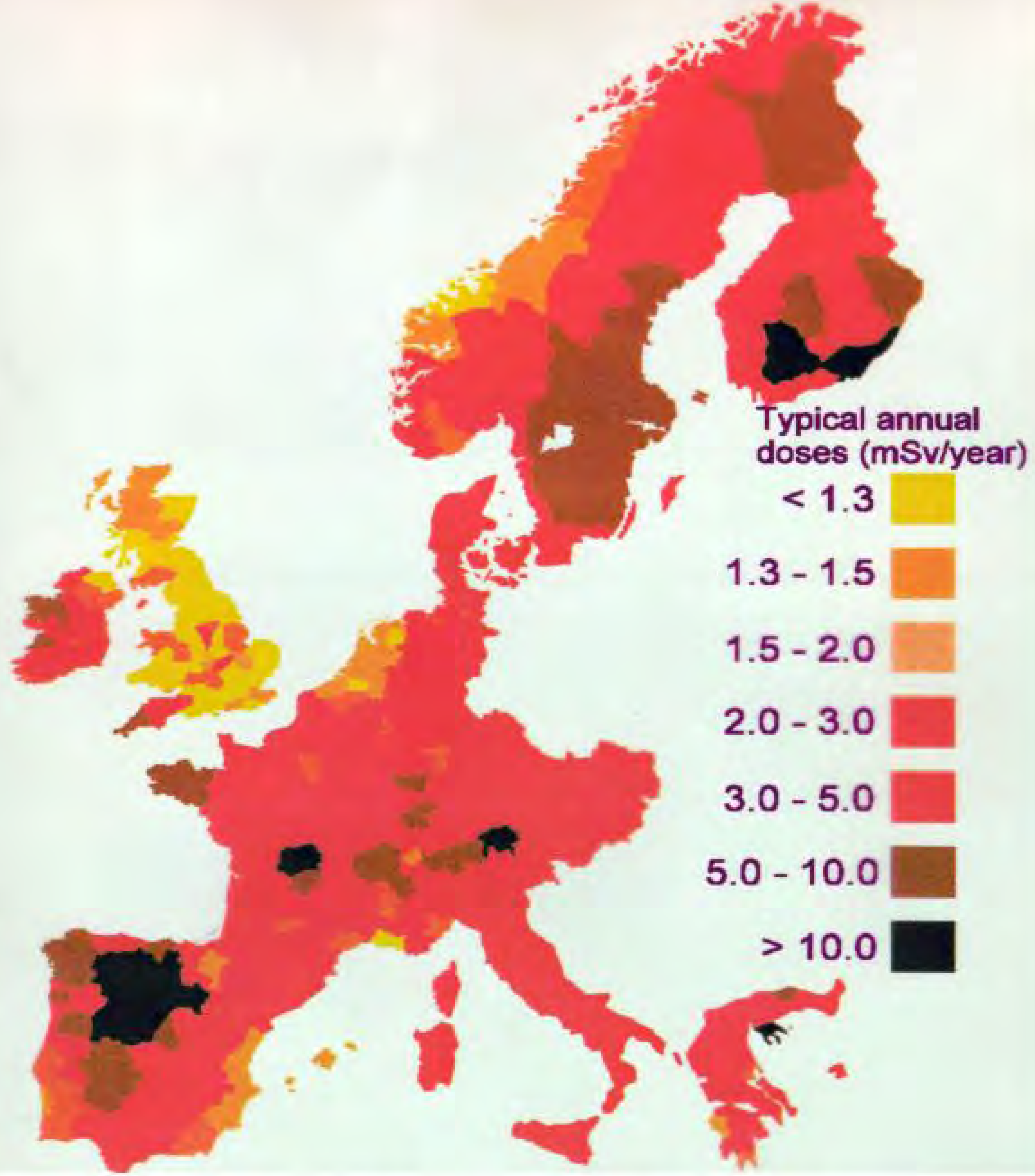


# UNSCEAR ESTIMATES

## Europe:

## 1st year doses attributable to Chernobyl

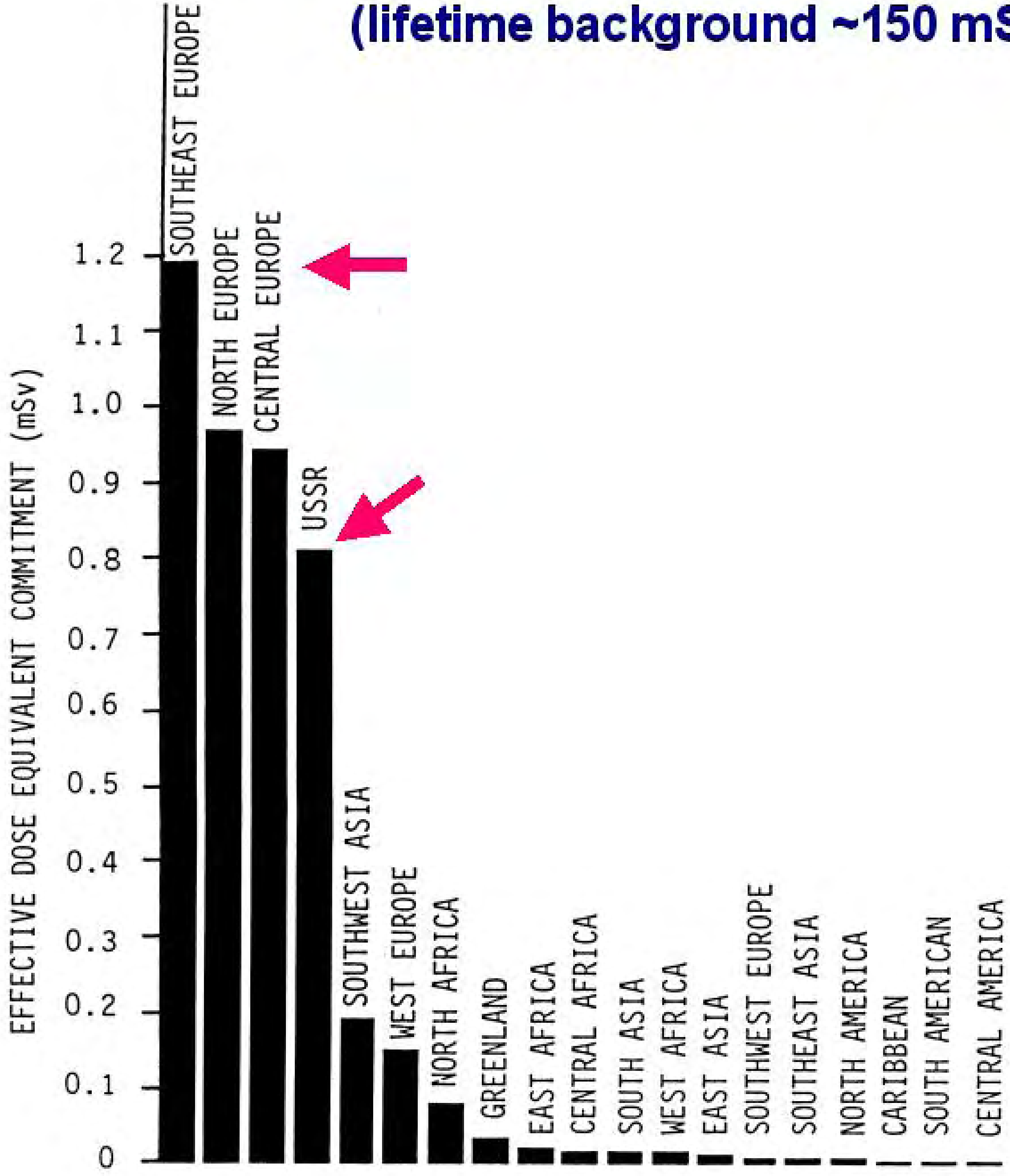
- Bulgaria<0.7 mSv/y
- Austria<0.7 mSv/y
- Finland<0.5 mSv/y
- majority<0.3 mSv/y




NATURAL BACKGROUND RADIATION

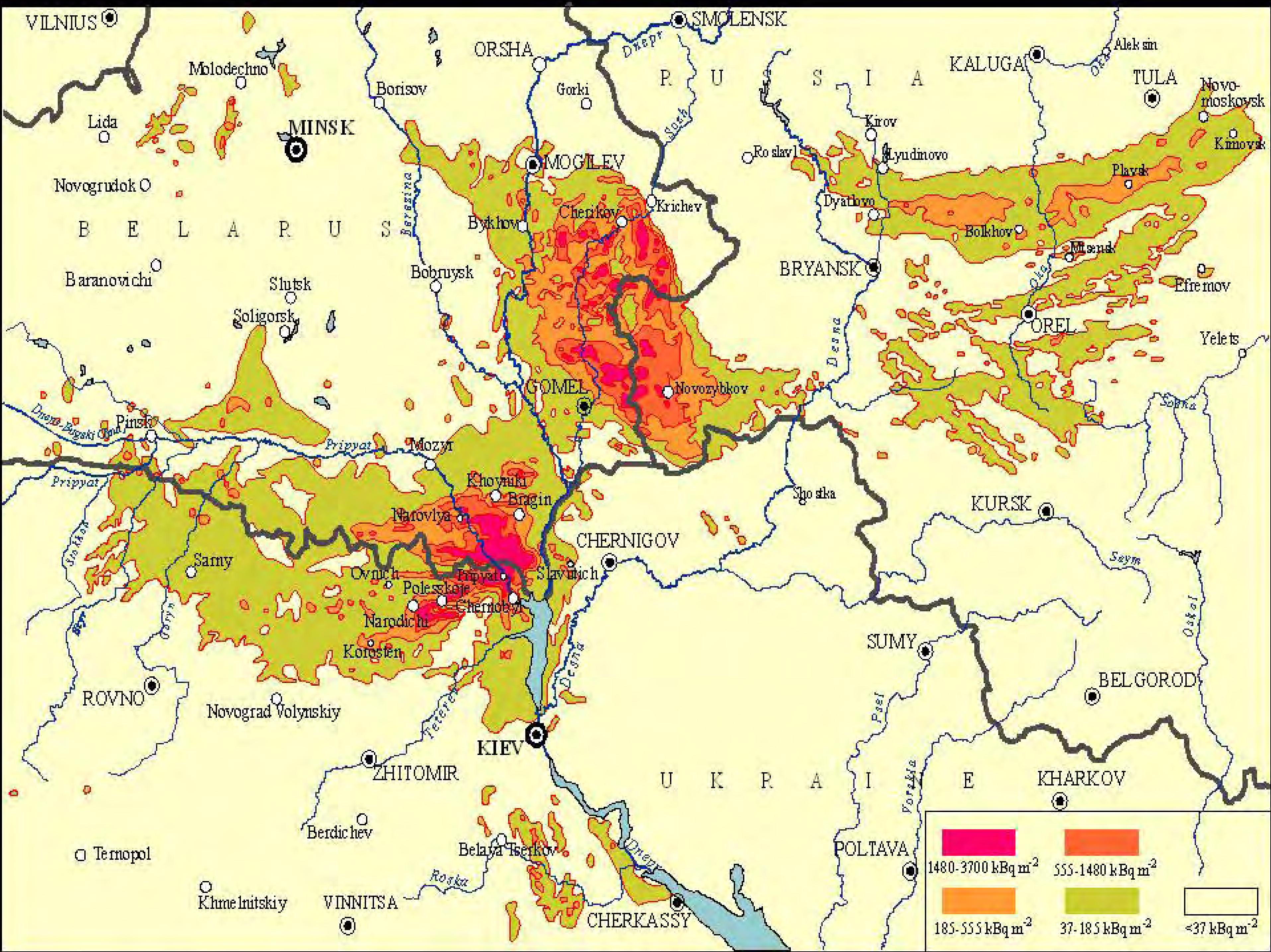
‘Committed’ Average Dose Attributable to Chernobyl

(lifetime background ~150 mSv)



# Kiev Conference
## Statement from Minister A.E.Romanenko:

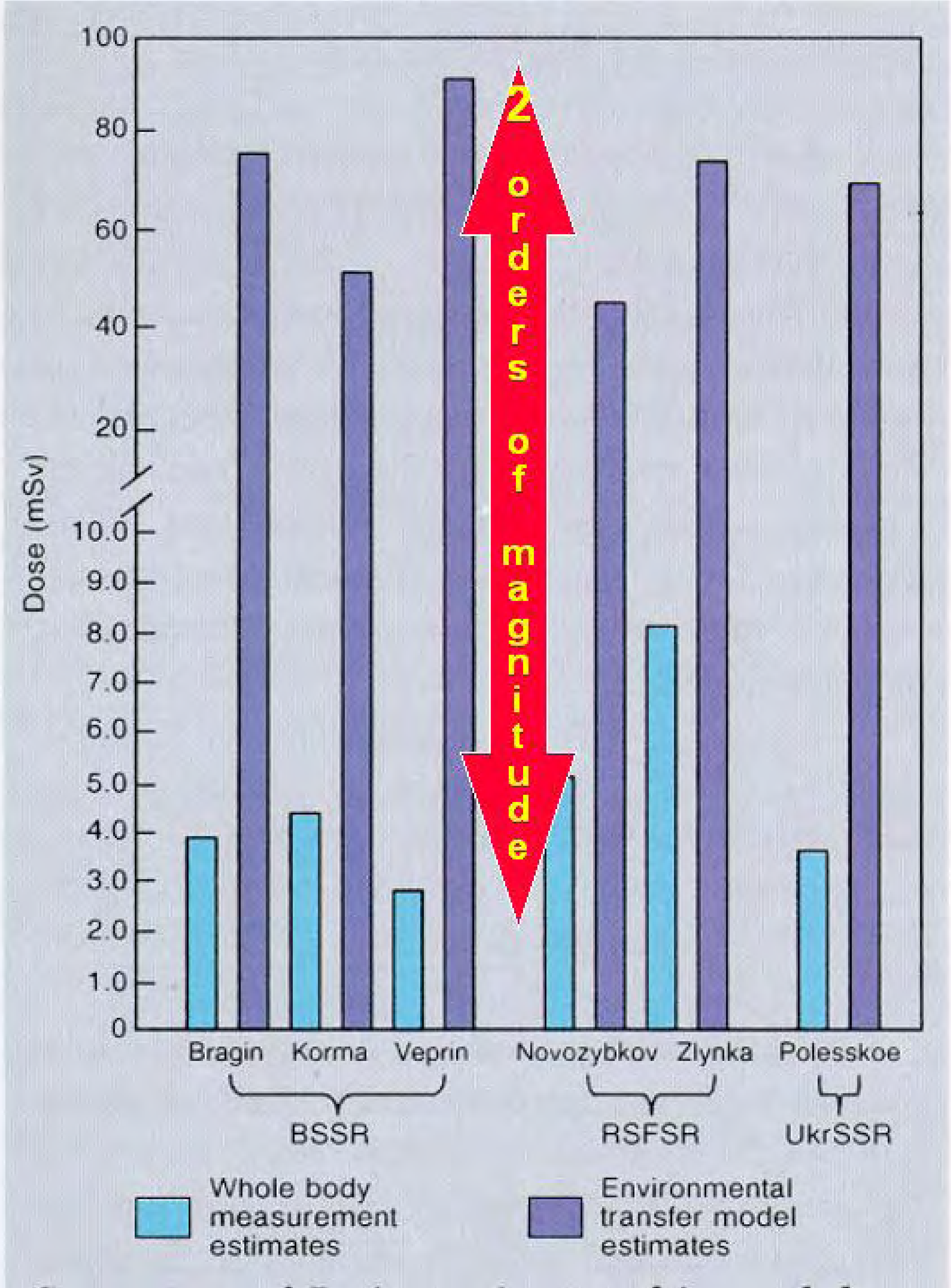
*'…the elimination of the accident's aftermath revealed serious shortcomings…physicians showed inadequate practical knowledge…the radiological service was short of dosimeters …the equipment [was] outdated and obsolete…the sanitary, educational and explanatory work among the population was obviously inefficient...'*



VILNIUS
Molodechno
Lida
MINSK
Borisov
ORSHA
Gorki
SMOLENSK
Dnepr
RUSSIA
KALUGA
Aleksin
TULA
Novomoskovsk
Kimovsk
Kirov
Lyudinovo
Roslavl
Sozh
MOGILEV
Krichev
Cherikov
Bykhov
Berezina
BELARUS
Novogrudok
Baranovichi
Slutsk
Soligorsk
Bobruysk
Dyatkovo
Bolkhov
Plavsk
Mtsensk
Efremov
BRYANSK
OREL
Oka
Yelets
Desna
Novozybkov
GOMEL
Pinsk
Dnepr-Bugski Canal
Pripyat
Mozyr
Khoyniki
Bragin
Narovlya
Shostka
KURSK
Seym
Sarny
Ovruch
Pripyat
Slavutich
CHERNIGOV
Polesskoje
Chernobyl
Narodichi
Korosten
SUMY
BELGOROD
Oskol
ROVNO
Novograd Volynskiy
Teterev
KIEV
ZHITOMIR
UKRAINE
KHARKOV
Berdichev
Ternopol
Belaya Tserkov
Ros
POLTAVA
Psel
Vorskla
Khmelnitskiy
VINNITSA
CHERKASSY
1480-3700 kBq m$^{-2}$
555-1480 kBq m$^{-2}$
185-555 kBq m$^{-2}$
37-185 kBq m$^{-2}$
<37 kBq m$^{-2}$

**Conclusion:**

**the radiation doses assessed through *in vivo* measurements were much lower than the theoretical estimates of scientists.**



# CHERNOBYL PROJECT CONCLUSIONS

- *"…there will be a radiogenic excess of thyroid cancers…*[and]*… a statistically detectable increase in the incidence of thyroid tumors in the future…"*
- *"…future increases over the natural incidence of cancer* [other than thyroid cancer] *or hereditary effects would be difficult to discern…"*

Distr.: GENERAL
WHO/EHG 95.19.



# V.6
# ORAL HEALTH INVESTIGATIONS: "ORAL HEALTH" PROJECT IN BELARUS

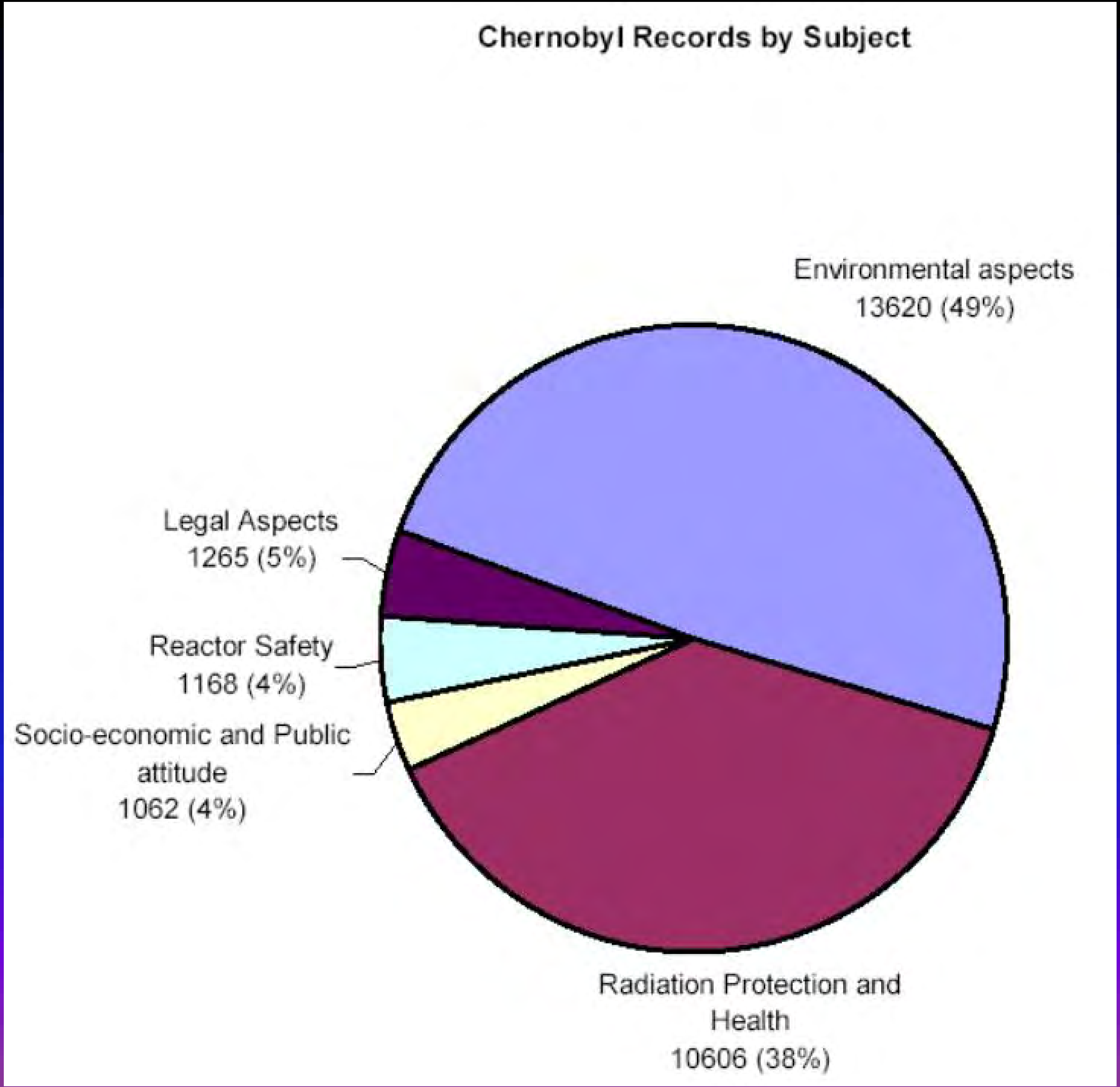
Investigations within the Project were conducted in the areas with a mean RN contamination of 185 kBq/m$^2$, 555 kBq/m$^2$ and also in clean zones. Under observation were more than 2686 residents distributed among age groups: 15, 18, 35-44, 65 and older. As a result of the investigations conducted it was established that the caries incidence

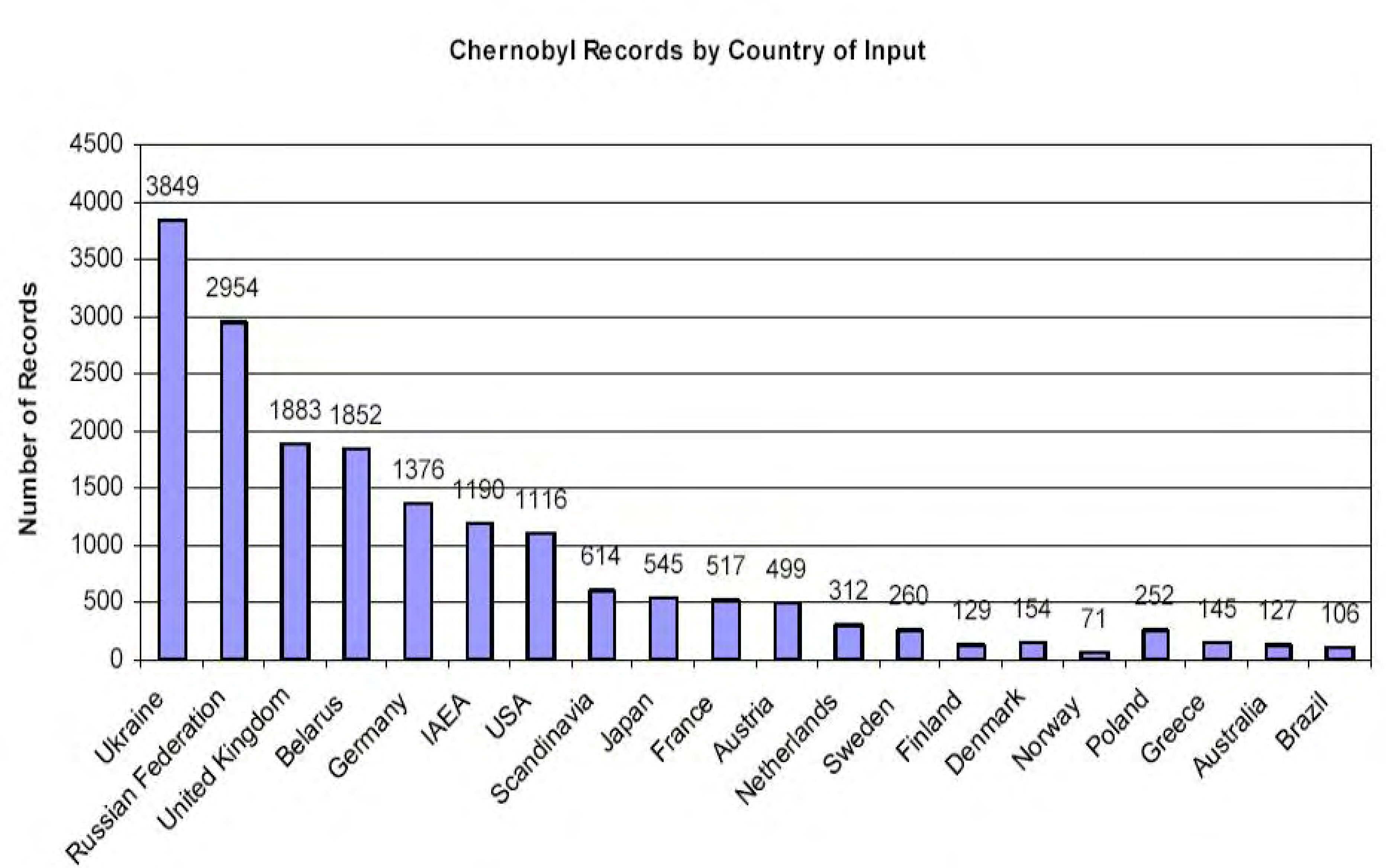
tors are known which are common to the initiation of a number of diseases.

They include microbe dental plaque and fluorine deficiency in foodstuffs and drinking water. From experience in preventive treatment under normal conditions

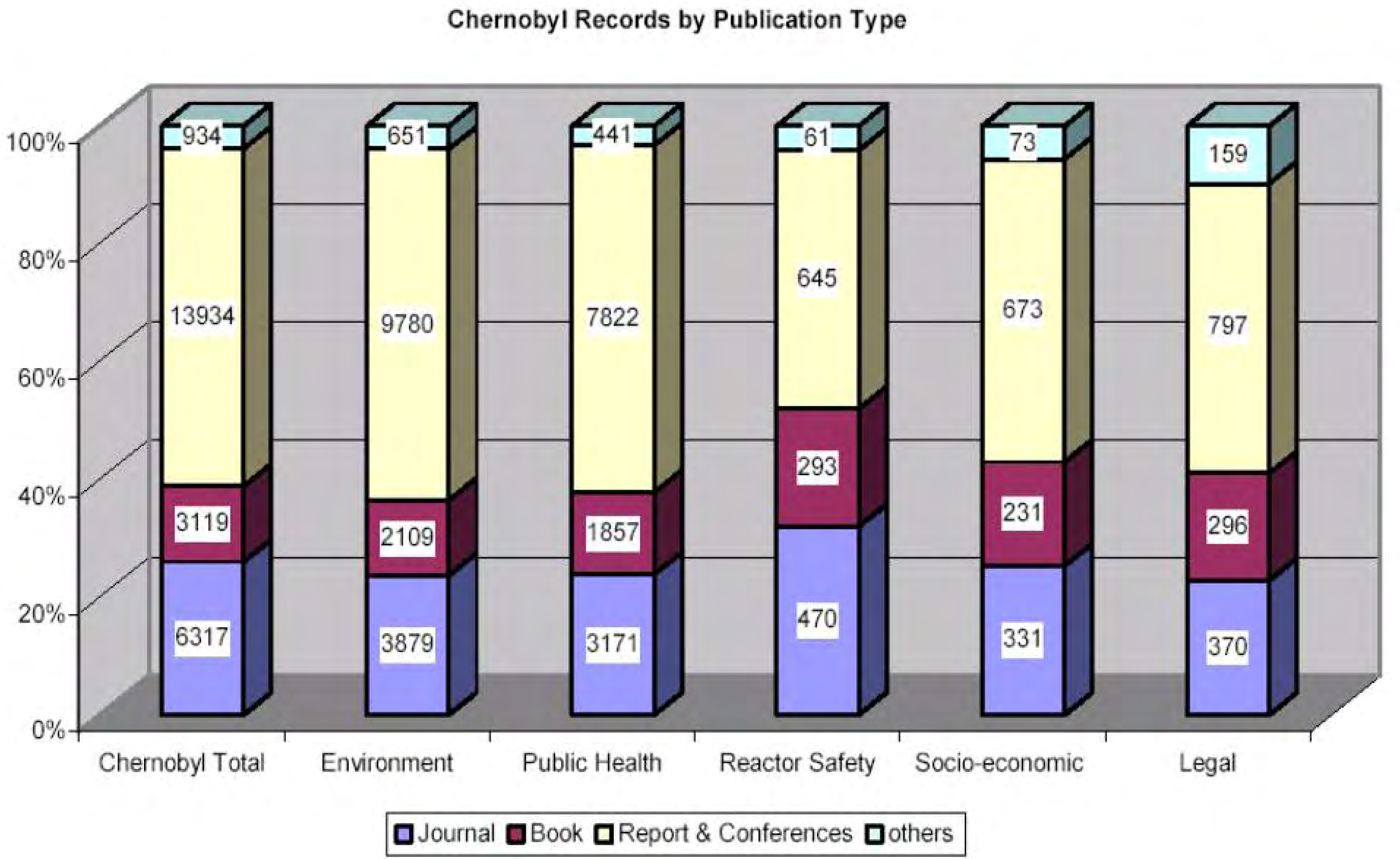
# A remarkable conclusion by WHO [*sic*]:

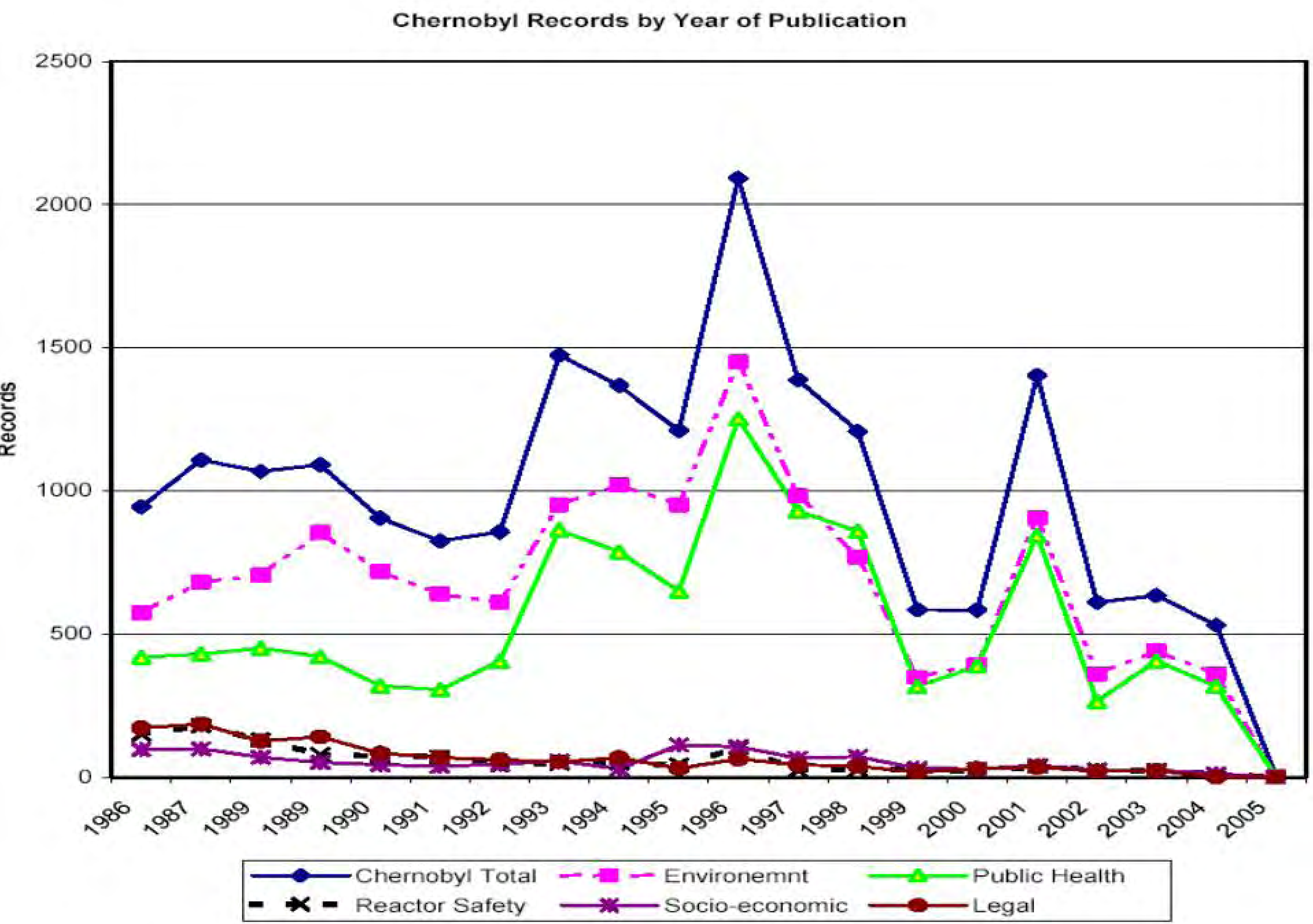
On the whole, the findings point to the fact that the contribution of non-radiation factors, in particular insufficient orgal hygiene, could have been much more substantial than the radiation factor in the development of the oral pathology in the residents of the RN contaminated territories.


Chernobyl Records by Subject
Environmental aspects
13620 (49%)
Legal Aspects
1265 (5%)
Reactor Safety
1168 (4%)
Socio-economic and Public
attitude
1062 (4%)
Radiation Protection and
Health
10606 (38%)

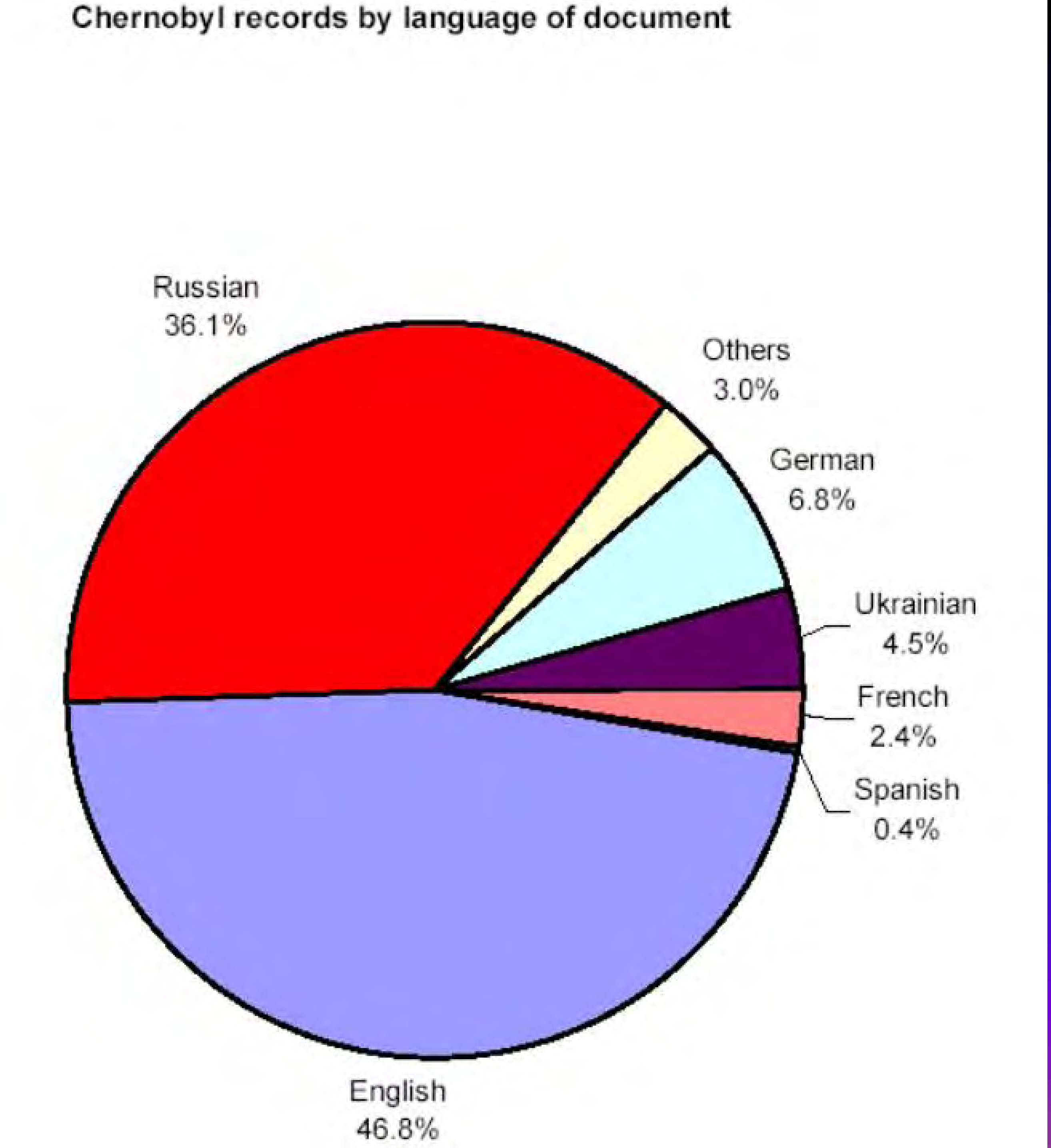


Chernobyl Records by Country of Input
Number of Records
0
500
1000
1500
2000
2500
3000
3500
4000
4500
3849
2954
1883
1852
1376
1190
1116
614
545
517
499
312
260
129
154
71
252
145
127
106
Ukraine
Russian Federation
United Kingdom
Belarus
Germany
IAEA
USA
Scandinavia
Japan
France
Austria
Netherlands
Sweden
Finland
Denmark
Norway
Poland
Greece
Australia
Brazil

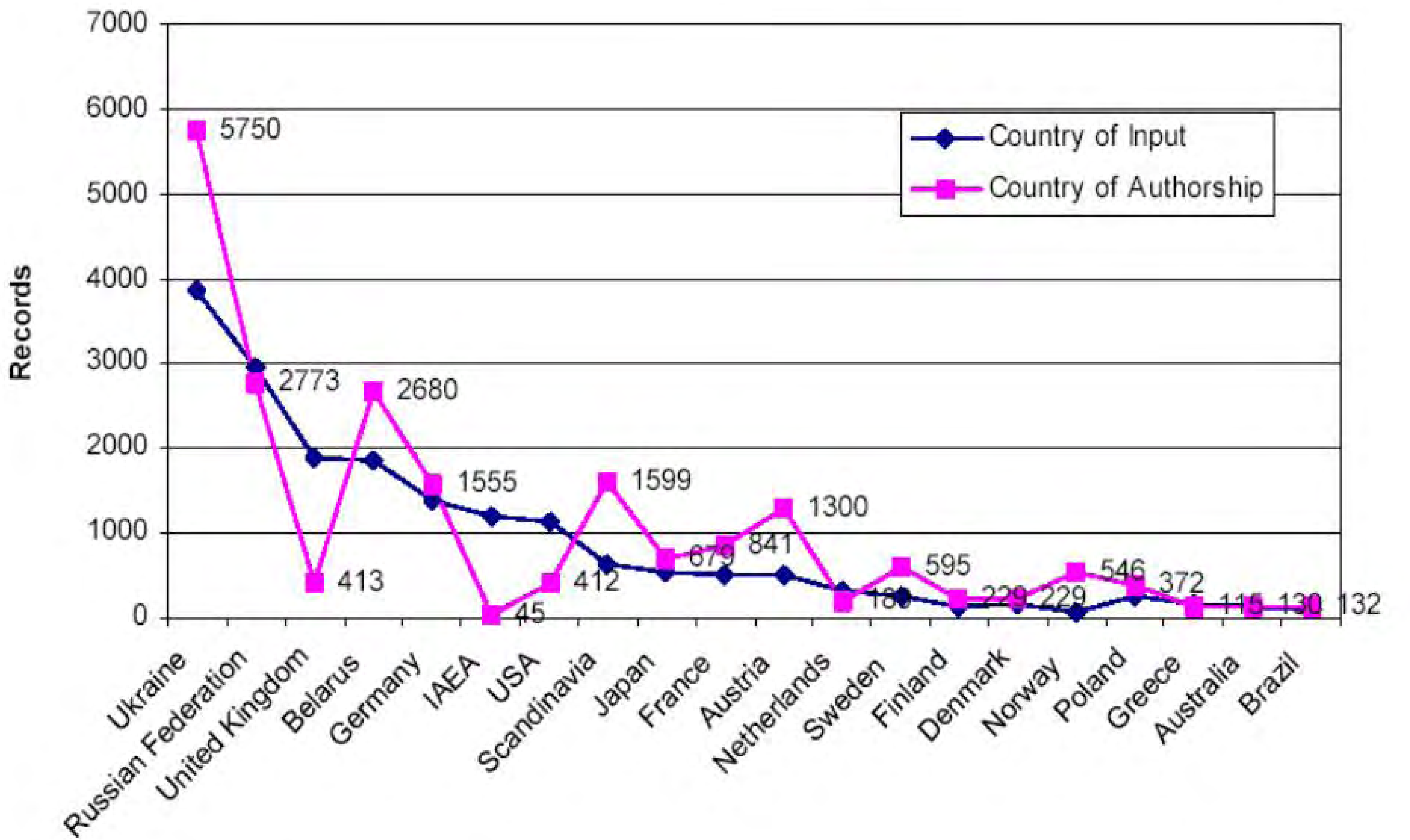

Chernobyl Records by Publication Type
100%
80%
60%
40%
20%
0%
934
13934
3119
6317
651
9780
2109
3879
441
7822
1857
3171
61
645
293
470
73
673
231
331
159
797
296
370
Chernobyl Total
Environment
Public Health
Reactor Safety
Socio-economic
Legal
Journal
Book
Report & Conferences
others



Chernobyl Records by Year of Publication
Records
2500
2000
1500
1000
500
0
1986
1987
1989
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Chernobyl Total
Environemnt
Public Health
Reactor Safety
Socio-economic
Legal


Chernobyl records by language of document
Russian
36.1%
Others
3.0%
German
6.8%
Ukrainian
4.5%
French
2.4%
Spanish
0.4%
English
46.8%

Country of Authorship



# The Chernobyl Forum

Vienna International Center; Vienna, Austria; September 6th, 2005

**Recommendations to the Governments of Belarus, the Russian Federation and Ukrania**

**on**

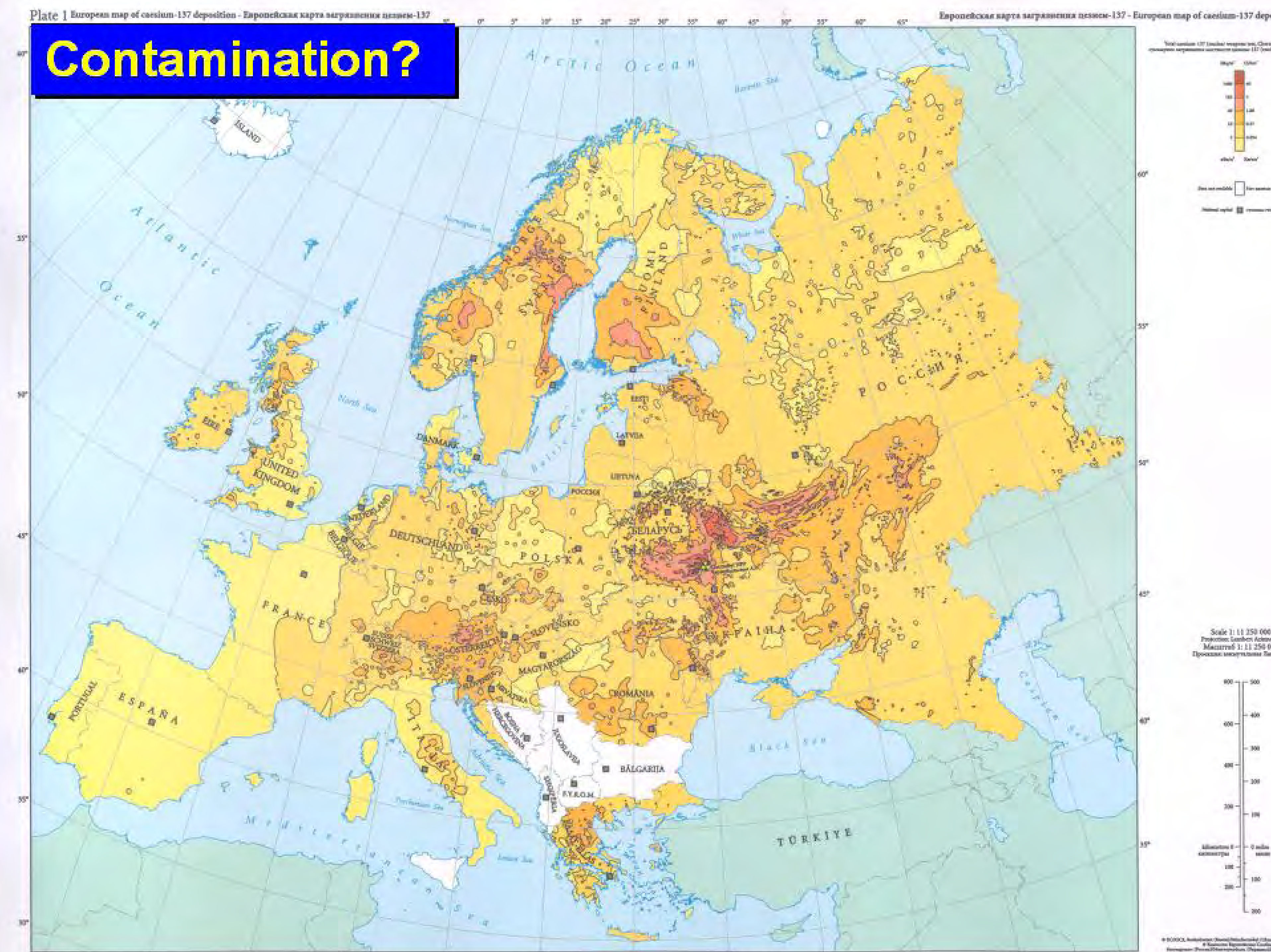
**environmental monitoring, remediation and research.**

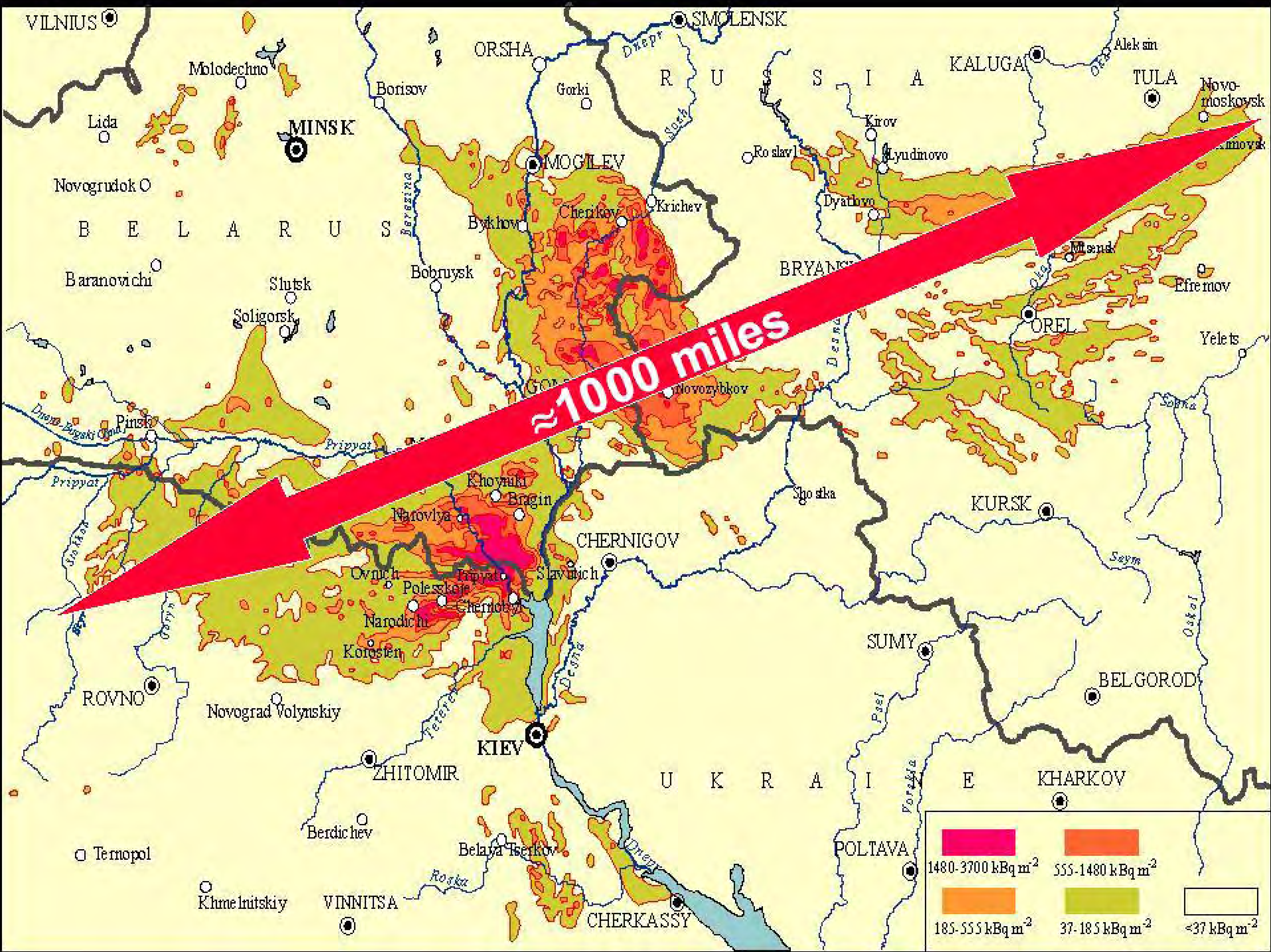
# Releases from Chernobyl

**Total Radioactivity Released = $2\ 10^{19}$ Bq**

| | |
|---|---|
| $^{131}I$ | $3\ 10^{18}$ Bq |
| $^{134,137}Cs$ | $4\ 10^{17}$ Bq |
| Noble gases | $7\ 10^{18}$ Bq |

# Contamination?





≈1000 miles
VILNIUS
SMOLENSK
ORSHA
KALUGA
TULA
MINSK
MOGILEV
BELARUS
RUSSIA
BRYANSK
OREL
KURSK
CHERNIGOV
KIEV
ZHITOMIR
ROVNO
SUMY
BELGOROD
KHARKOV
POLTAVA
VINNITSA
CHERKASSY
UKRAINE
Pripyat
Chernobyl
Gomel
Novozybkov
Bobruysk
Slutsk
Pinsk
Baranovichi
Korosten
Narodichi
Polesskoje
Slavutich
Khoyniki
Bragin
Narovlya
Cherikov
Krichev
Bykhov
Borisov
Gorki
Molodechno
Lida
Novogrudok
Soligorsk
Roslavl
Kirov
Lyudinovo
Dyatkovo
Mtsensk
Efremov
Yelets
Novomoskovsk
Aleksin
Shostka
Novograd Volynskiy
Berdichev
Belaya Tserkov
Ternopol
Khmelnitskiy
Dnepr
Desna
Pripyat
Sozh
Oka
Seym
Berezina
Teterev
Psel
Ros
1480-3700 kBq m$^{-2}$
555-1480 kBq m$^{-2}$
185-555 kBq m$^{-2}$
37-185 kBq m$^{-2}$
<37 kBq m$^{-2}$

# Significant radionuclides

**IODINE ⇒**

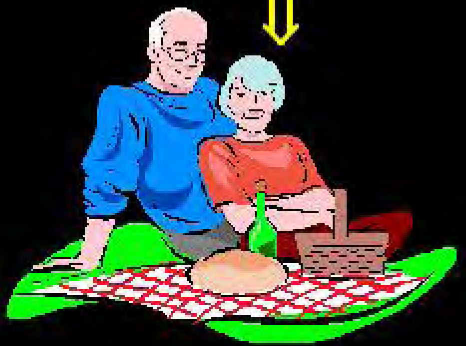
(THYROID GLAND)

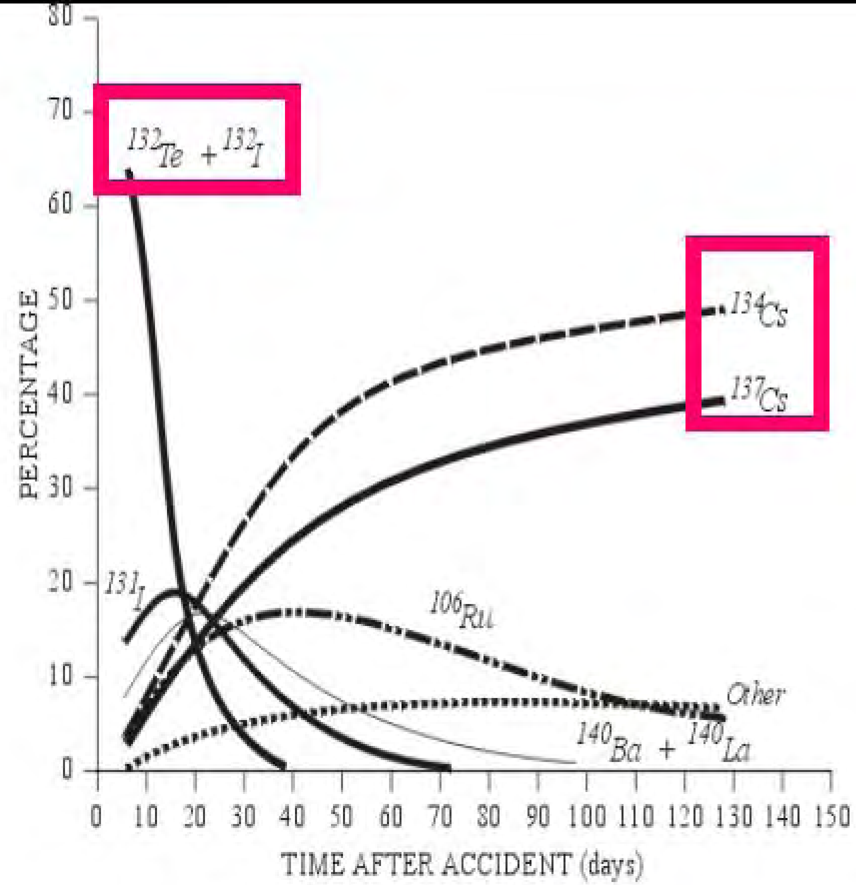
**CAESIUM**

⇓

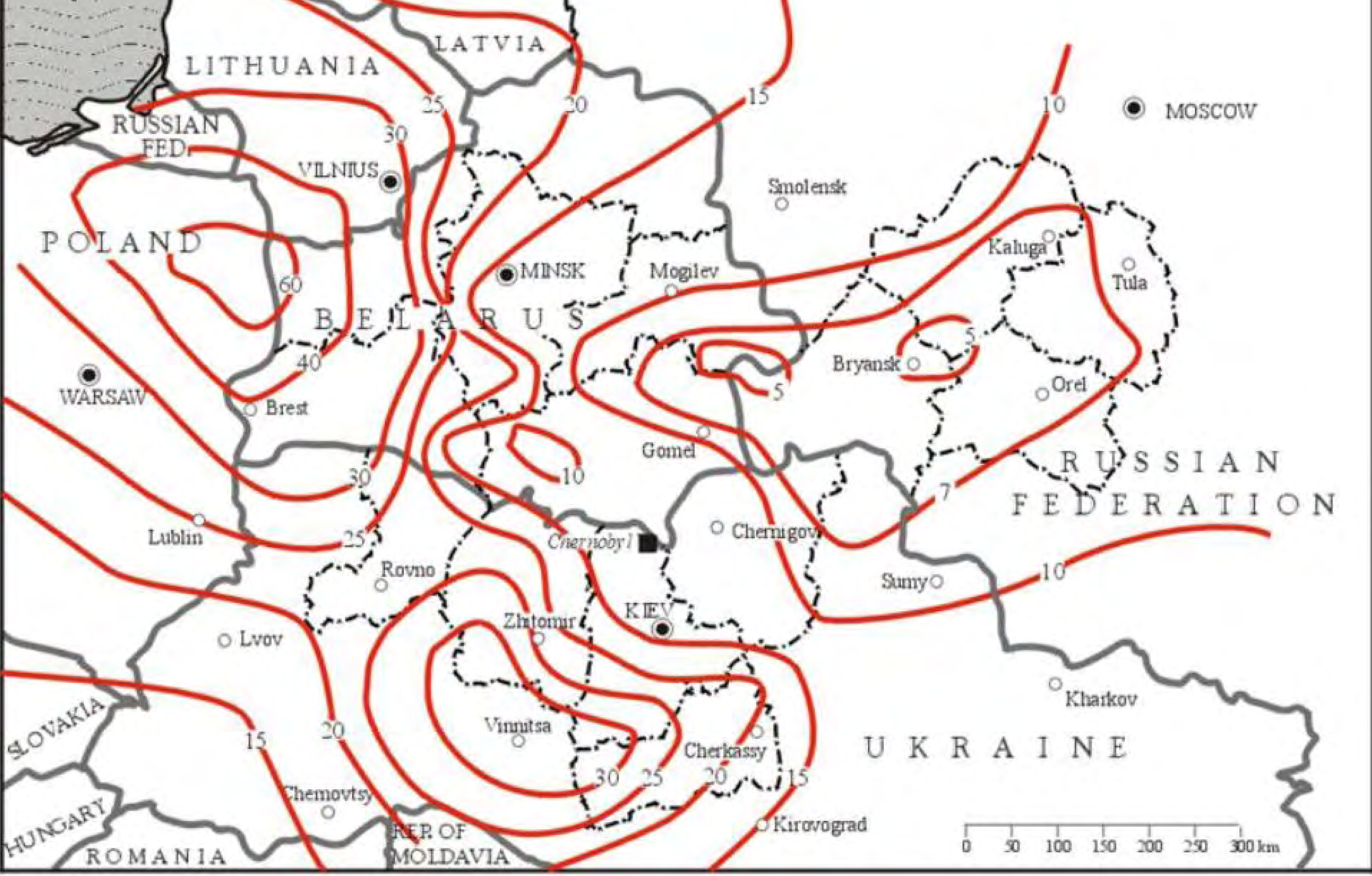
(WHOLE BODY EXPOSURE)

⇓



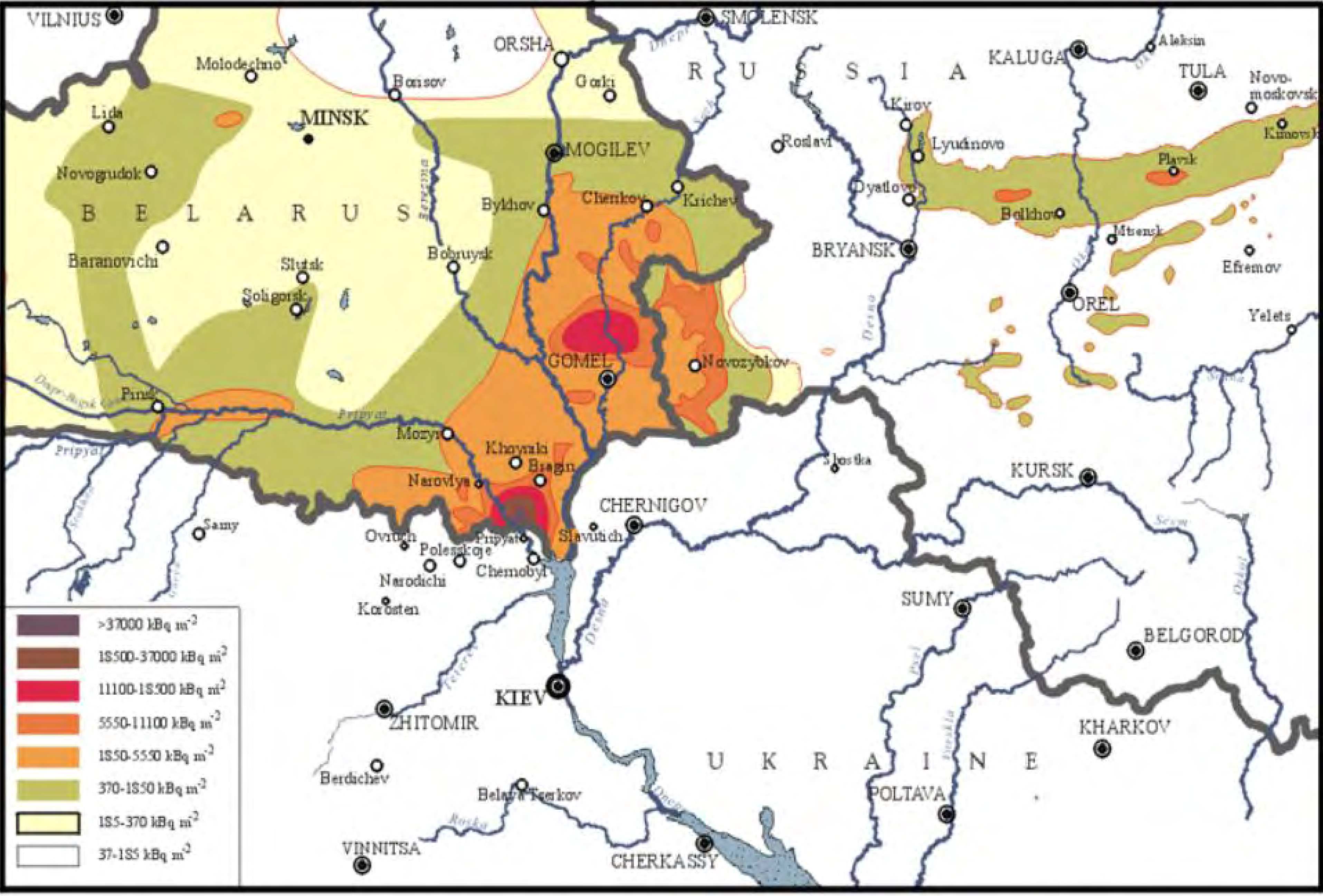



Contributions of radionuclides to the absorbed dose rate in air in a contaminated area of Russia during the first several months after the Chernobyl accident

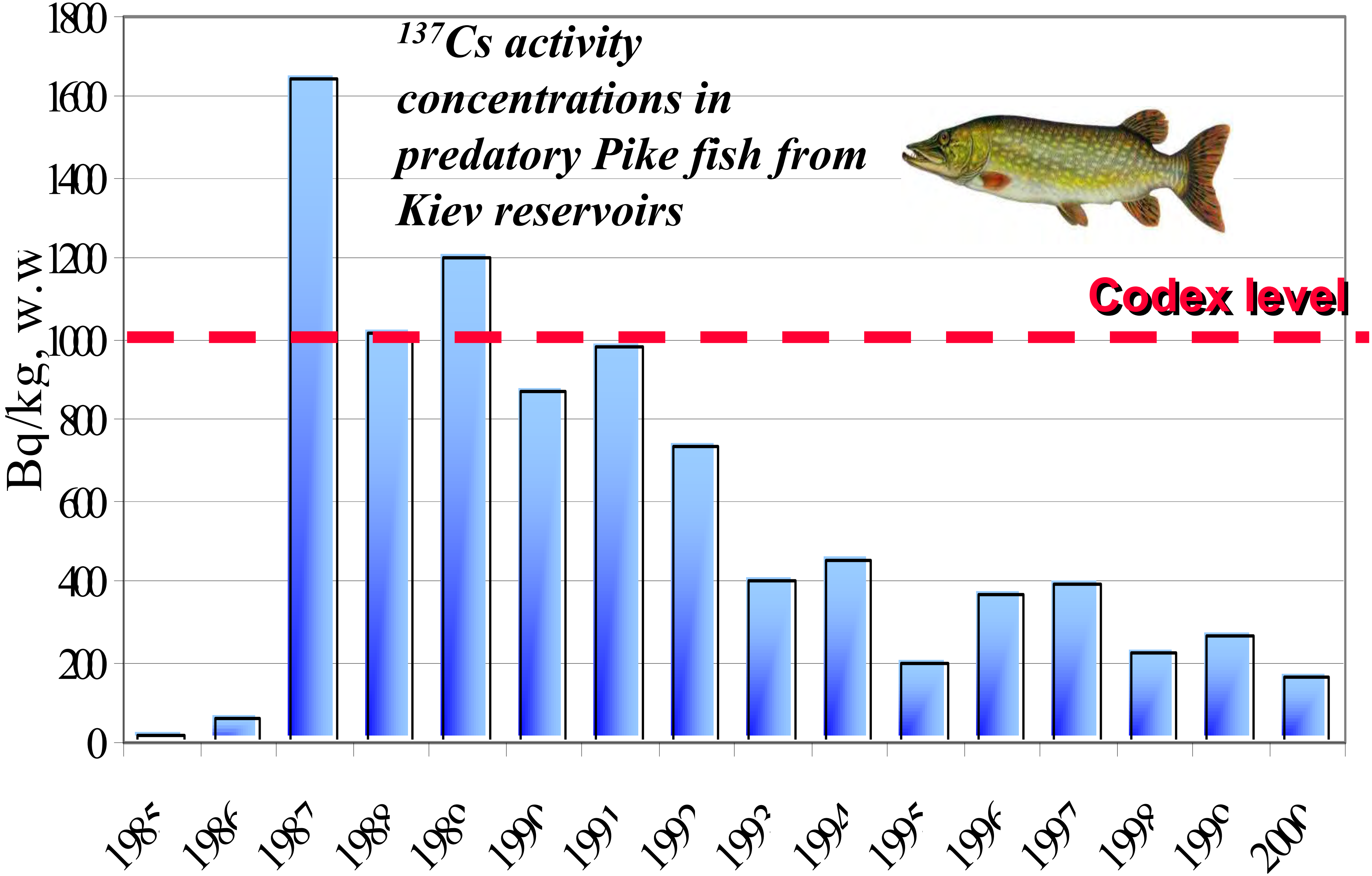



**Estimated pattern of iodine-131/caesium-137 activity ratio over the European territory of the former USSR resulting from the Chernobyl accident [S30].**

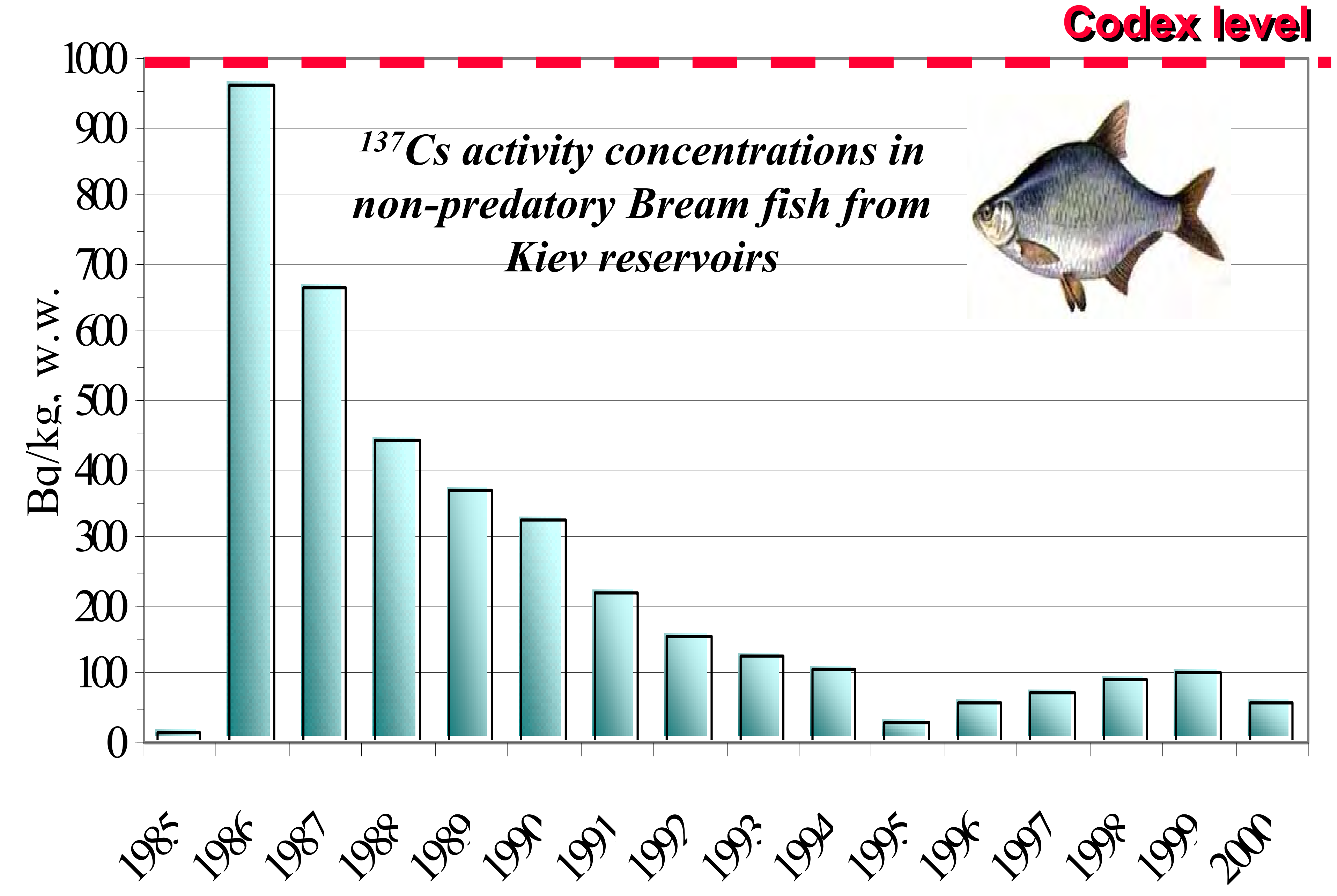
*(Values decay corrected to 1 May 1986).*



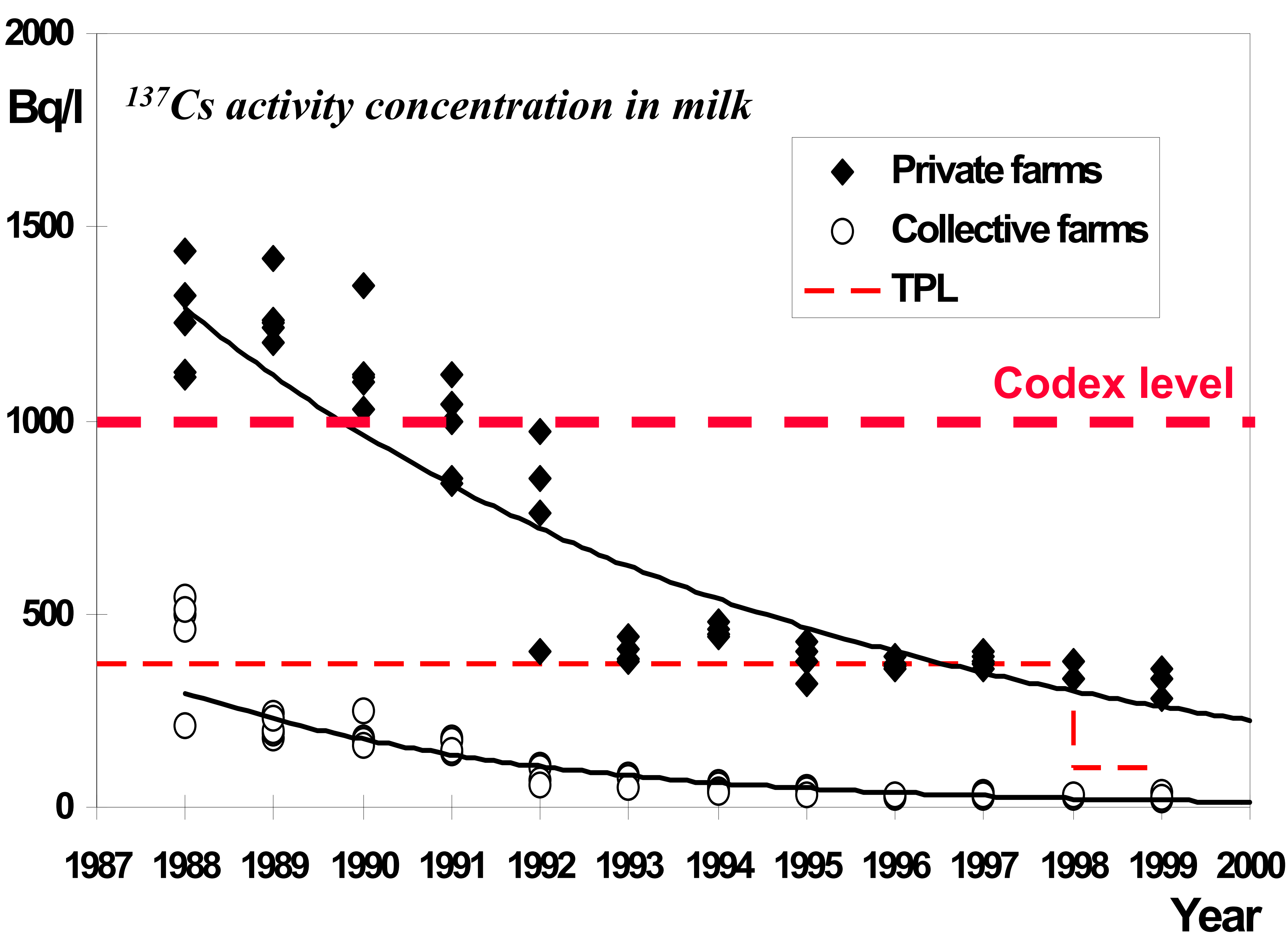

**Estimated surface ground deposition in Belarus and western Russia of iodine-131 released in the Chernobyl accident [B25, P19].**



$^{137}$Cs activity concentrations in predatory Pike fish from Kiev reservoirs
Codex level
Bq/kg, w.w
1800
1600
1400
1200
1000
800
600
400
200
0



Codex level
$^{137}Cs$ activity concentrations in non-predatory Bream fish from Kiev reservoirs
Bq/kg, w.w.
1000
900
800
700
600
500
400
300
200
100
0
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

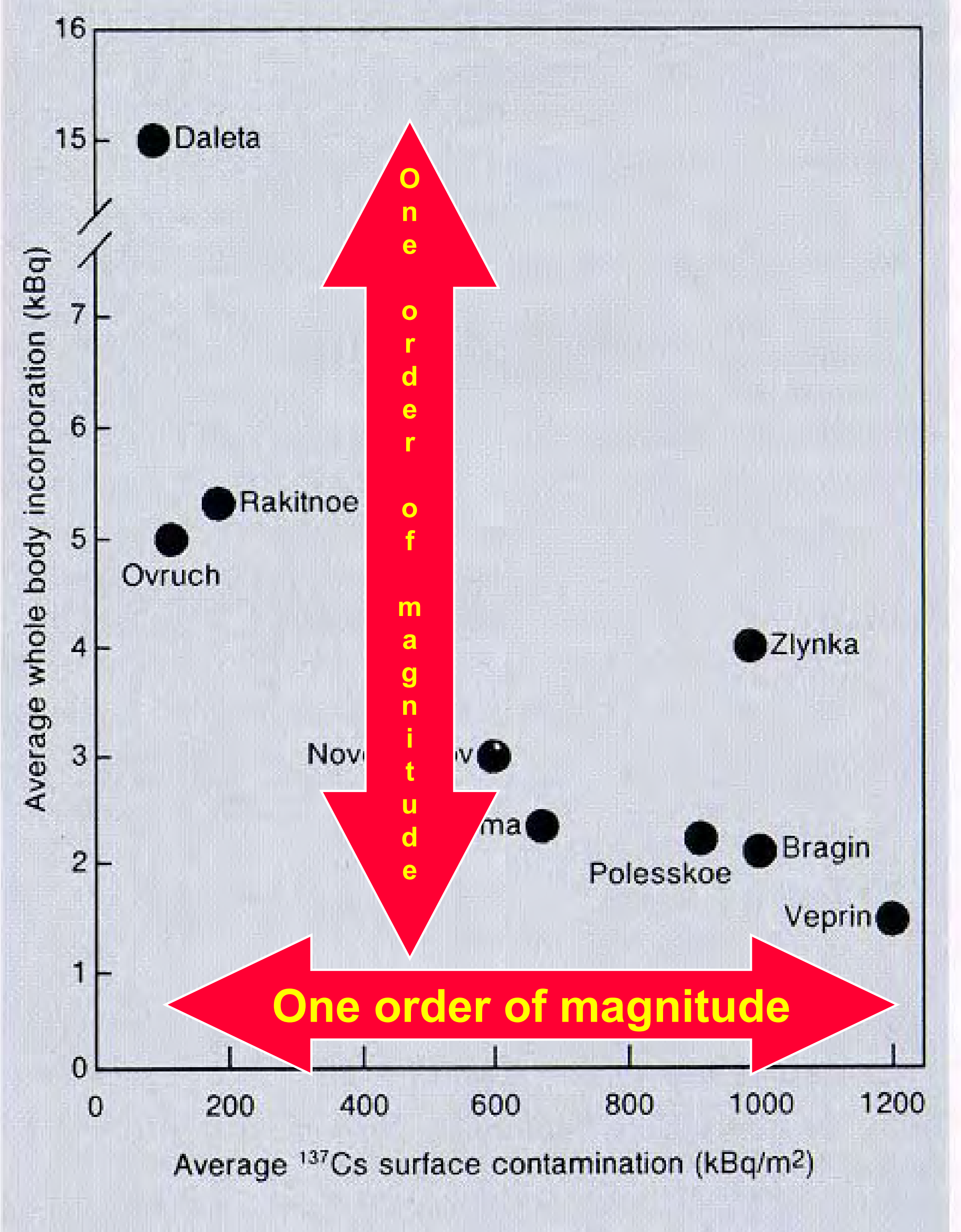


2000
1500
1000
500
0
Bq/l
137Cs activity concentration in milk
Private farms
Collective farms
TPL
Codex level
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
Year

# Exposure of residents affected by Chernobyl

| | Average doses (1986-1995) External | Internal | Total |
|---|---|---|---|
| Russian Federation | 4 | 2.5 | 6.5 mSv |
| Belarus | 5 | 3 | 8 mSv |
| Ukraine | 5 | 6 | 11 mSv |
| Average (10 years) | 5 | 3 | 8 mSv |
| (lifetime) | 9 | 4 | 13 mSv |

**Higher contamination does not necessarily deliver higher doses!**



## Control group

"N" people

"C" cancers

"*n*" probability of 'natural' cancer

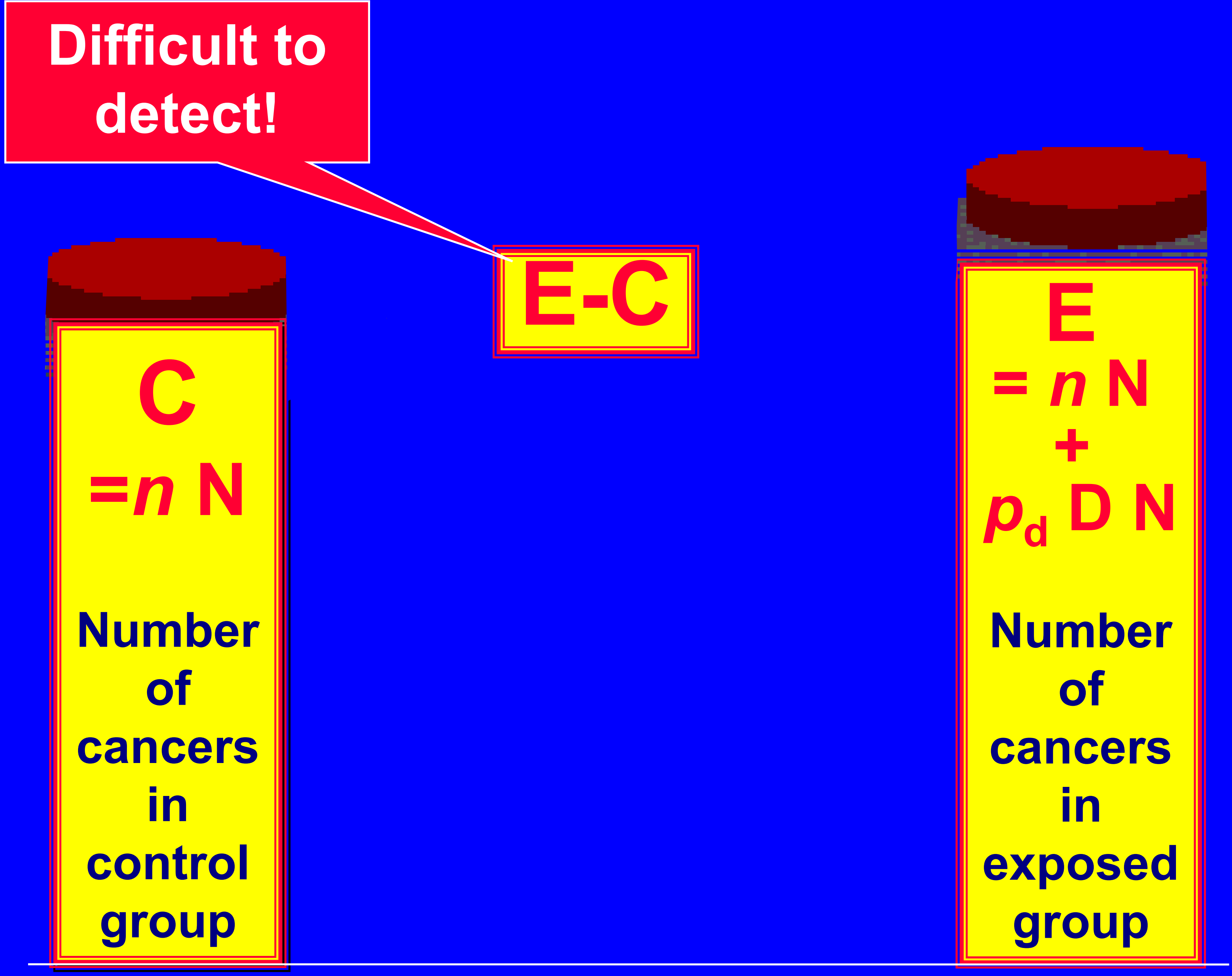
## Exposed group

"N" people

"E" cancers

"*n*" probability of 'natural' cancer

'$p_D$' probability of 'radiation' cancer


Difficult to detect!
E-C
C
$= n\,N$
Number of cancers in control group
E
$= n\,N + p_d\,D\,N$
Number of cancers in exposed group

# Epidemiological significance

- The standard deviation is

$$\sigma = \sqrt{2\, n\, \mathrm{N} + p_{\mathrm{d}}\, \mathrm{D}\, \mathrm{N}}$$

- If the excess cancers are to be detected with a statistical confidence of 95%

$$\mathrm{E} - \mathrm{C} > 2\,\sigma$$

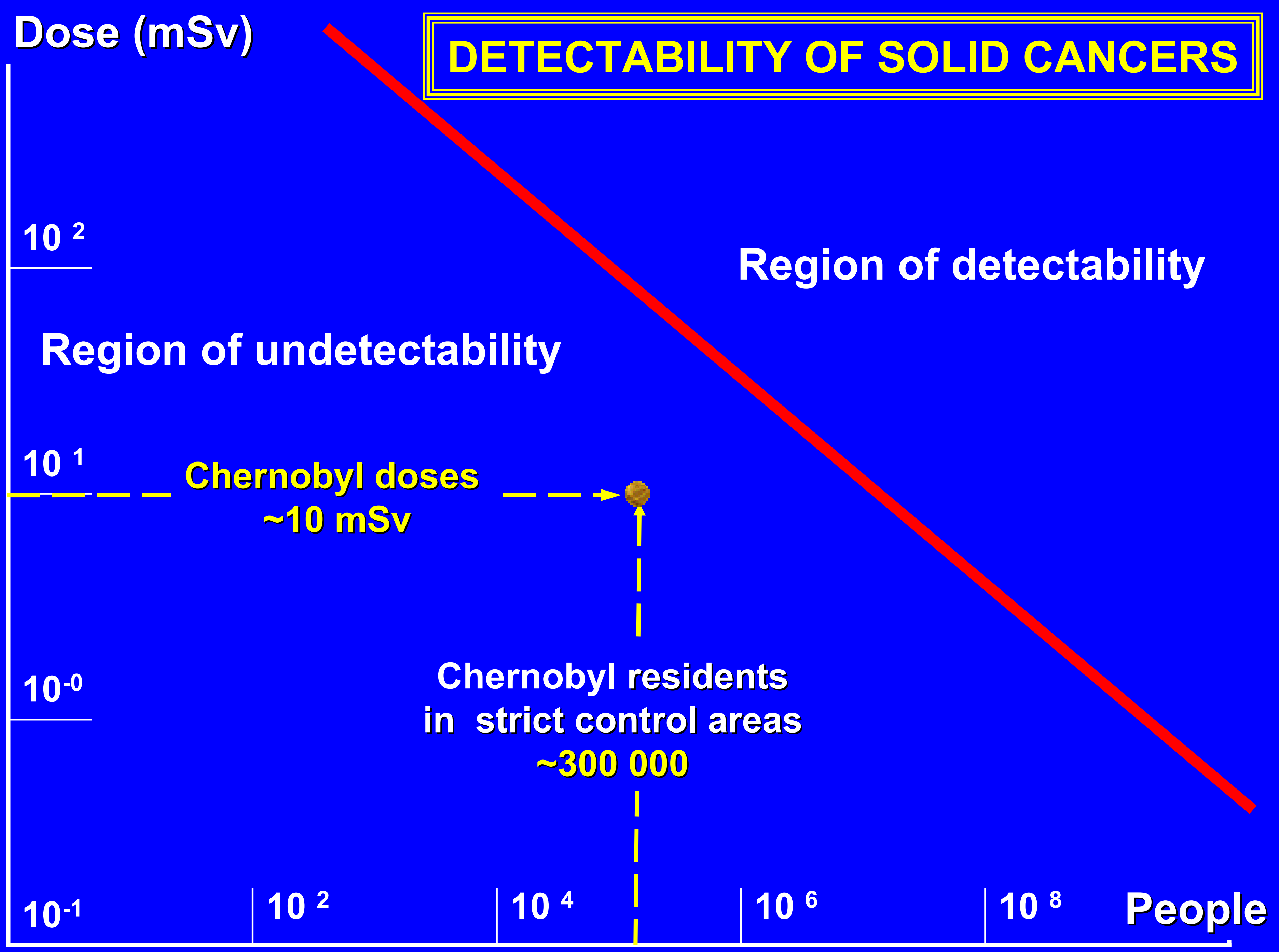
# Epidemiological significance

Operating algebraically and as $n >> p_d$ D,

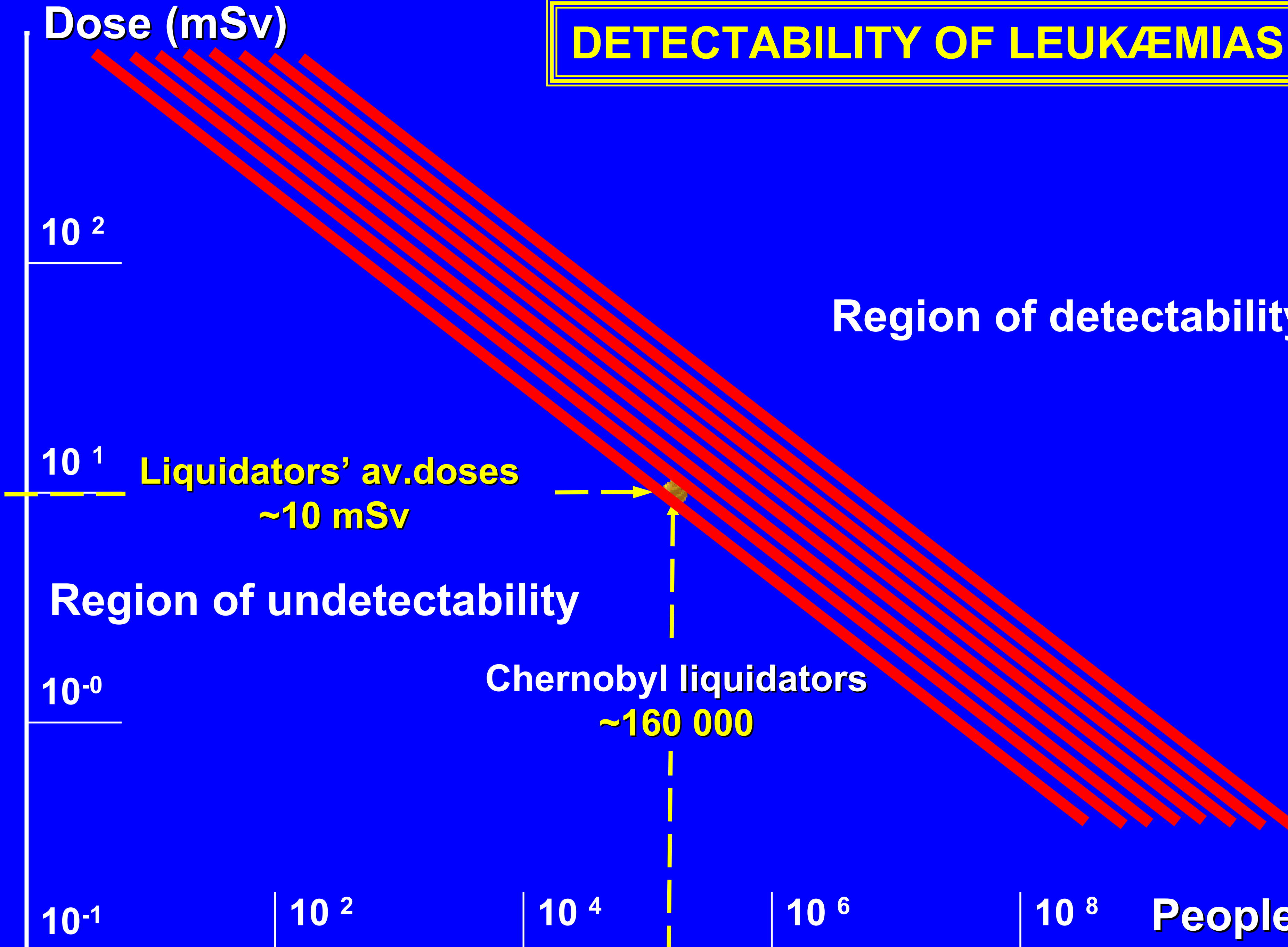
$$\boxed{N > \text{constant} / D^2}$$

which is the equation giving the number of people, N, needed for detecting excess cancers at dose D.

(Constant = $8\, n / p_d^2$)


DETECTABILITY OF SOLID CANCERS
Dose (mSv)
10 2
10 1
10-0
10-1
Region of detectability
Region of undetectability
Chernobyl doses
~10 mSv
Chernobyl residents
in strict control areas
~300 000
10 2
10 4
10 6
10 8
People

# DETECTABILITY OF LEUKÆMIAS

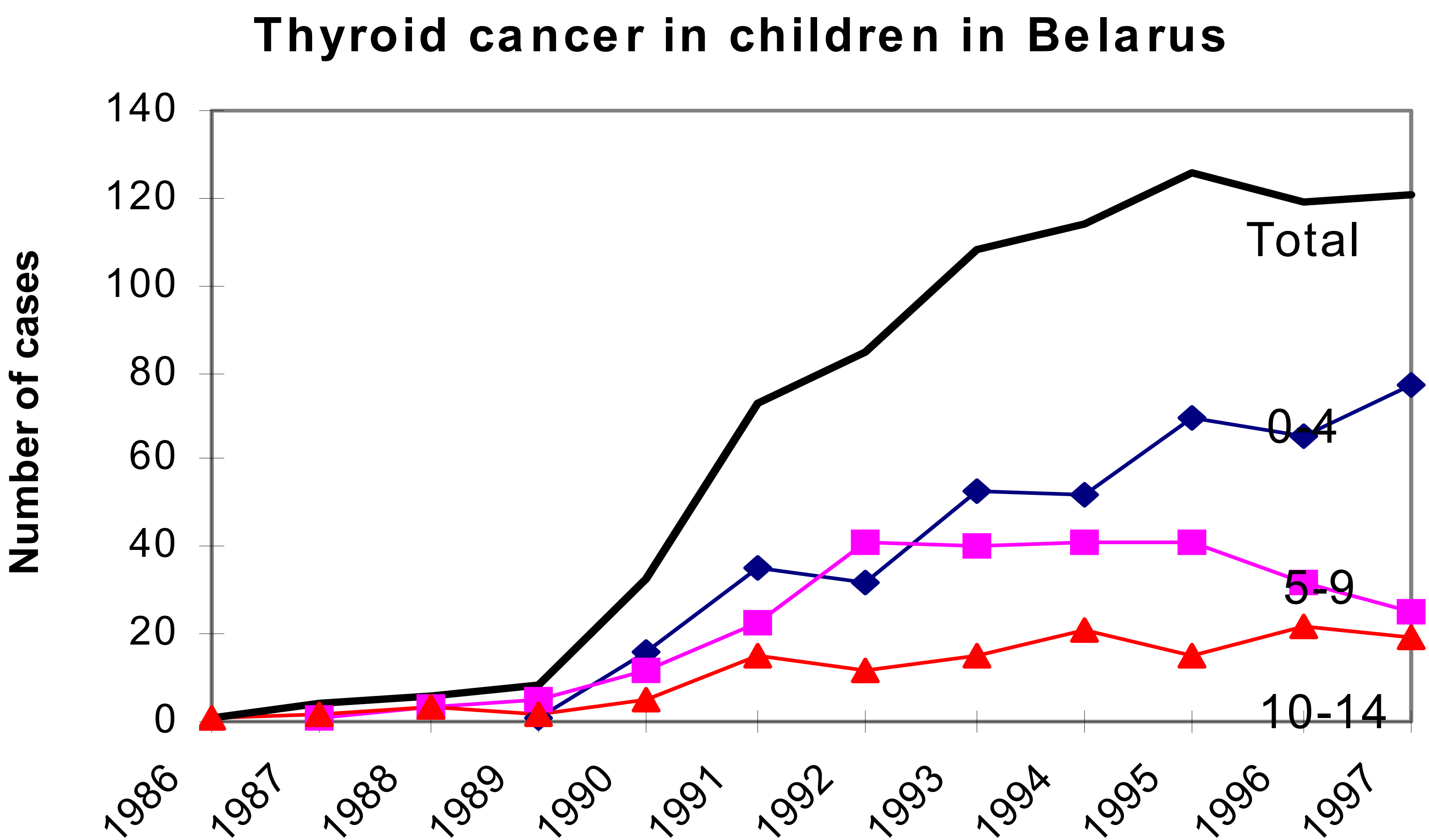


# Epidemiological significance thyroid cancer in children

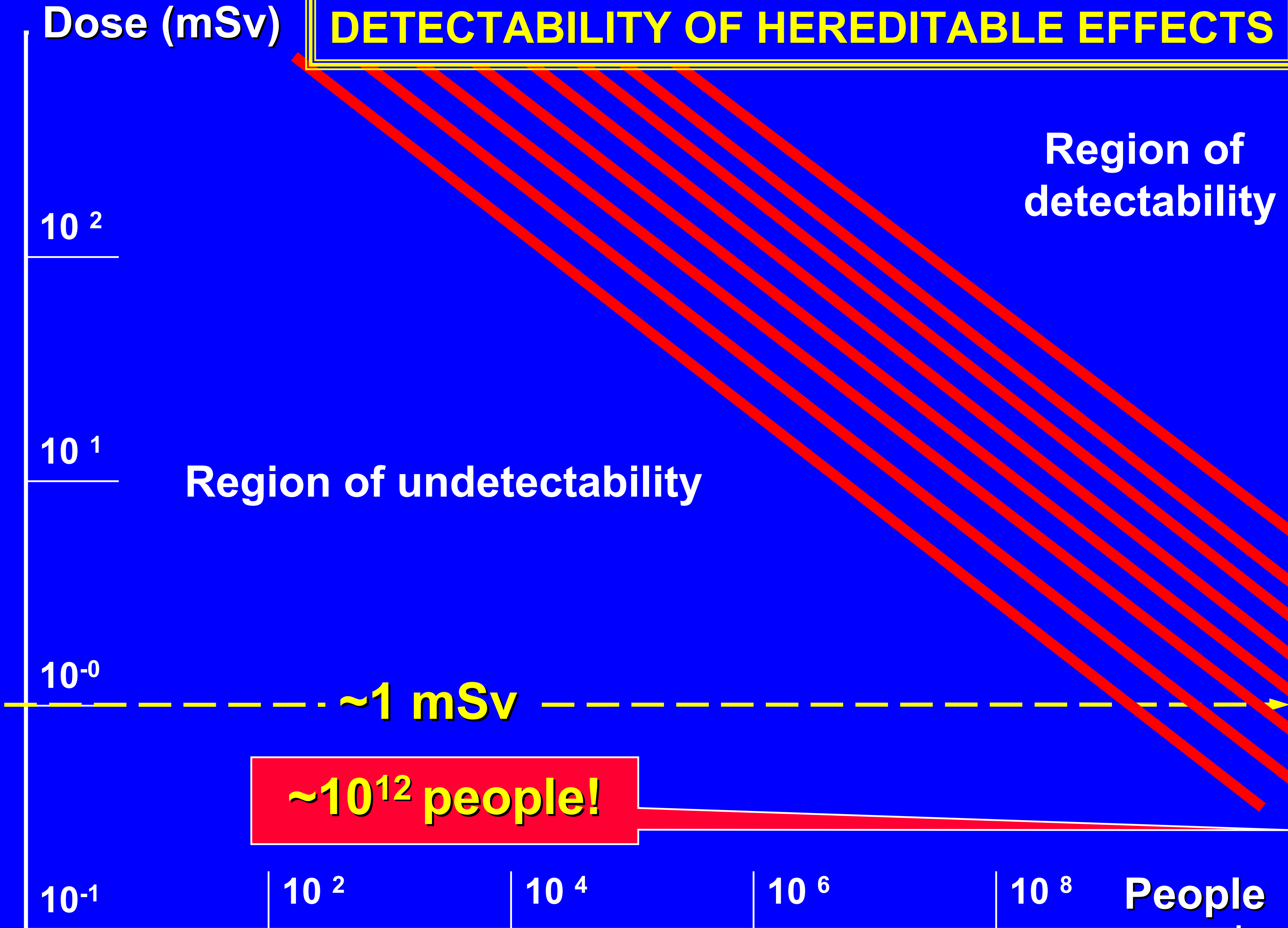
## $N > \sim 10000\ mSv^{-2} / D^2$

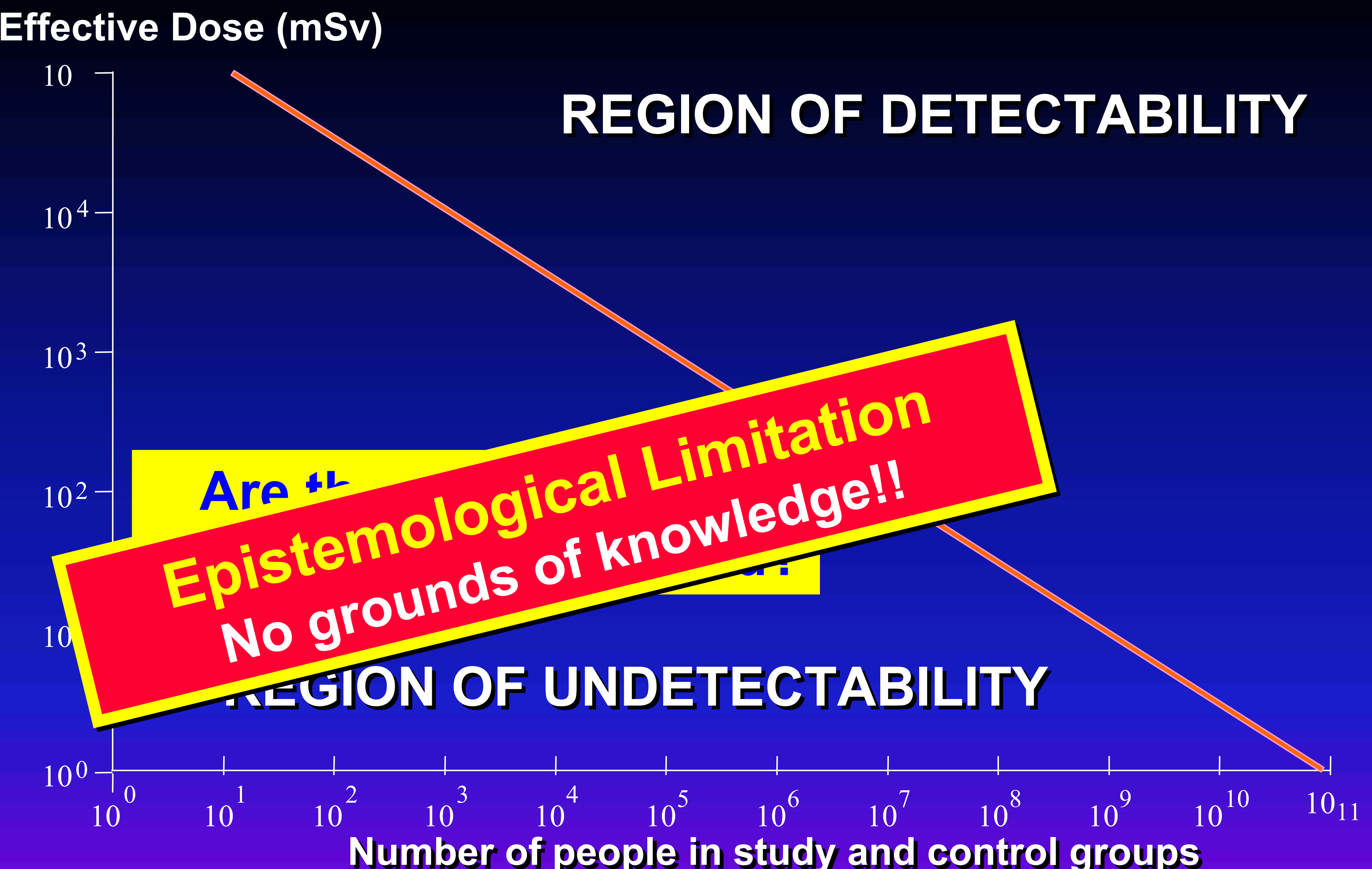
| Dosis, D (mGy) | ~ Number of people, N |
|---|---|
| 1 | 10.000 |
| 10 | 1.000 |
| 100 | 100 |

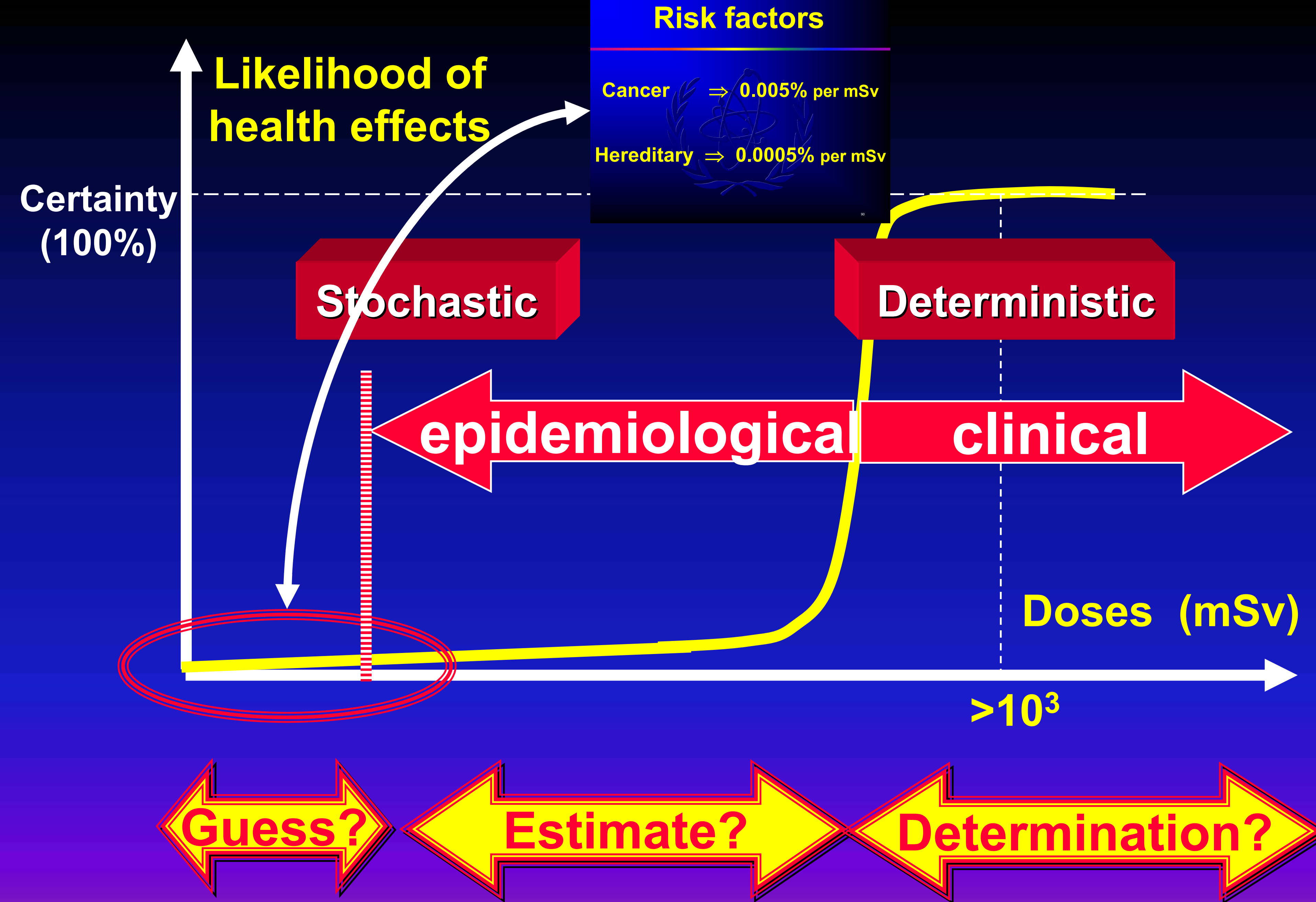
# Thyroid cancer in children in Belarus



# DETECTABILITY OF HEREDITABLE EFFECTS



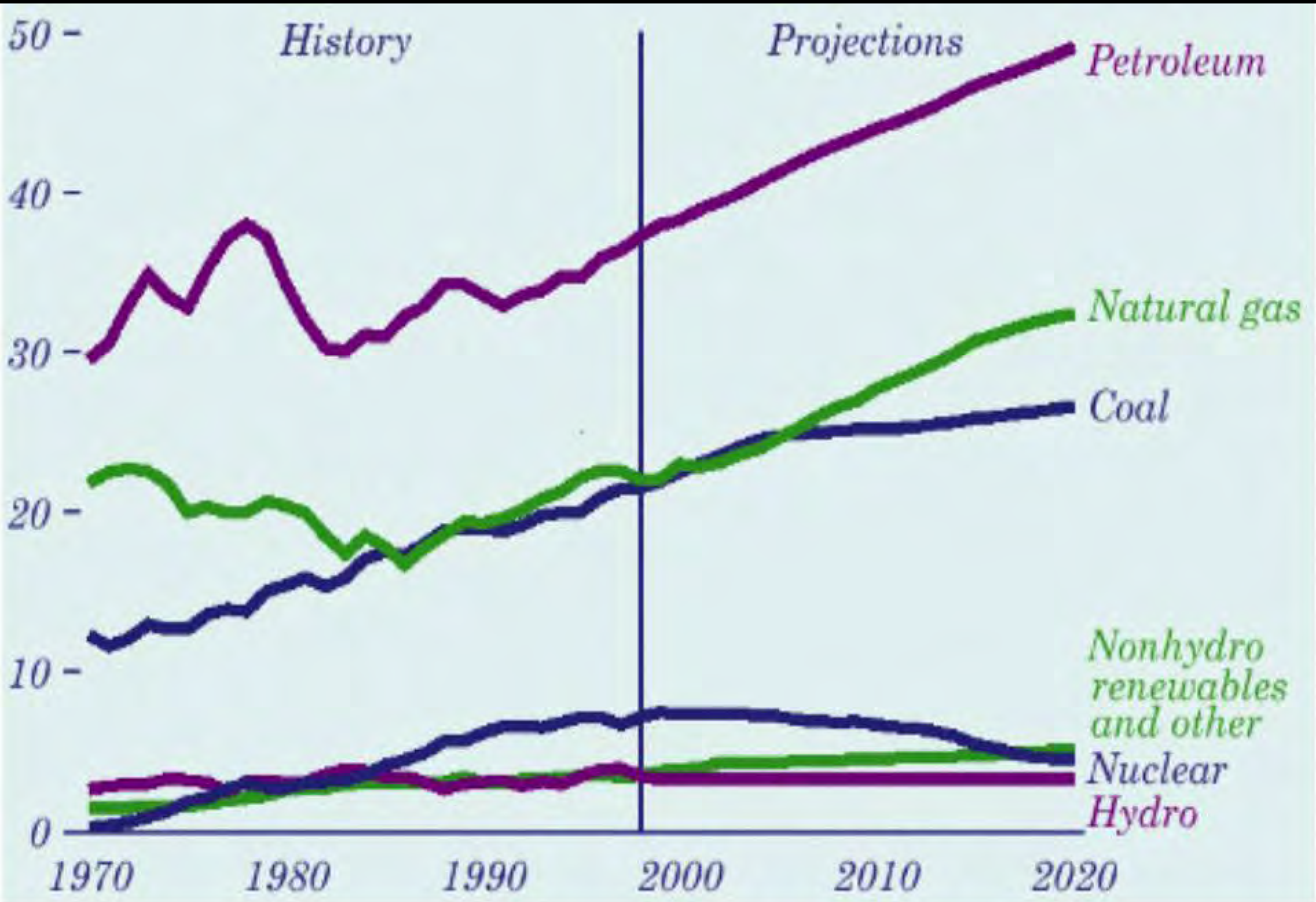

Effective Dose (mSv)
10
$10^4$
$10^3$
$10^2$
10
$10^0$
REGION OF DETECTABILITY
Are th
Epistemological Limitation
No grounds of knowledge!!
REGION OF UNDETECTABILITY
$10^0$ $10^1$ $10^2$ $10^3$ $10^4$ $10^5$ $10^6$ $10^7$ $10^8$ $10^9$ $10^{10}$ $10_{11}$
Number of people in study and control groups


Risk factors
Cancer ⇒ 0.005% per mSv
Hereditary ⇒ 0.0005% per mSv
Likelihood of health effects
Certainty (100%)
Stochastic
Deterministic
epidemiological
clinical
Doses (mSv)
$>10^3$
Guess?
Estimate?
Determination?

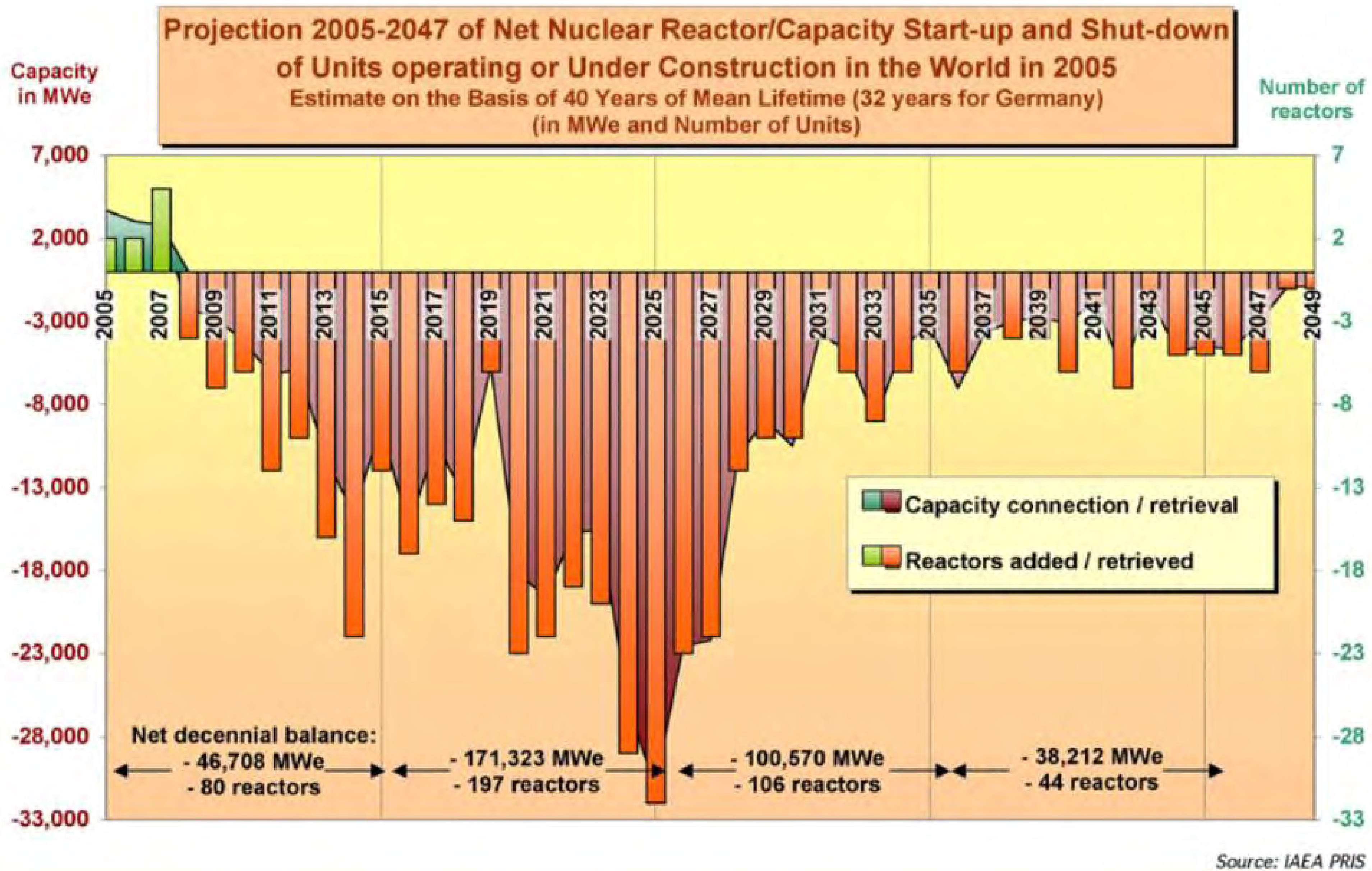
# Radiation Health Effects of the Chernobyl Accident

- ✓ 30 rescuers died promptly
- ✓ Few 100s. rescuers were injured
- ✓ Around 2000 children-thyroid cancers reported
- ✓ No detectable increases of other cancers (incidence or mortality).

# Chernobyl impact on the development of nuclear power



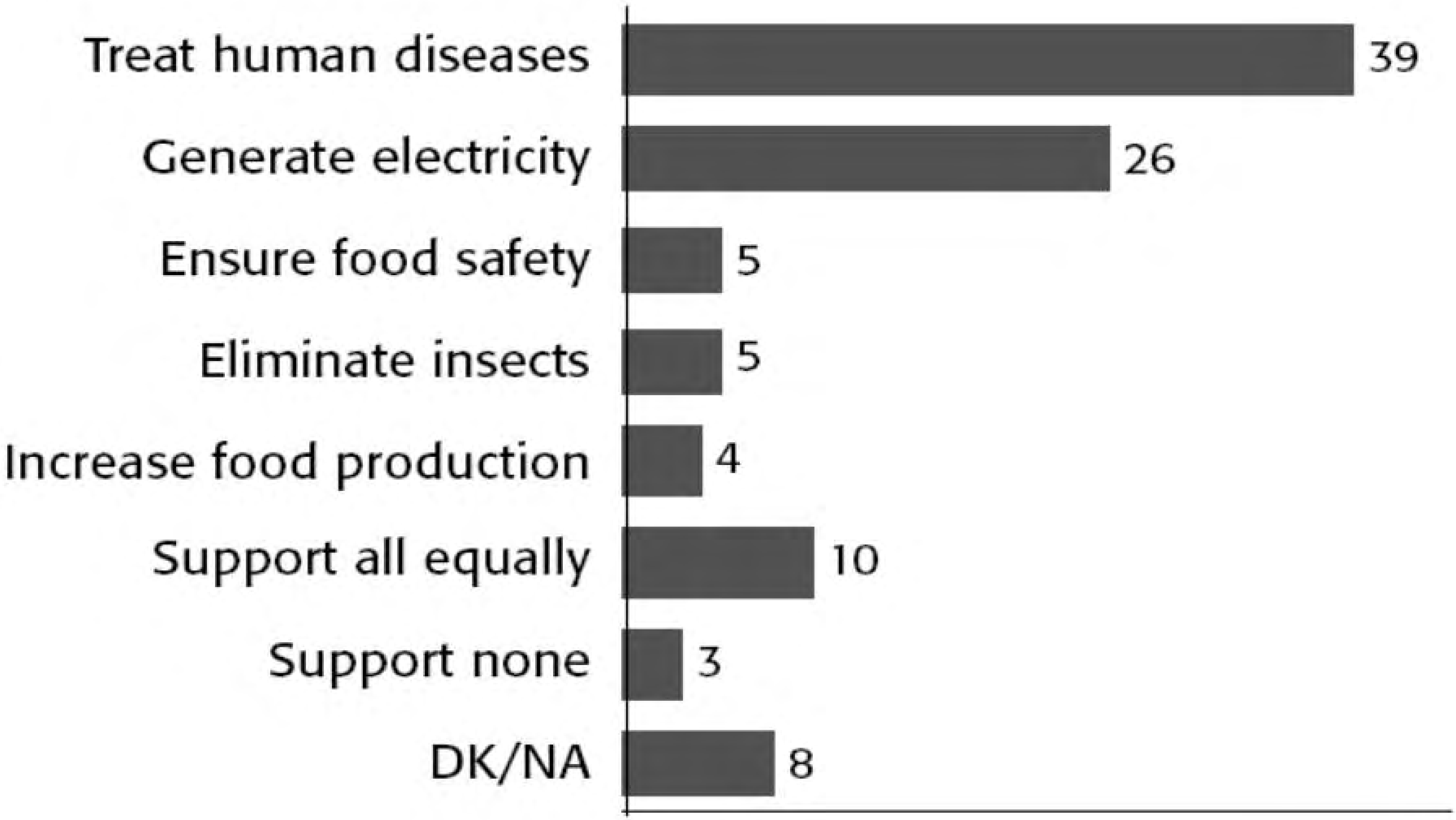

http://www.geocities.com/brf116/projection.jpg

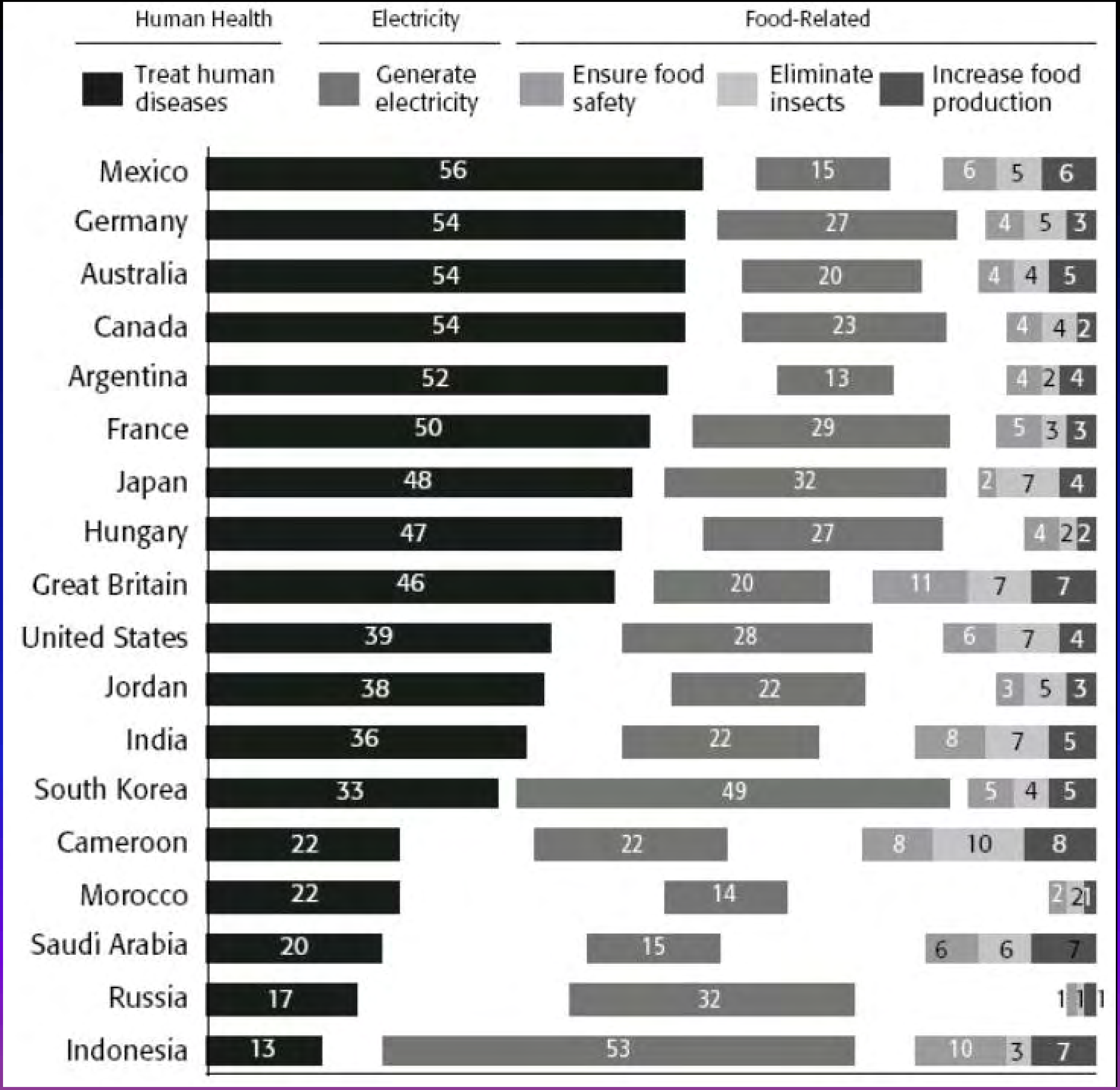



**http://images.google.com/imgres?imgurl=http://www.neimagazine.com/journals/Power/NEI/June_2005/attachments/Slide7.jpg&imgrefurl=http://www.neimagazine.com/story.asp%3FsectionCode%3D76%26storyCode%3D2030047&h=600&w=800&sz=459&tbnid=0fFffvxTyYq4VM:&tbnh=106&tbnw=142&hl=en&start=8&prev=/images%3Fq%3Dnuclear%2Benergy%2Bprojection%26svnum%3D10%26hl%3Den%26lr%3D%26rls%3DGGLD,GGLD:2004-25,GGLD:en%26sa%3DG**

## Support for Peaceful Applications of Nuclear Technologies

Total 18 Countries

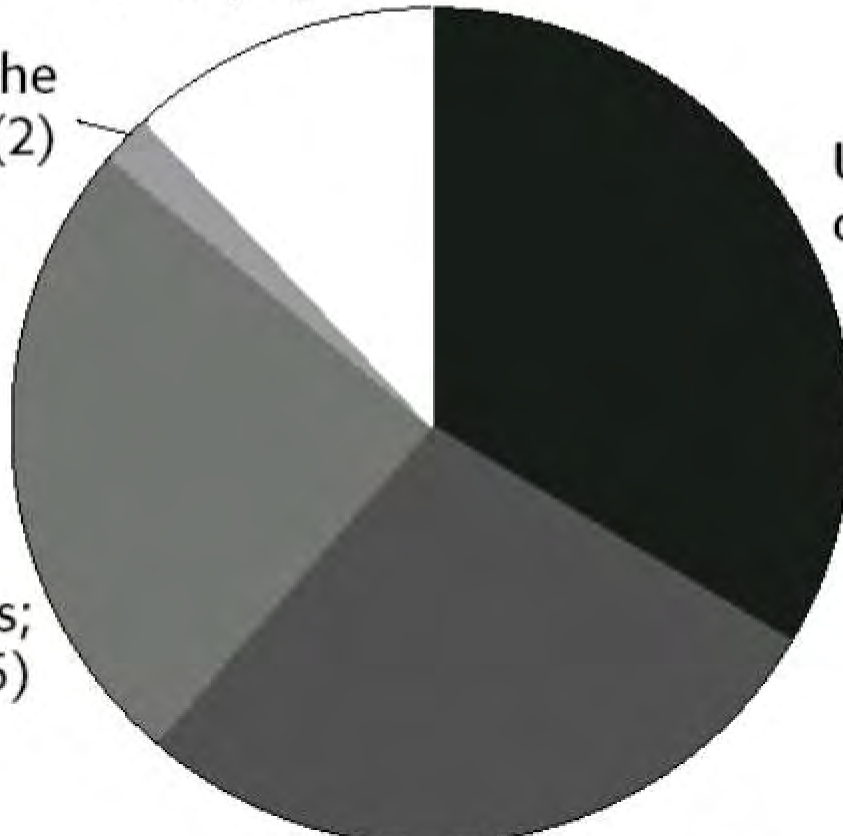




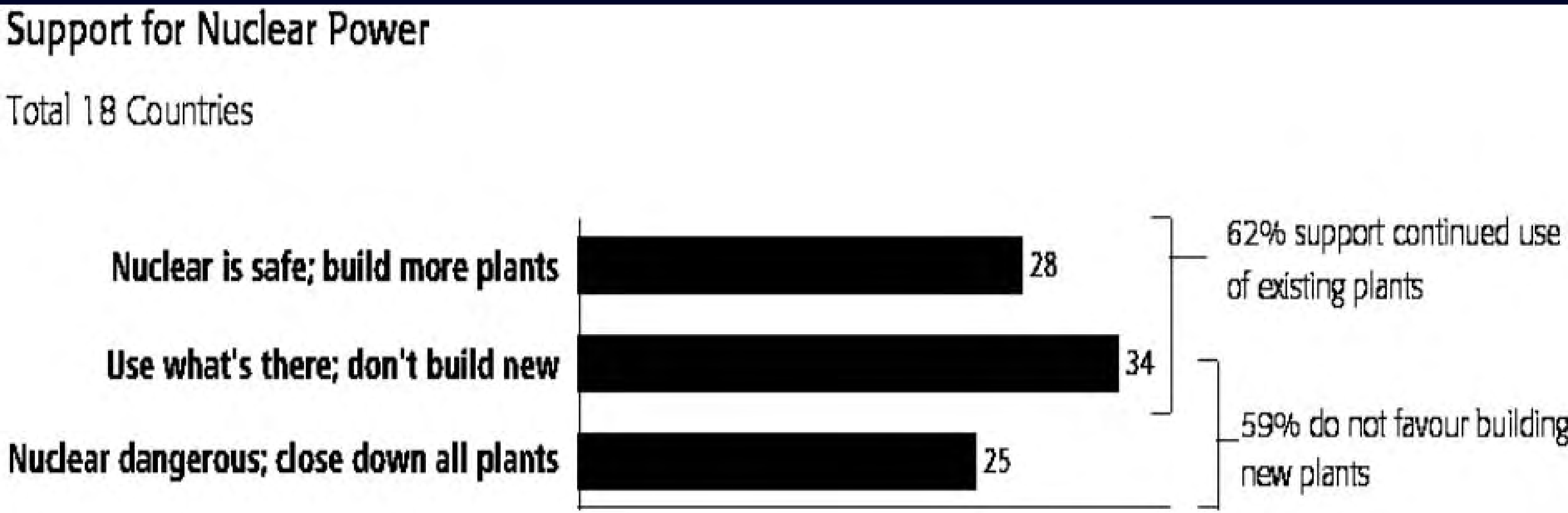
Human Health
Electricity
Food-Related
Treat human diseases
Generate electricity
Ensure food safety
Eliminate insects
Increase food production
Mexico 56 15 6 5 6
Germany 54 27 4 5 3
Australia 54 20 4 4 5
Canada 54 23 4 4 2
Argentina 52 13 4 2 4
France 50 29 5 3 3
Japan 48 32 2 7 4
Hungary 47 27 4 2 2
Great Britain 46 20 11 7 7
United States 39 28 6 7 4
Jordan 38 22 3 5 3
India 36 22 8 7 5
South Korea 33 49 5 4 5
Cameroon 22 22 8 10 8
Morocco 22 14 2 2 1
Saudi Arabia 20 15 6 6 7
Russia 17 32 1 1 1
Indonesia 13 53 10 3 7

# Support for Nuclear Power

Total 18 Countries

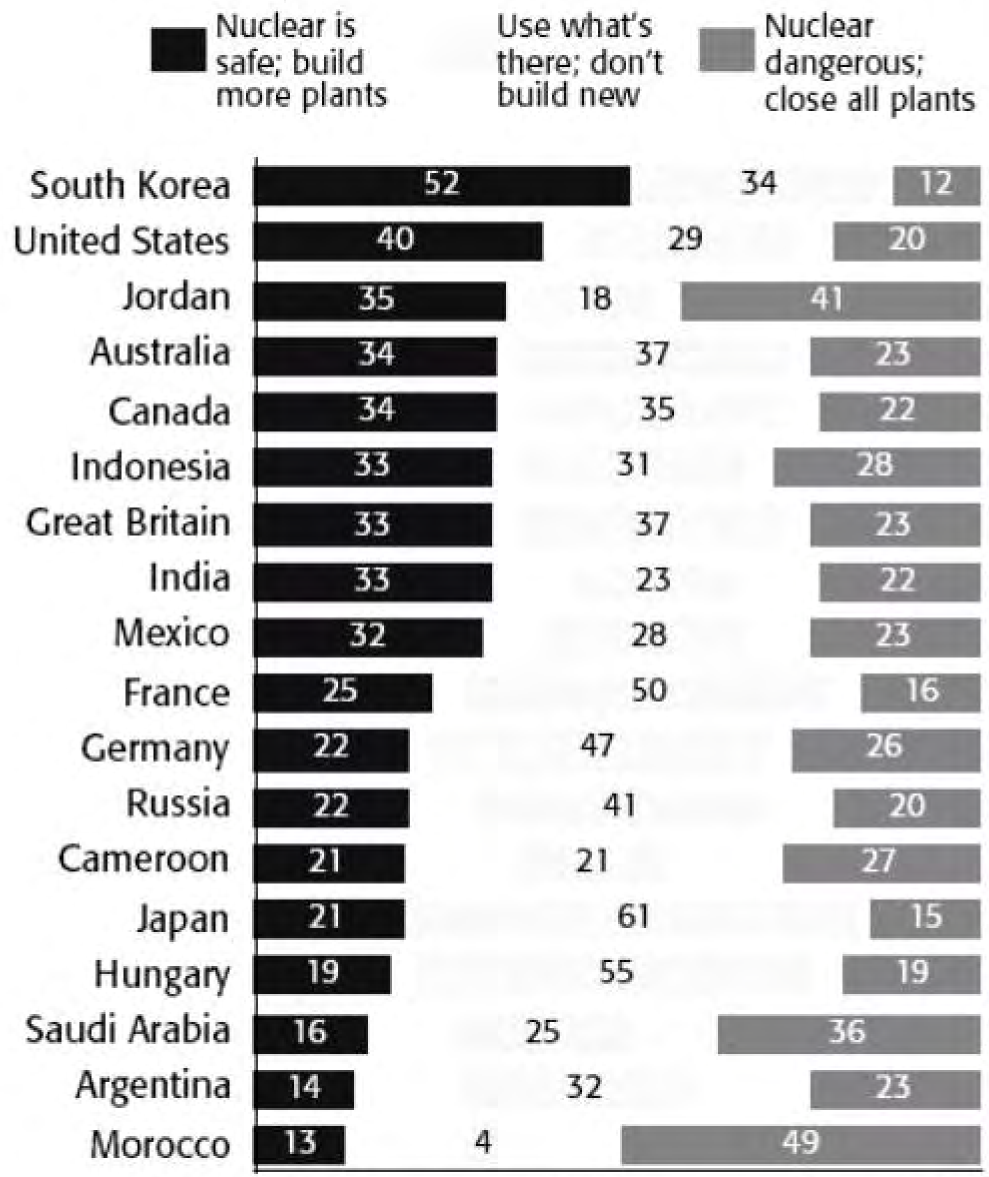



Q. 5


Support for Nuclear Power
Total 18 Countries
Nuclear is safe; build more plants
Use what's there; don't build new
Nuclear dangerous; close down all plants
28
34
25
62% support continued use of existing plants
59% do not favour building new plants

## Support for Nuclear Power

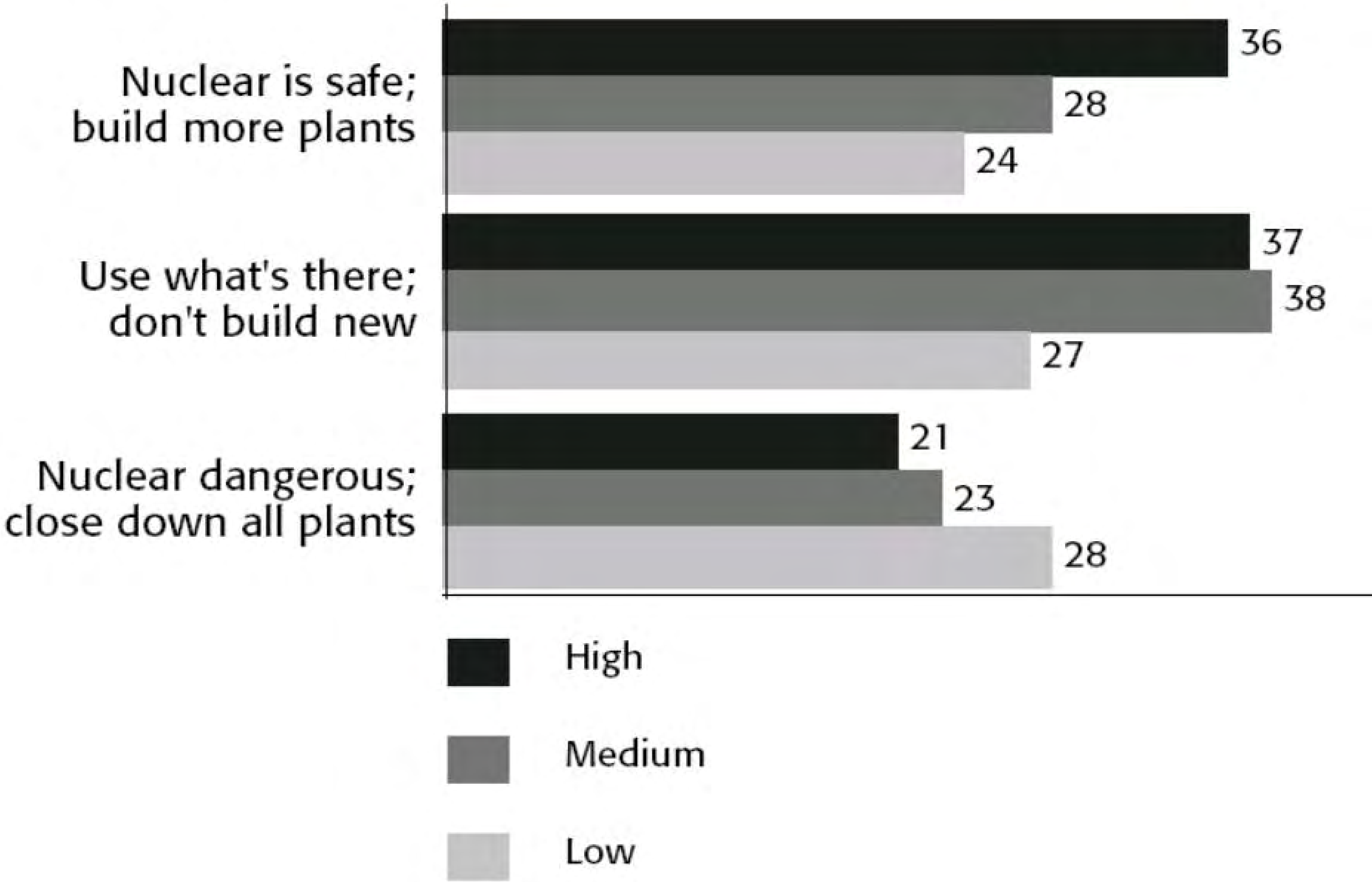
By Country




The white space in this chart represents "DK/NA" and "None of the above / other."

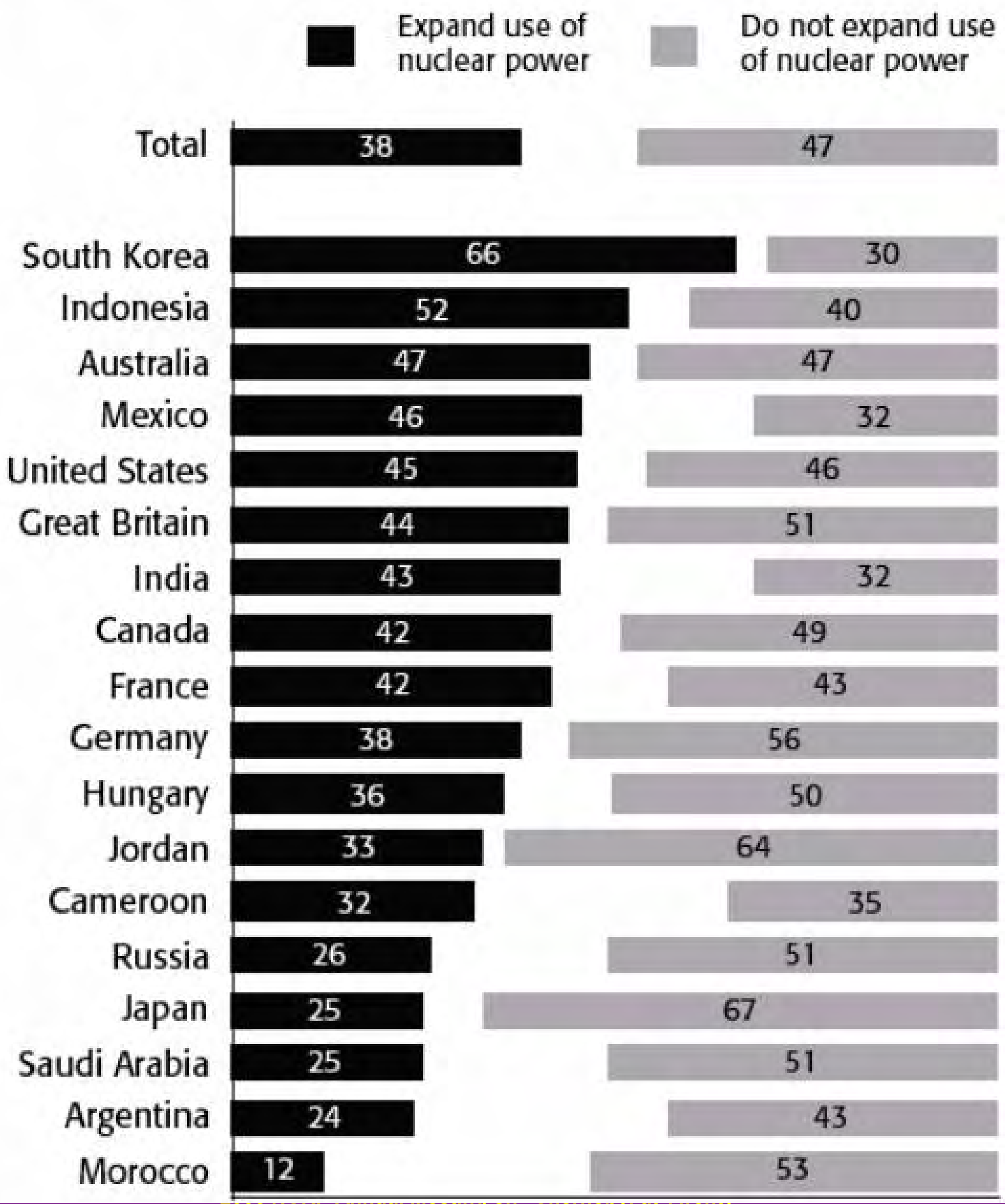
## Support for Nuclear Power

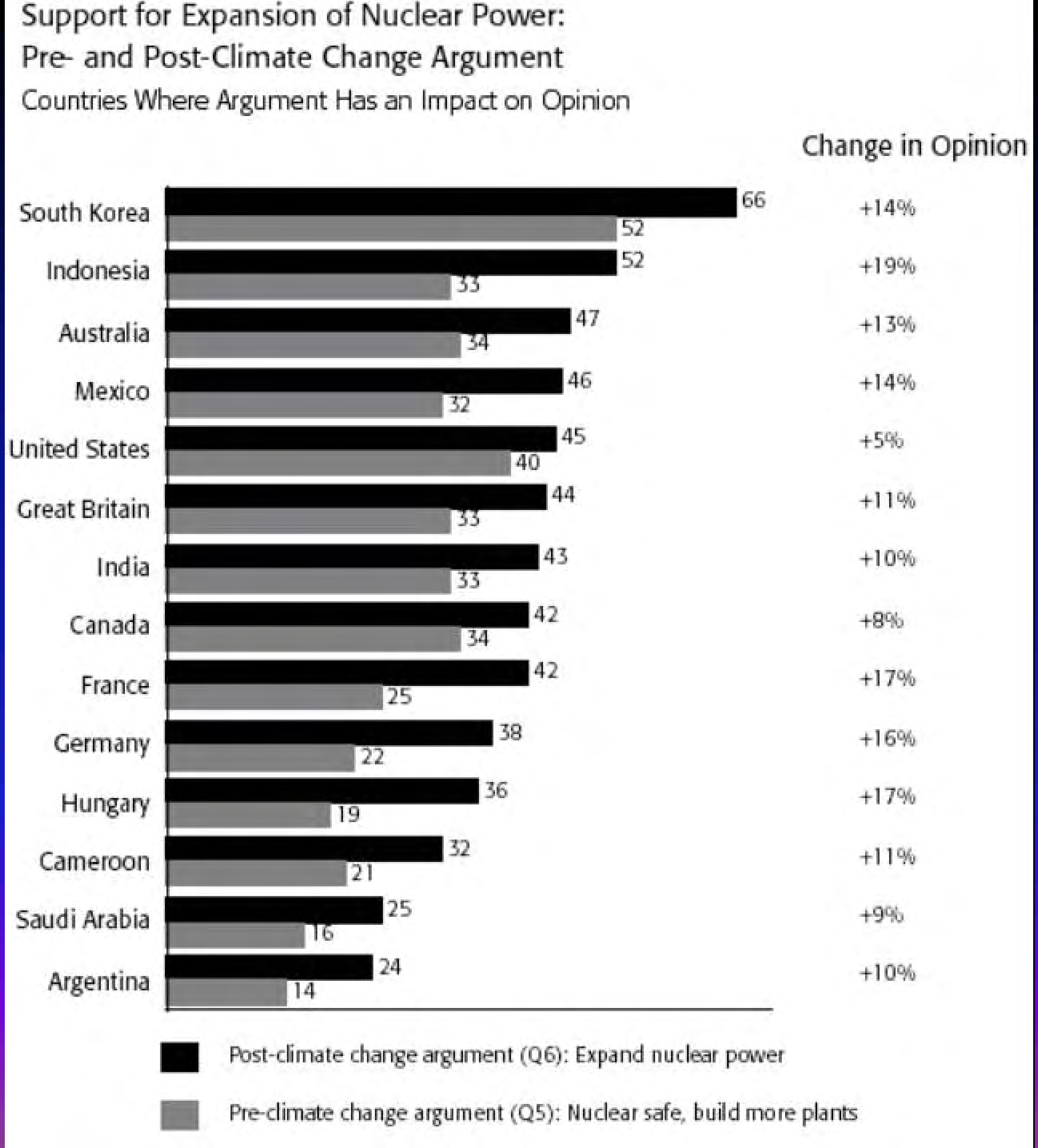
By Level of Education



# Nuclear Power as an Answer to Climate Change

By Country




Support for Expansion of Nuclear Power:
Pre- and Post-Climate Change Argument
Countries Where Argument Has an Impact on Opinion
Change in Opinion
South Korea 66 52 +14%
Indonesia 52 33 +19%
Australia 47 34 +13%
Mexico 46 32 +14%
United States 45 40 +5%
Great Britain 44 33 +11%
India 43 33 +10%
Canada 42 34 +8%
France 42 25 +17%
Germany 38 22 +16%
Hungary 36 19 +17%
Cameroon 32 21 +11%
Saudi Arabia 25 16 +9%
Argentina 24 14 +10%
Post-climate change argument (Q6): Expand nuclear power
Pre-climate change argument (Q5): Nuclear safe, build more plants

# It can be demonstrated that:

The **radiation health effects**

**<u>attributable to Chernobyl</u>**

are relatively limited

# But it should be emphasized that Chernobyl triggered:

- political cataclysm
- social tragedy and
- economic ruin…

…which, in turn, weakened the population's general well-being.

**The Chernobyl impact and its trans-boundary implications have been apparent to people around the world**

**Not surprisingly, Chernobyl has had devastating consequences for nuclear power and for the world energy strategy.**

## Is there any solution to this conundrum of universal loss of confidence?

**I submit that the answer is an authoritative nuclear safety regime.**

# In summary:

## if governments wish to resuscitate nuclear power…

**the time is ripe for them undertaking binding commitments!…**

…for a

-harmonized,

-efficient and

-sustainable

**global nuclear safety regime!**

**The IAEA is the only organ within the UN system with specific statutory responsibilities on radiation protection and safety**

# The Nobel Peace Prize

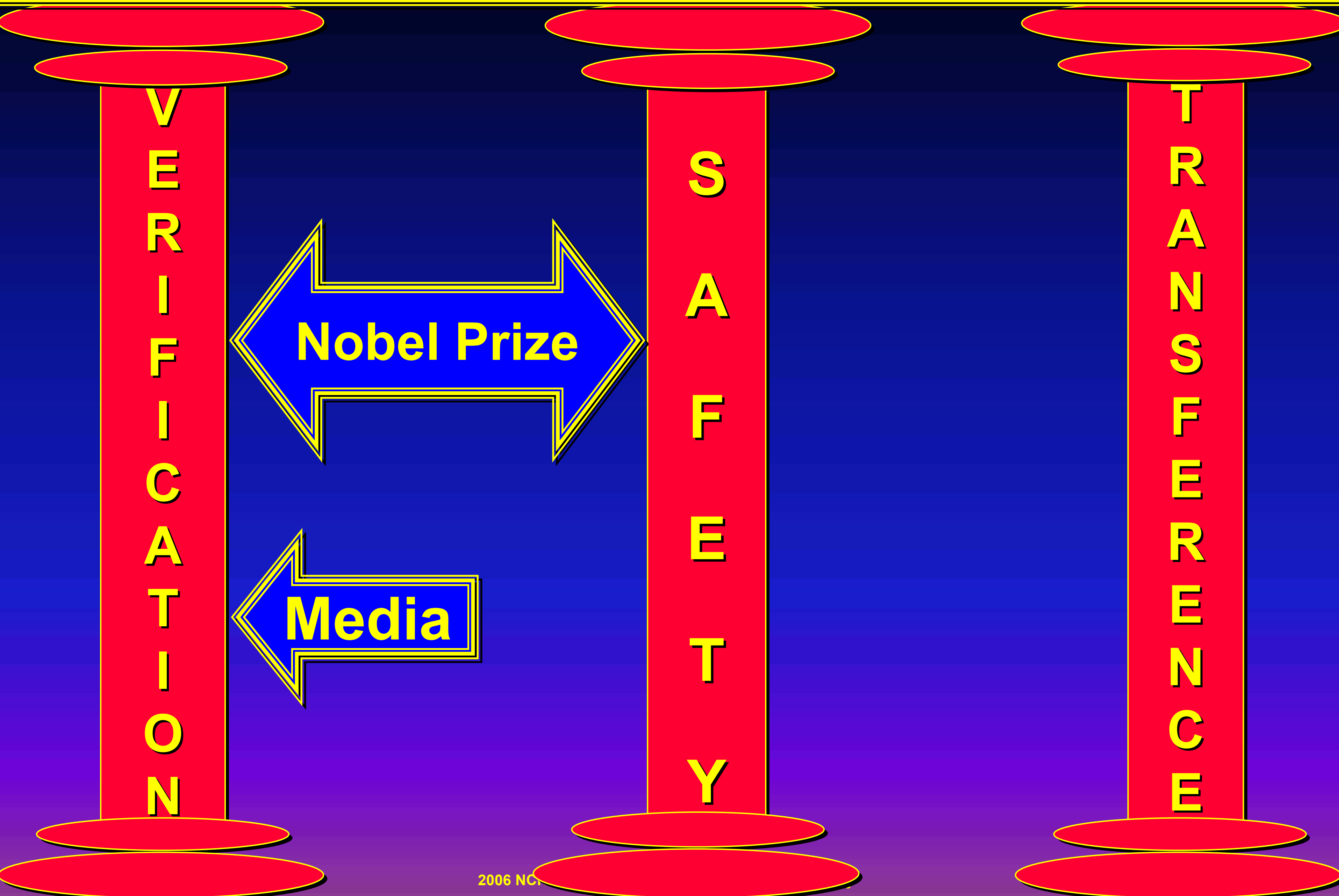
## 2005

**“For their efforts**

**[i] to prevent nuclear energy from being used for military purposes and**

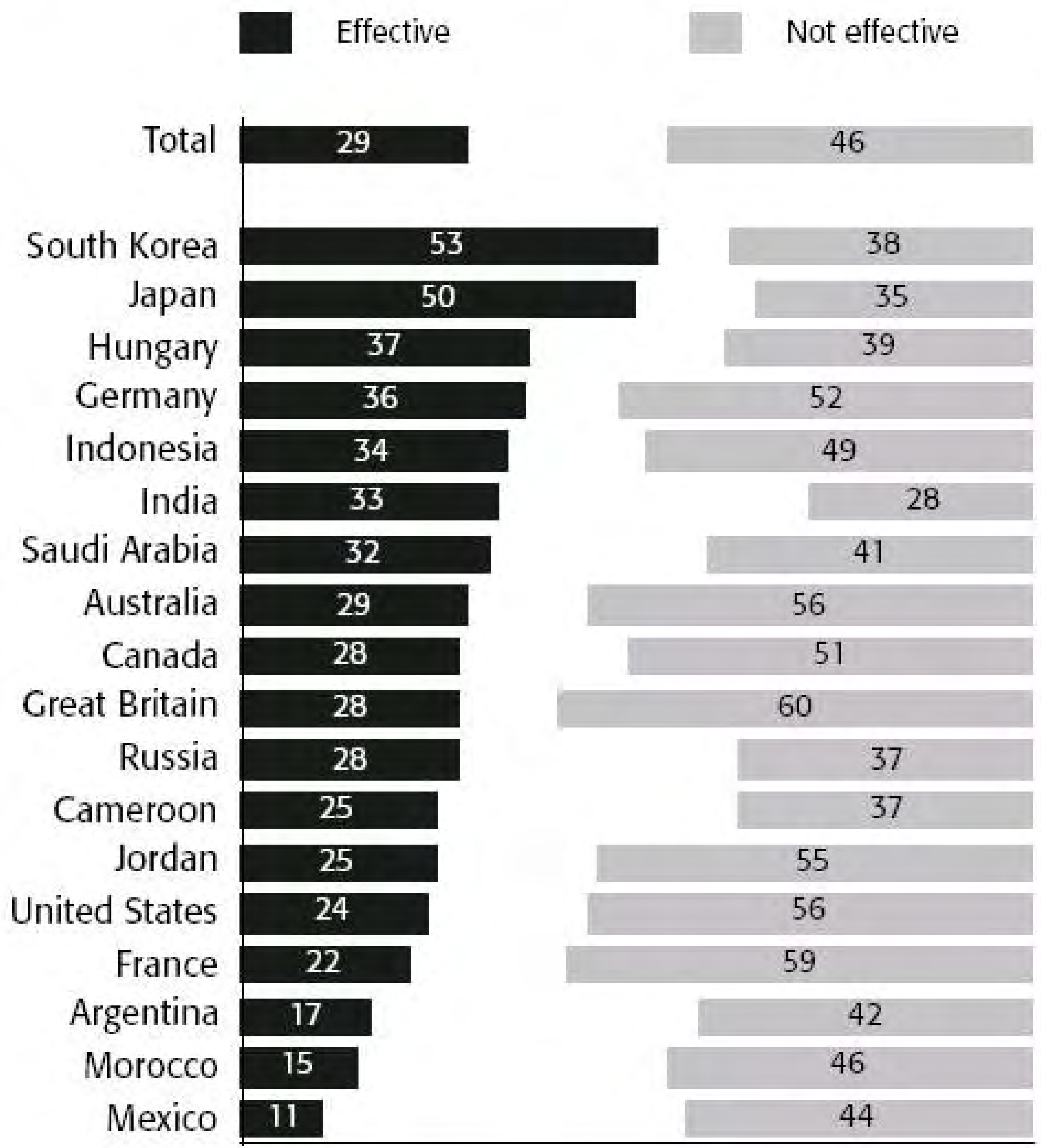
**[ii] to ensure that nuclear energy for peaceful purposes is used in the <u>safest possible way</u>“**

# International Atomic Energy Agency



# Effectiveness of IAEA Inspections

## By Country



# Closing Remarks

**Thomas S. Tenforde**

***President***

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- April 16-17, 2007
- Crystal Forum of the Crystal City Marriott, Arlington, Virginia