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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
OECD Nuclear Energy Agency

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

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8:15 a.m. **Introduction**
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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.

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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.

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).

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:

- 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.

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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.

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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
OECD Nuclear Energy Agency

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

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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

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