The Legacy of Chornobyl: 1986 to 2006 and beyond

Briefing prepared and presented by

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***Introduction**:*

It is an honor to speak before this panel of distinguished members of the United States Congress, foreign ambassadors, and accomplished scientists, physicians and academicians. I am privileged to share my thoughts concerning the aftermath of the Chernobyl Nuclear Accident twenty years ago. It is with the deepest sympathy and respect for the citizens of Ukraine, Belarus and the far reaches of Eastern Europe and Scandinavia affected by this unfortunate accident, that I submit this brief report and appeal for coordinated and collaborative study of the aftermath of the Chernobyl Nuclear Accident.

This meeting was organized to observe a milestone; the passage of twenty years since the explosion and fire at the Chernobyl Nuclear Power Station. Twenty years have passed since I gasped at the brief announcement that Sweden had detected increased radioactivity in the atmosphere and the isotopes suggested that a reactor meltdown had occurred, probably in the Soviet Union. I wondered then what legacy this event would have for the people and the environment in Eastern Europe. At the time I never guessed that I would spend much of my academic life exploring those contaminated places. Twenty years is a long time. Yet milestones of time are just empty markers without measures of the lessons learned. Time should be the vehicle of change, of progress made towards observation, experimentation, learning, application, and improvement of the human condition. The Chernobyl accident was a catastrophe. Hundreds, likely thousands, of lives will be lost. One-hundred thirty five thousand lost their homes and livelihood. Thousands more live in uncertainty because of the unknown effects of their exposures. Billions of dollars were spent to remedy the losses of agriculture and industry. Still, people make difficult decisions based on rumors and innuendo because we can not give them the assurances and knowledge that they need. After twenty years they assume we know the answers. They think we have designed the studies and evaluated the outcomes that can guide them through their fears of what may lie ahead. They imagine that we have garnered all we can from the pains of their misfortune to ensure their safety and make strategic plans. Twenty years is a long time.

Would it surprise this audience today if I stated that the death toll from the Chernobyl accident will be between 50 and 93,000 persons? Does this range seem absurd to you given our 21st Century technology? Yet, these numbers are seriously bantered in the press by advocates or dissenters wishing to advance their agenda. Such disparity of facts leaves lawmakers and laymen with little foundation on which to base decisions. Baseless confusion on likelihood of effect led thousands of expectant parents in Europe and Scandinavia to opt for voluntary abortions in the first years after the

Chernobyl accident. Yet the World Health Organization has found no relationship between exposure to Chernobyl fallout and the incidence of congenital birth defects. This tragedy was brought about not by radiation but by the fear of what radiation may do. Would it surprise you today to learn that some of the most highly regarded scientific journals reporting biological effects at Chernobyl do not require that radiation dose be reported, and that sample collection sites be listed? This is so, even though quantification and repeatability are the essence of science. Why are we not skeptical at such reports that predict the effects of radiation with less accuracy than our nightly weather forecast?

The United States National Academy of Science committee on the Biological Effects of Ionizing Radiation (BEIR) reports have strived to compile and assess the cancer and health effects from exposure to ionizing radiation. The BEIR VII reassessment leads to a rate of 0.057 cancer deaths per Sv whole-body dose for humans, leading to an estimated 4,000 cancer deaths in those directly exposed to Chernobyl radiation. Application of this rate to humans worldwide leads to an estimated death toll of about 34,000. Although we will never be able to test the accuracy of any estimate we must strive to be responsible in our reports because, as was evident in Europe, extreme views can lead to tragic results, evidenced by unneeded abortions.

After twenty years, we still founder somewhere between the benign and sensational when it comes to radiation. We have yet to turn the Chernobyl catastrophe into something bittersweet, with parcels of good that rise above the pools of despair. Much progress has been made; much of it by the people in this room. We will hear of lessons learned and witness advancements on many fronts. But I feel the consensus will be that the progress is not enough and that we have failed to live up to society's expectation. A recent CNN poll confirms my suspicion; 75% of those asked felt that we had not learned enough lessons from the Chernobyl accident. Our lack of commitment to apply recent advances in science and technology to Chernobyl's problems is seen as by most citizens as a lost opportunity. This rift will deepen if there is another nuclear incident on American soil. Resolution of the intricacies of Chernobyl's mysteries will require more than reliance on uncoordinated studies with varying standards and minimal longevity. What is required is the bold introduction of a coordinated effort that enforces standards of data gathering and assessment, establishes the protocols for collegial cross-checking, and preserving samples for repeated studies and future diagnostic advances. Without such coordination, we shall likely fritter away meager resources on disconnected and unrepeatable studies. We should endeavor now to make the milestones of the next twenty years ones of substance with meaningful application to solving issues of human and environmental health and safety.

Surveillance and Reconstruction of Industrial Disasters: Reconstruction of Chernobyl's Plumes:

In the first two days after the explosion and fire at the Chernobyl Nuclear Power Plant (ChNPP; Figure 1), the fate of the citizens of Pripyat, Ukraine (population

50,000) was held in check by the direction and speed of the wind. The outskirts of the city were only 3 km NW of reactor IV where the accident occurred at 0120h, 26 April 1986. Nuclear fuel particles were propelled by high volumes of steam from the breached reactor, contaminating areas as far west as Poland and as far north as Scandinavia by the end of the second day. The close proximity of the city to the reactor made it vulnerable to contamination by nuclear fuel covering a wide range of particle sizes (2 – 100 μm) from an exposed core inventory containing about 3 GCi of radionuclides. Evacuation of the citizens finally commenced at thirty-six hours after the explosion, using over one-thousand buses sequestered from surrounding cities. Prior to that time, the two major radioactive plumes had already been deposited and heavy contamination virtually enveloped the city. The inhabitants suffered moderate radiation doses over their 37 hours of exposure. It is clear, however, that doses would have been much greater if the main bodies of the western or northern plumes had traveled through the city. Thus, the 50,000 residents of the city of Pripyat, Ukraine avoided large losses of life by the fortunate directions of the winds on the days following the Chernobyl accident. If either of these plumes had traveled through the main portions of the city, nuclear power would suffer a much more sinister reputation that it does today (Figures 2-3).

The Western Trace released on 26 April 1986 traveled on a bearing of 264 degrees at a height of about 290 meters and covering a width of 660 meters in the forested areas west of reactor IV (see Figure 4). This plume had a high density of nuclear fuel particles and conveyed a dose rate of approximately 15 Sieverts per day (1,500 RAD/day). If this plume had moved along a bearing of 280 - 300 degrees, passing through the city of Pripyat, Ukraine, radiation doses would have been sufficient to kill hundreds, or most likely, thousands, via acute radiation sickness and mortality from induced cancers. On the subsequent day (27 April 1986) winds at 1200 meters altitude carried the Northern Trace plume directly toward the city of Pripyat. As radioactive particles fell, however, northeasterly winds at 300 meters shifted the major segments of the plume away from the city, sparing the residents dose rates of about 1.6 Sieverts per day (Figure 5). Even though the Northern Trace was over 9 times less dense than the first plume released, inhalation of its airborne particles conveyed risk of lifetime morbidity from cancer of over 50%.

Our research team has completed a digital reconstruction of Pripyat and the nearby Chernobyl nuclear complex. Over 470 buildings have been positioned using GPS devices, and their heights and footprints determined. Radiation measurements throughout the city will be conducted during the summer of 2004. These radiation values together with the virtual reality 3-D computer-generated map of Pripyat enable mathematical reconstruction of the flow and deposition patterns of radioactive fallout as it moved among the buildings, streets, and recreation areas. Used interactively, the resulting model based on ground-truth data allows us to accurately predict urban depositions under different wind conditions. This capability is a valuable tool for predicting impacts of urban exposures in other cities, including cities in the United States that are vulnerable to attack with radiation dispersion devices (RDDs). The unique ground-truth model from the Pripyat project also is invaluable for testing hypothetical models presently in development in several national laboratories.

Because many of the radioactive particles released at Chernobyl were similar in size to biological aerosols, dispersion patterns determined from our work at Chernobyl are relevant to terrorist releases of either agent. Despite the excellent progress that has been made on the primary objectives of locating and reconstructing the major plumes of radiation released by the Chernobyl accident and discerning the potential health effects of such plumes if released into populated areas, much work remains to be done that is of critical strategic importance to the United States and allies. Experiences from dirty bomb deployment drills have shown that different models may yield very different predictions for the direction and speed of radioactive plumes. We anticipate that rectification of observed and predicted fallout patterns from Pripyat will facilitate improvement of existing models. These opportunities are unique to the Chernobyl region and should be exploited to develop a database of radiation dispersion and observed impacts resultant from such a release of radiation. The observed patterns of radioactive contamination not only permit accurate reconstruction plume dynamics and potential health risks, but also they permit us to design, test, and refine predictive models. Despite the importance of post-accident data for guiding response and remediation efforts, the fate and effects of toxicants released by industrial events in other countries have largely been ignored by U.S. agencies. There is currently no central repository of environmental data and human health risk assessments for industrial accidents that have occurred around the world.

Relevance of the Chernobyl Accident to United States Security and Strategic Planning:

A recent survey showed that radioactive leaks, chemical spills and other man-made industrial disasters strike terror into people far more than natural calamities such as hurricanes, tornadoes and earthquakes. Storms and natural hazards are relatively immediate, are considered to be unavoidable, and without long-lasting, cumulative effects as found in many industrial disasters. Although more people have died from natural disasters than from industrial ones, people blame federal and local governments for inadequate oversight of industrial complexes when accidents occur. Additionally, people often blame the regulatory agencies for lack of enforcement and not learning lessons from prior incidents. Concerns for reducing the potential for future industrial accidents are heightened because society is rapidly expanding into more hazardous areas, economic damages for environmental hazards are increasing tremendously, and because industrial complexes are becoming likely targets for terrorist activities. The aftermaths of Hurricane Katrina and Rita have clearly demonstrated that our federal agencies must be prepared. Citizens expect that we will apply the lessons learned from past mistakes to strategic preparedness. Rapid decisions require ready answers. Answers require experience and training based on sound surveillance and reconstructions of past tragedies.

Protection from Radiation Dispersion Devices (RDD), or dirty bombs, is of primary part of the National Defense Strategy of the United States and its allies. In the formation of our defenses and response strategies to deployment of RDD's, we must be able to predict the influences of complex structures in the urban environment on the movement of aerosols. Predictions of radiation dispersal in the urban canyon can be done in two ways. First, we have generated complex mathematical models and simulation programs to project the dispersion of the particles. Secondly, we may use past releases of radiation and particles to actually measure the influences of buildings, avenues, and recreation areas on particle dispersion. Data from real-life releases can be used to assess the accuracy of existing models and permit us to refine them appropriately. There are very few places where we can make these real measurements. The abandoned city of Pripyat, Ukraine, adjacent to the Chernobyl nuclear reactor is the only large-scale urban environment exposed to a large plume of radiation. Texas Tech scientists have been involved in assessing this radiation for the past 14 years. In the last few years we have measured the dispersion of radiation from the Chernobyl reactor and examined the fallout patterns in forest, agricultural lands, over wetlands and lakes, and throughout the city of Pripyat. We have digitally re-created the entire city and have databases detailing the radioactive deposits surrounding each apartment building, each of the 15 schools and kindergartens, in every city park, and along the roadsides of every city street.

In every nuclear incident involving the release of radiation, answers to four questions are of immediate and paramount importance: 1) What are the likely health and biological impacts of the radiation in the environment? 2) What are the radiation doses producing the effects incurred by exposed humans and organisms? 3) What are the likely movements of radionuclides beyond the point of release and how will this radiation affect the quality of life for generations to come in the affected region? and, 4) What protective measures and cleanup technologies may be employed to reduce the radiation dose and prevent the movements of radionuclides into populated areas? Answers to these questions can only be gained by detailed research of past accidents, experience with the health and biological impacts associated with a wide range of radiation doses, and by thorough refinement of the predictions of theoretical models with empirical data gathered from accident sites. Despite the tragic nature of accidents at nuclear power plants such as Chernobyl, lessons learned from high levels of environmental radiation are invaluable for strategic planning in the advent of future accidents, determining the effectiveness of cleanup technologies, and tracking the biological health risks associated with chronic exposure to radiation. The Chernobyl Exclusion Zone with its 100+ abandoned villages, its modern cities left in ruin, its one-thousand square kilometers of fallow forests and farmland, offers an unprecedented outdoor laboratory for assessing the impacts of environmental radiation.

One hundred twelve villages were evacuated as a result of the Chernobyl accident. Models derived from data gathered at Chernobyl offer the opportunity to assess the potential impacts of future incidents. Effectiveness of countermeasures to reduce radiation dose and to impede dispersion of radioactive materials will be especially valuable in developing strategic responses to such incidents.

Biological Effects to Native Fauna and Flora:

The biological impacts to native fauna and flora have been subtle. The heavy fallout in the Western Trace, the first plume released by the explosion, resulted the death of about 400 hectares of Scottish Pine forest west of the Chernobyl Nuclear Complex. Indeed, the radiation doses in this region of the Red Forest killed much of the mammalian and avian fauna. These extraordinary doses were confined to within five kilometers of the reactor, however. Most of the larger fuel particles, associated with higher doses, settled close to the reactor. The lighter particles were carried farther and yielded lower radiation doses when they settled. The path of the Western Trace was very succinct (Figure 2); thus, zones of high radioactivity were not situated far from areas with relatively sparse contamination. Many refugia wherein animals were not exposed to fatal radiation were available for repopulating the zones of extirpation. Acute radiation effects contributing to increased mortality and decreased reproduction in biota exposed to the paths of the Western and Northern Traces occurred. The mosaic pattern of radioactive deposition and reduction of human land use practices in the area facilitated the recovery of terrestrial populations in the Chernobyl Exclusion Zone. Today, in areas outside of the Red Forest, 2 – 8 kilometers from the reactor IV, you would not suspect you were in a radioactive environment without the use of electronic detection devices. Species diversity and genetic diversity in mammals is not different than in relatively uncontaminated areas outside of the Chernobyl Exclusion Zone. No acute radiation induced effects have been observed in regions outside of the 30 kilometer exclusion zone. Inside the zone, ecosystems have shown remarkable recovery and resilience to this insult.

In all credible field studies at Chernobyl, the biological impacts to plants and animals in the Chernobyl Exclusion Zone are consistent with radiobiological data obtained in experimental and environmental exposures to ionizing radiation. It is troubling to see a number of studies appearing in the scientific literature that report improbable genetic damage with no data on radiation exposure or dose. Often, specific collection sites are omitted as well. Science is the study of variation and the process of attributing that variation to specific causes. Credible science is repeatable, and studies that purport to have evidence contrary to currently accepted principles *must* be repeated. Poor science should not be tolerated by funding agencies, should not be published by reputable journals, and should not be given credence in the popular press. The scientific literature is replete with conflicting evidence concerning the biological and genetic effects resulting from exposures of organisms to the radioactive fallout from nuclear accidents. Because risk assessments, regulatory compliance statutes, and effectiveness of countermeasures and remediation actions are often evaluated on the basis of these published reports, it is imperative that conclusions of scientific investigations into the effects of ionizing radiation on humans and organisms be based on sound scientific principles. There are many species of plants and animals living in the most radioactive environments at Chernobyl. These species are carrying out the development of sperm and eggs, embryological growth and aging while receiving unparalleled chronic doses of radiation. Twenty years have passed since the Chernobyl accident, yet the extent of damage to the health of individuals exposed remains hotly debated in some circles. Therefore, there is a need for focused studies that allow the examination of consequences directly related to chronic radiation exposure.

Establishment of an international laboratory for radiation studies at Chernobyl:

Recognition of the importance and effectiveness of long-term studies at Chernobyl was given by the governments of the United States of America and Ukraine in the formation of the joint Agreement to establish the International Radioecology Laboratory. On July 22, 1998, a Government-to-Government agreement was signed to establish The International Radioecology Laboratory. The Secretary of Energy endorsed the critical nature of this lab to the fulfillment of the mission of the United States Department of Energy. The International Radioecology Laboratory currently employs 15 full time scientists and technicians in the city of Slavutych, Ukraine. The laboratory has served as the base for Chernobyl studies for scientists from ten countries. The USA - Ukraine agreement did not provide any mechanism for continued funding of research after the laboratory was completed.

Because of the strategic nature of the Ukraine and eastern European countries, close development of collaborative research and development programs is in the best interest of U. S. foreign policy. Currently, the International Radioecology Laboratory is serving a vital function in service of the United States of American, its coalition partners in Iraq, and the newly established country of Iraq by training Iraqi scientists in radiation counting techniques, assaying radioactivity in soil samples from the Al Tuwaitha Nuclear Facility south of Baghdad, and working with U.S. scientists to characterize the former nuclear facilities in Iraq in preparation for decommissioning and disposal/storage of wastes.

Recommended Actions:

1) The Chernobyl Exclusion Zone offers a unique outdoor laboratory for examining the fate and effects of environmental radioactivity. Because of the threats to use nuclear material as a vehicle of terror against the United States, the Chernobyl Exclusion Zone offers a setting to reverse-engineer the movements of radioactive and biological aerosols through urban environments. Comparisons of actual and predicted flows of radioactive aerosols through urban and rural settings will be invaluable for testing the accuracy of models of aerosol dispersion.

It is recommended that funds be identified to conduct coordinated studies between institutions experienced in the measurements of actual fallout patterns in the Chernobyl region and those designing and implementing models of

aerosol dispersion in the urban canyon and rural settings. These studies should emphasize the need for early identification of the source, flow, and risks associated with radiation releases.

2) Knowledge of biological effects of chronic, low-dose, radiation is important to the citizens of the United States. Knowledge will prevent hysteria surrounding accidental and terrorist releases of radiation and will reduce the associated indirect, psychological effects. At the present time there is no funding program that specifically targets using Chernobyl-related data in any coordinated fashion. The debate over low-dose radiation is exacerbated by a paucity of studies coordinated among multiple laboratories, lack of associated radiation dosimetry/exposure information, lack of preserved biological samples, and incomplete sampling localities.

It is recommended therefore that funds be identified for a very unique program to quantify environmentally-relevant radiation doses to biota in the Chernobyl region. The program guidance should stipulate that funded studies must include analyses of replicate samples in at least two independent laboratories using the same samples; the analyses must be performed in a double-blind manner wherein neither lab is cognizant of whether samples are from radioactive or control regions; radiation dosimetry to the samples will be performed independently of the laboratories examining genetic/molecular responses; the funded studies may involve experimental manipulations of radiation doses to examine molecular, biological, or genetic responses and repair. The funded laboratories must agree to jointly publish the main body of the research and openly discuss the discrepancies and resolutions required. It is recommended that the laboratories include those from all participating countries (i.e., European Union, United Kingdom, Ukraine, United States, Canada).

3) The biota in the Chernobyl region offers a unique resource for evaluation of genetic and molecular effects from environmental ionizing radiation. Although great strides have been made in the twenty years since the Chernobyl accident, future breakthroughs will offer boundless opportunities to measure the subtleties of molecular change. We should endeavor now to preserve samples from all biological samples collected from the Chernobyl region together with descriptive databases with associated collection localities (GPS coordinates), radiation content, radioactive environment, and dosimetry information. Links of the samples to published data and DNA sequences (i.e., GENBANK) should also be included. Subsamples of these samples could be shipped to requesting institutions.

It is recommended that a central repository be established to preserve and maintain samples of organisms and tissues from the Chernobyl region for the purposes of future evaluations. The material may also be used to replicate analyses on important studies that merit duplication. Currently, the frozen tissue bank and DNA preservation facility at Texas Tech University Museum is the only known

Chernobyl specimen repository.

4) International research presents unique problems for scientists from visiting countries. One of the biggest challenges is having an organized, equipped facility with experienced staff to assist scientists in obtaining, preserving, and measuring the samples. This is especially true when considering that samples are being gathered from a radioactively contaminated environment. The International Radioecology Laboratory in Slavutych, Ukraine, built in 1999, has been an invaluable resource for scientists from the USA and other countries. However, the laboratory is inadequately funded and needs to update its equipment.

It is recommended that funds set aside for Chernobyl-related research include contractual agreements to operate the International Radioecology Laboratory and provide for capital equipment upgrades. This laboratory would then, by default, contribute to each of the projects recommended above in a logistical and analytical manner.

Conclusions:

Escalation of terrorist threats against the United States of America have poignantly demonstrated our need to realistically evaluate risks to the citizenry and develop strategic plans for responsive actions in the advent of future escalation. Of particular concern are terrorists' threats to disperse nuclear materials into populated areas via "dirty" weapons or attacks on nuclear production and storage facilities. Fallout from the Chernobyl nuclear accident presents the best opportunity to evaluate the impacts of releases of radiation into populated regions and the environment. A comprehensive understanding of the environmental, human-health, and socio-economic impact of public exposure to nuclear contaminants is in the national interest of the United States and coalition partner nations. The issues at stake, and the need for information and planning, require quick responses based upon knowledge gained from prior studies, coordination of assessment personnel, and rapid acquisition and integration of new information at the point of attack.

Terrorist activities are often intended to disrupt and destabilize society rather than incur loss of life. Our best defense, therefore, is to gather and disseminate accurate information that portrays the real risks and impacts of potential terrorist activities. Fear of radioactivity has been perpetuated by the decades of the cold war, but is often unfounded. At this time there is little understanding of the short- and long-term effects of the deployment of dirty weapons. Also, we need to know better how radioactive elements may course through city streets, among buildings, or how radiation doses may be distributed within and among dwellings. One difficulty to understanding these issues is having an example location that has been exposed to the conditions of a dirty weapon. The vacant cities and villages in the Chernobyl region offer actual settings in which we can measure the dispersion of radiation in populated areas and compare results to predictions of existing national-defense models.

Twenty years is a long time. It is time enough for ninety-nine percent of the radioactivity released by the Chernobyl explosion and ten-day fire to decay away to harmless elements. It is time enough for the memories of poignant events to become blurred by the rush of everyday occurrences that push the fine details aside. It is time enough for nations once with powers on a par with our own to weaken, fall, and reassemble into unforeseen alliances. It is time enough for advances in science, in society, and in technology to yield unprecedented changes that contribute to longer lives, healthy life styles, and security for the citizens of our nation. But twenty years is time enough for new and novel threats to our security to arise and strike without warning. It is time enough for legacies of past events to coalesce to make us remember that catastrophes are not always instantaneous, but move so slowly that their advance is almost unnoticed and its lessons unheeded. Unfortunately, twenty years is long enough for us to put events behind us, thinking that time has resolved all threats and that remedies have been parlayed and rendered to relieve the pain of those once suffering. And, it is time enough for us to believe that we have learned all we can and have garnered all the good possible from those events so long ago.

We can not afford to ignore this disaster. We must act now, while the signatures of Chernobyl's legacy remain on the countryside, in the cities, and in the molecules of the people and biota affected. We must act now for we are at the height of an unprecedented revolution in molecular methodology that allows us to identify the finest details of genetic change. We must act now because nuclear power and nuclear threats are growing issues on the world stage. We must plan now for the next disaster and be responsible to the citizens who have entrusted their security to us. We must act now to ensure the next milestone is not an empty marker but the sentinel of progress, understanding, and improvement of the human condition.

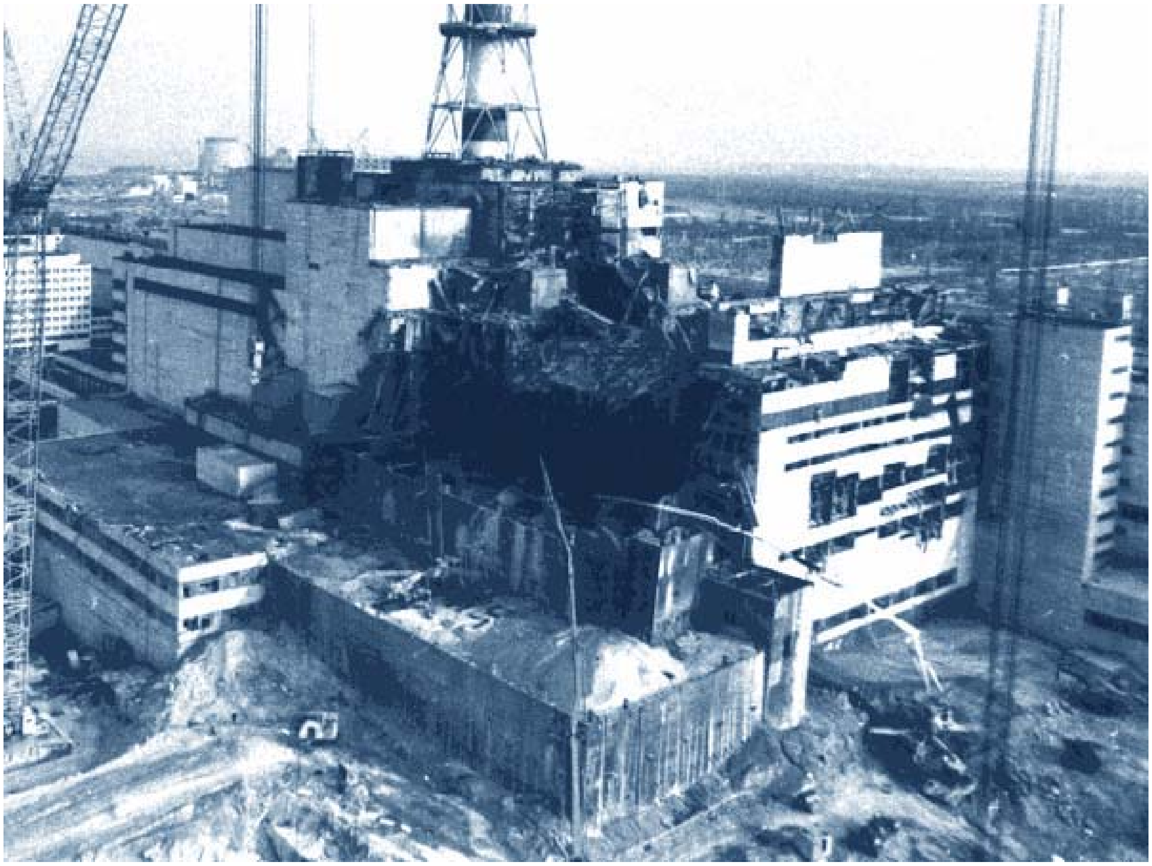

Figure 1. Aftermath of the explosion and 10-day fire at Chernobyl Nuclear Complex reactor number IV. The opening leading to the exposed reactor core can be seen below the striped stack. A hastily constructed shelter was completed in 1987 which covers the ruined reactor. A new shelter is currently planned for completion before the end of the decade.

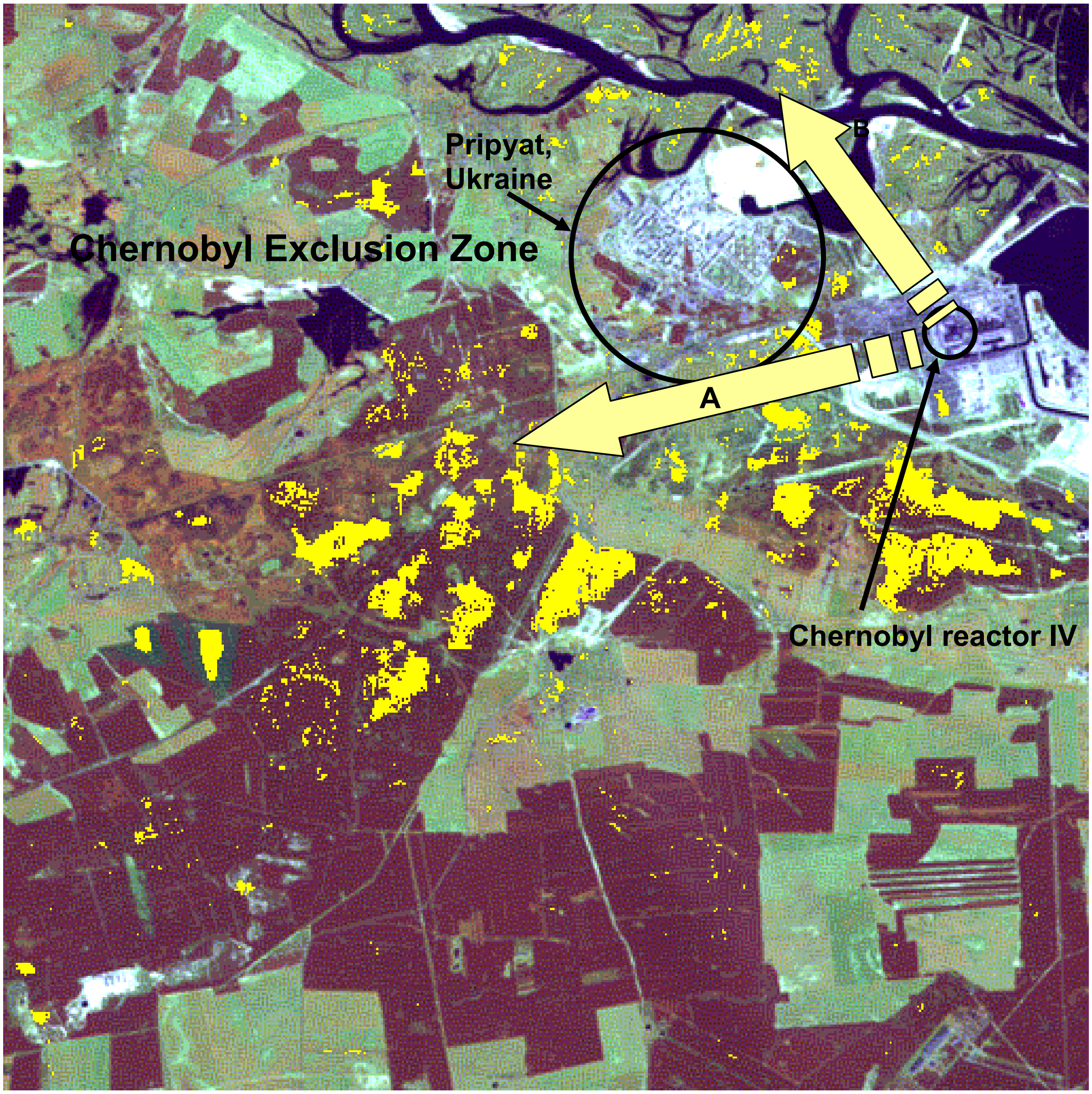

Figure 2. Aerial photograph of the region surrounding the Chenobyl Nuclear Power Station, the abandoned city of Pripyat, Ukraine, and the forests and agricultural lands most affected by the two major radioactive plumes, the Western Trace (arrow A) and the Northern Trace (unlabeled arrow).

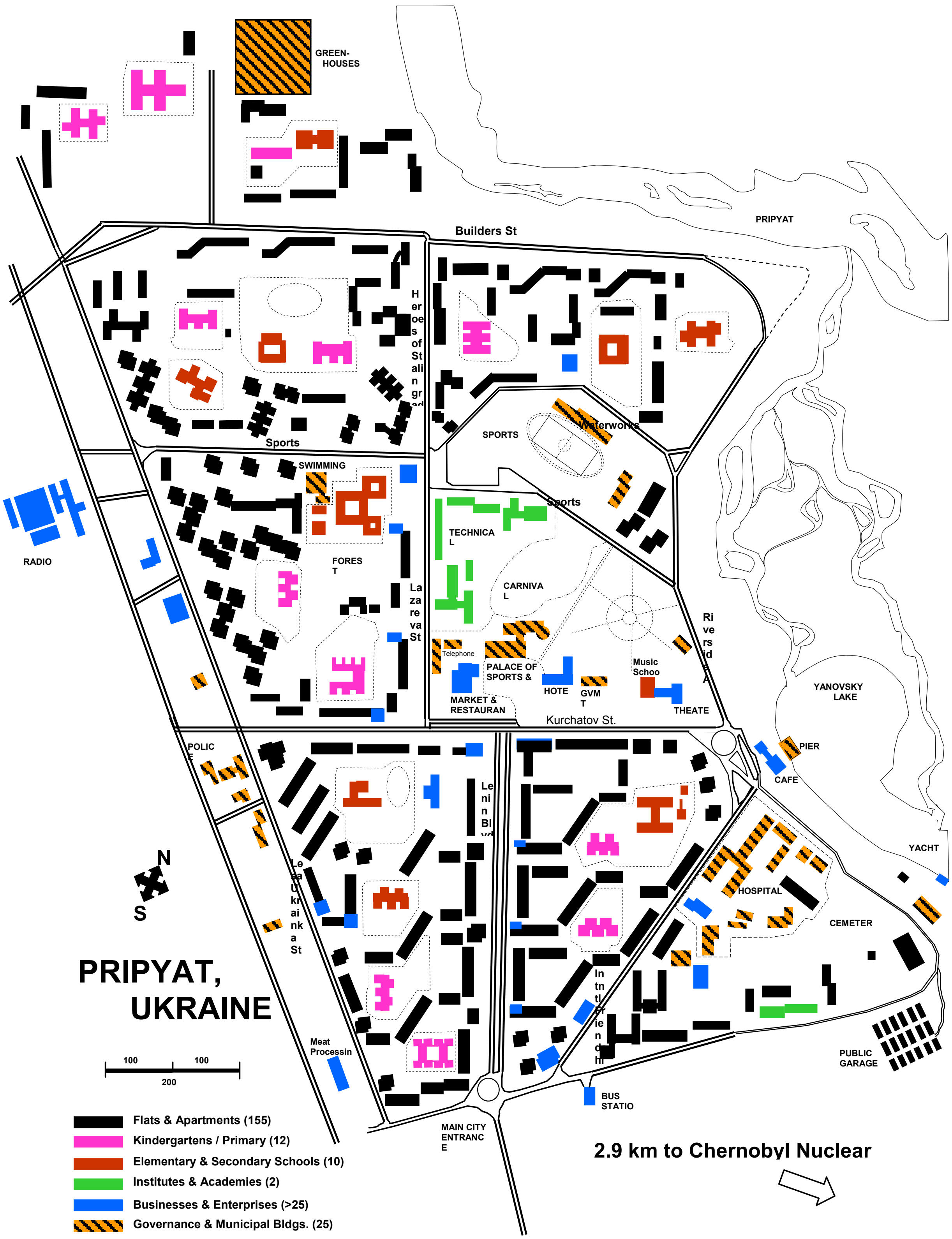

Figure 3. Graphical reconstruction of the layout for the abandoned city of Pripyat, Ukraine. The city gate was only 2.9 km (~2miles) from the Chernobyl reactor number IV that exploded on 26 April 1986. The 50,000 citizens of Pripyat were evacuated 36 hours after the explosion. Average doses to citizens were about 11 milliSieverts. The city and radiation patterns have now been digitally reconstructed for applications of aerosol dispersion (by Ronald K. Chesser and Brenda E. Rodgers 2005).

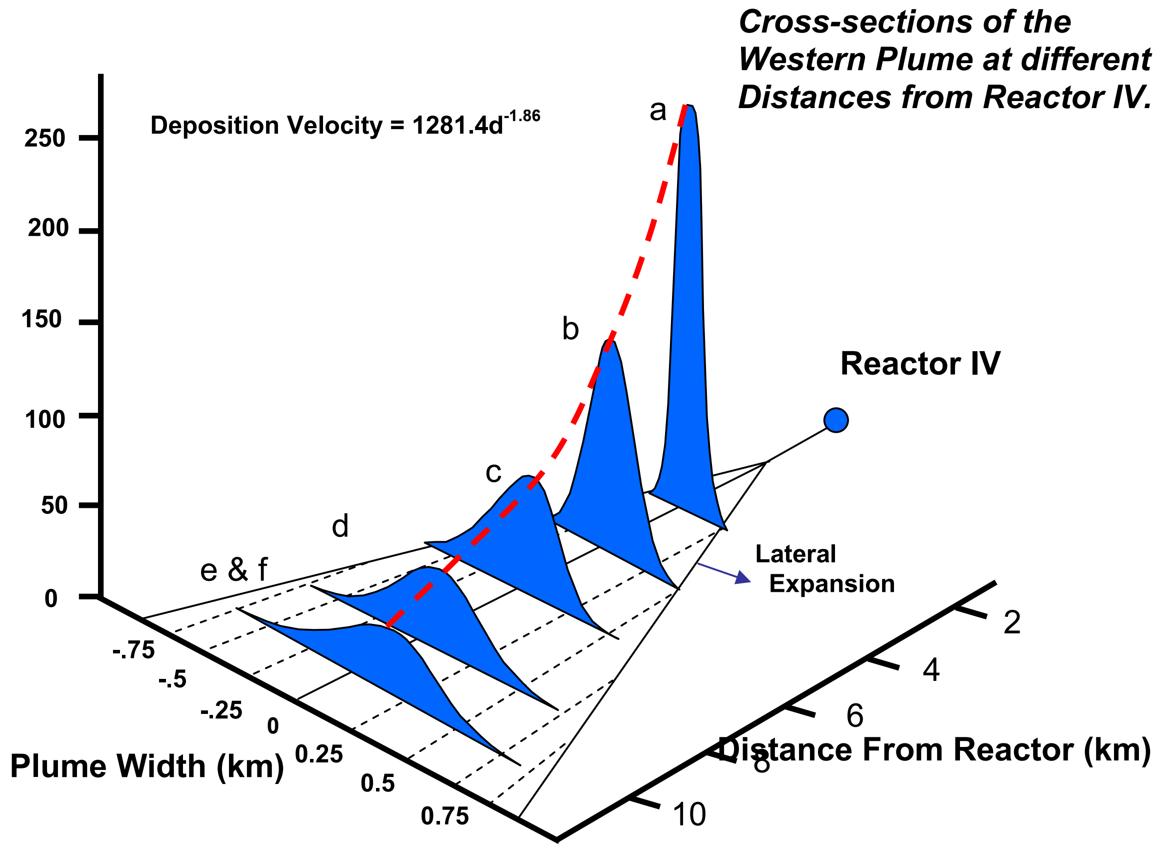

Figure 4. Graphical depiction of the Western Trace, the first plume released by the Chernobyl reactor explosion. The relatively rapid decline in radioactivity as one moves away from the reactor was a function of the particle sizes in the fallout plume. Larger, heavier particles were deposited near the reactor while smaller, lighter ones were carried larger distances from the explosion. Very small aerosols were carried high in the atmosphere and were dectected in Sweden on 27 April 1986.

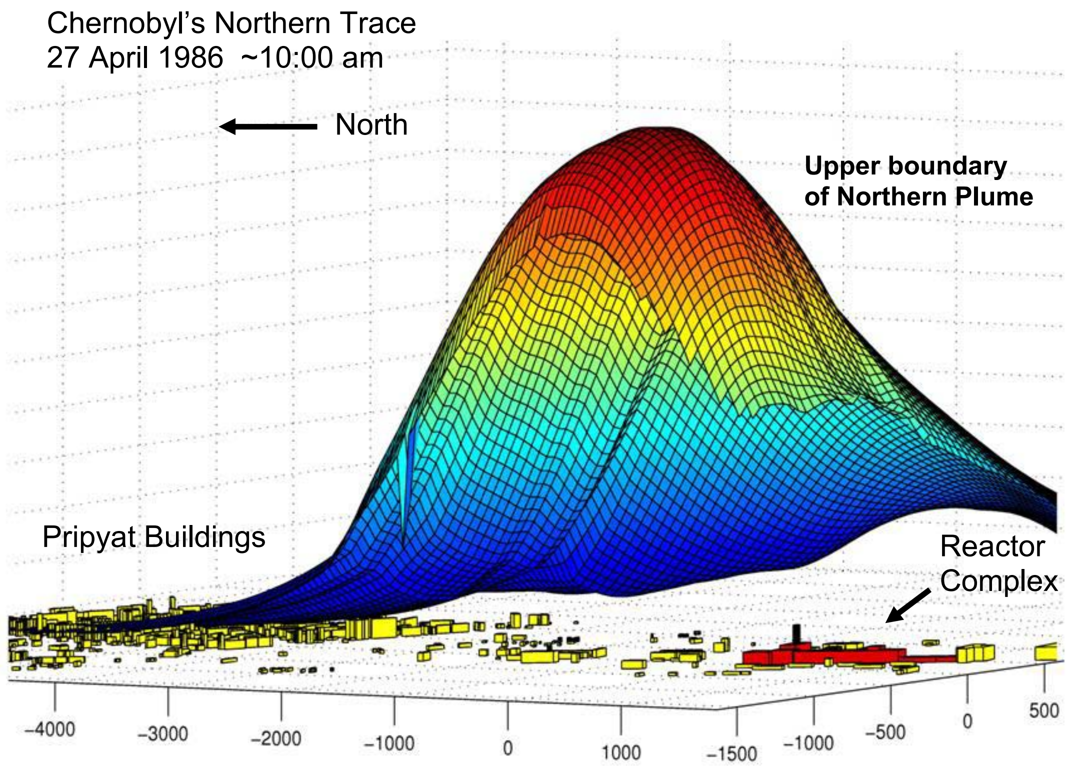

Figure 5. Graphical depiction of the second major plume released by the Chernobyl Nuclear Accident, the Northern Trace. As the graphic shows, only the tail of the plume traveled through the city of Pripyat, Ukraine. Our reconstruction of the directions, dimensions, and physical characteristics of Chernobyl's Northern Trace clearly shows that the citizens of Pripyat, Ukraine were spared massive radiation exposures by the fortunate nature of the winds on 27 April 1986. The city was evacuated several hours after this plume was deposited. This city is the only real-life example of the flow of radiation through an urban environment. It is recommended that empirical data be compared with theoretical predictions of fallout patterns to determine the accuracy of aerosol dispersion models. The plume model and digital reconstruction of the city were prepared by Ronald K. Chesser and Brenda E. Rodgers.