Research on the Aftermath of Chernobyl: Have Lessons Been Learned?

Jonathan M. Samet, MD, MS
Distinguished Professor and Flora L. Thornton Chair, Department of Preventive Medicine, Keck School of Medicine
Director, USC Institute for Global Health

Beebe Symposium
November 2, 2016
Washington, DC
GENERAL COMMENTS
Gilbert W. Beebe Symposium on 30 Years after the Chernobyl Accident

Current and Future Studies on Radiation Health Effects

The National Academies of Sciences • Engineering • Medicine
Definition of Health

“A state of complete physical, mental and social well-being and not merely the absence of disease or infirmity”

— World Health Organization

What are “radiation health effects”? 
Major Nuclear Disasters


Table 1: Past severe nuclear accidents (International Nuclear and Radiological Event Scale level 5 or higher)

<table>
<thead>
<tr>
<th>Location</th>
<th>Date</th>
<th>Type of accident</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kyivtst, Chelyabinsk Oblast, Russia (then USSR)</td>
<td>Sept 29, 1957</td>
<td>Chemical explosion of containment tank of liquid radioactive waste at military installation</td>
</tr>
<tr>
<td>Windscale Piles, UK</td>
<td>Oct 10, 1957</td>
<td>Fire of nuclear reactor at military installation designed to produce plutonium</td>
</tr>
<tr>
<td>Three Mile Island, PA, USA</td>
<td>March 28, 1979</td>
<td>Partial core melt at civilian nuclear reactor</td>
</tr>
<tr>
<td>Chernobyl, Ukraine (then USSR)</td>
<td>April 26, 1986</td>
<td>Core explosion and fire at civilian nuclear reactor</td>
</tr>
<tr>
<td>Fukushima, Japan</td>
<td>March 11, 2011</td>
<td>Core melt-through; three reactor cores damaged; three reactor buildings damaged by hydrogen explosions</td>
</tr>
</tbody>
</table>

Are findings transferrable? Externally valid?

<table>
<thead>
<tr>
<th>Dose estimates</th>
<th>Implications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average effective dose of residents: 170 mSv (preceding evacuation); 520 mSv (effective dose equivalent)</td>
<td>Restriction of information about accident by government</td>
</tr>
<tr>
<td>Maximum estimated thyroid doses of residents: the order of 10 mGy (adults); 100 mGy (children)</td>
<td>Poor preparedness before accident; milk distribution banned 10 km north of Windscale Works to 20 km to the south</td>
</tr>
<tr>
<td>Maximum effective dose: 40 mSv (emergency worker); effective dose of residents living within 80 km: 0.015 mSv (average); 0.85 mSv (maximum)</td>
<td>Scarcity of information about nuclear power plant condition and evacuation plan; no effective plan for hospital and nursing care facility evacuation</td>
</tr>
<tr>
<td>Workers with acute radiation syndrome: &lt;2-1 Gy (41 people); 2-2-4.1 Gy (50 people); 4-2-6-4 Gy (22 people); 6-5-16-6 Gy (21 people); average thyroid dose of residents: 349 mGy (adult evacuees); 1548 mGy (preschool children evacuees); 138 mGy (adults in contaminated areas); 449 mGy (preschool children in contaminated areas)</td>
<td>Restriction of information about accident by government; delay in implementation of public protection; long-term psychological issues</td>
</tr>
<tr>
<td>Maximum effective dose: 678 mSv (emergency worker); maximum thyroid dose: 12 Gy (emergency worker); maximum effective dose of residents: 25 mSv (external); maximum average thyroid dose of infants in the most affected district: 80 mSv</td>
<td>Severe health effects of evacuation and relocation of hospital inpatients and elderly people needing nursing care; psychosocial issues after accident; poor risk communication</td>
</tr>
</tbody>
</table>

USSR—Union of Soviet Socialist Republics.

How Can a Nuclear Disaster Harm People?

- **Acute consequences**
  - High-level exposure → Radiation Sickness
  - Psychological stress → Anxiety/Depression

- **Long-term consequences**
  - Radiation exposure → Cancer Risk
  - Psychological/Social Stress → Cardiovascular disease risk
  - PTSD
  - Depression/Anxiety
Nuclear disasters and health: lessons learned, challenges, and proposals

Ohtsuru, Akira et. al

Figure 2: Nuclear disaster cycle

Medical issues in a compound disaster. Boxes refer to measures specifically needed in a nuclear disaster, those not in boxes are measures common to any large-scale disasters.
PubMed Citation Analysis: ‘Disaster’

# of Publications (per year)

Publication Year

- 1945
- 1948
- 1951
- 1954
- 1957
- 1960
- 1963
- 1966
- 1969
- 1972
- 1975
- 1978
- 1981
- 1984
- 1987
- 1990
- 1993
- 1996
- 1999
- 2002
- 2005
- 2008
- 2011
- 2014

- 0
- 500
- 1000
- 1500
- 2000
- 2500
- 3000
- 3500
WHY DO STUDIES?
Why research?

• “Known knowns”
  – Refining risk estimates
• ”Known unknowns”
  – Hazard identification: new outcomes
  – Completing understanding of dose-response
• ”Unknown unknowns”
  – Overturning strong priors
  – Finding surprises

Apologies to Donald Rumsfeld
“Surveillance, when applied to a disease, means the continued watchfulness over the distribution and trends of incidence through the systematic collection, consolidation and evaluation of morbidity and mortality reports and other relevant data.”


1912 – 1993
## Research or Surveillance

<table>
<thead>
<tr>
<th><strong>Research</strong></th>
<th><strong>Surveillance</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Data gathering to advance knowledge</td>
<td>Data gathering to track events for decision-making</td>
</tr>
<tr>
<td>Implement to take advantage of opportunity to generate data</td>
<td>Can overlap with research</td>
</tr>
<tr>
<td>Results may/may not benefit those exposed</td>
<td>Sentinel events may be of interest</td>
</tr>
</tbody>
</table>
Why research after a nuclear disaster

- Address unanswered questions
  - Risks of specific radionuclides
  - Non-stochastic effects
  - Neuropsychological consequences
- Refine risk estimates for decision-making
- Communicate with stakeholder groups
- Build resources for future research
  - Biorepositories
Why surveillance after a nuclear disaster?

• Watch for surprises
• Identify problems needing intervention
• Evaluate the effectiveness of interventions
• Have data to communicate to all stakeholders
What have we learned over the 30 years (that is new)?

• Thyroid cancer in children story
• CLL in liquidators
• Cataract at lower doses than expected
• Lasting neuropsychological consequences
Guidelines for Exposure Assessment in Health Risk Studies Following a Nuclear Reactor Accident

André Bouville,1 Martha S. Linet,2 Maureen Hatch,2 Kiyohiko Mabuchi,2 and Steven L. Simon2

1National Cancer Institute (retired), National Institutes of Health (NIH), Department of Health and Human Services (DHHS), Rockville, Maryland, USA; 2Division of Cancer Epidemiology and Genetics, National Cancer Institute, NIH, DHHS, Rockville, Maryland, USA

BACKGROUND: Worldwide concerns regarding health effects after the Chernobyl and Fukushima nuclear power plant accidents indicate a clear need to identify short- and long-term health impacts that might result from accidents in the future. Fundamental to addressing this problem are reliable and accurate radiation dose estimates for the affected populations. The available guidance for activities following nuclear accidents is limited with regard to strategies for dose assessment in health risk studies.

OBJECTIVES: Here we propose a comprehensive systematic approach to estimating radiation doses for the evaluation of health risks resulting from a nuclear power plant accident, reflected in a set of seven guidelines.

DISCUSSION: Four major nuclear reactor accidents have occurred during the history of nuclear power production. The circumstances leading to these accidents were varied, as were the magnitude of the releases of radioactive materials, the pathways by which persons were exposed, the data collected afterward, and the lifestyle factors and dietary consumption that played an important role in the associated radiation exposure of the affected populations. Accidents involving nuclear reactors may occur in the future under a variety of conditions. The guidelines we recommend here are intended to facilitate obtaining reliable dose estimations for a range of different exposure conditions. We recognize that full implementation of the proposed approach may not always be feasible because of other priorities during the nuclear accident emergency and because of limited resources in manpower and equipment.

CONCLUSIONS: The proposed approach can serve as a basis to optimize the value of radiation dose reconstruction following a nuclear reactor accident.


Epidemiologic studies are usually undertaken several years after the accident to allow time for the health consequences to be expressed, are based on the analysis of observed adverse health effects, and seek to ascertain risks of these adverse effects in comparison with the background or baseline rates. Such investigations typically involve the collection of exposure and outcome data for the study participants and require individual dose estimation.

The basic difference in these two types of studies is that risk projections generate expected rates of disease whereas epidemiologic studies generate observed rates of disease. In this commentary, we discuss dose assessment and data collection guidelines to support both types of studies.

Four past reactor accidents have each resulted in irreparable damages to the power plant and in substantial radiation exposures involving ≥ 1,000 people as a consequence of the releases of radioactive materials into the environment. The first of those accidents took place in 1957 at Windscale in the United Kingdom and was caused by a fire in the reactor, which was mainly used for the
Table 1. Value of applying guidelines to the different types of health risk studies.

<table>
<thead>
<tr>
<th>Guideline</th>
<th>Strategy</th>
<th>Value to risk projection studies</th>
<th>Value to epidemiologic studies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Early phase</td>
<td>Late phase</td>
</tr>
<tr>
<td>1</td>
<td>Creation of a roster of exposed persons</td>
<td>Unnecessary</td>
<td>Unnecessary</td>
</tr>
<tr>
<td>2</td>
<td>Collection of individual-based radiation measurements</td>
<td>Useful</td>
<td>Useful</td>
</tr>
<tr>
<td>3</td>
<td>Collection of personal information on exposed persons</td>
<td>Unnecessary</td>
<td>Unnecessary</td>
</tr>
<tr>
<td>4</td>
<td>Collection of data on radiation field</td>
<td>Essential</td>
<td>Essential</td>
</tr>
<tr>
<td>5</td>
<td>Calculation of realistic unbiased doses</td>
<td>Useful</td>
<td>Essential</td>
</tr>
<tr>
<td>6</td>
<td>Validation of dose estimates</td>
<td>Unnecessary</td>
<td>Useful</td>
</tr>
<tr>
<td>7</td>
<td>Evaluation of uncertainties of dose estimates</td>
<td>Unnecessary</td>
<td>Highly useful</td>
</tr>
</tbody>
</table>

*Source: Bouville et al. Environmental Health Perspectives 2014*
Fig 2. The distribution of psychological distress in evacuation zone (A) and environmental radiation levels (μSv/h) in evacuation zone (B). The distribution of psychological distress showed pattern similar to the environmental radiation levels on a prefectural map of Fukushima (based on the levels reported in a local newspaper Fukushima Minpo dated January 20, 2012). Spearman’s rank correlation showed that the proportion of those in the evacuation zone who scored ≥13 on the K6 was significantly highly correlated with the environmental radiation levels ($r = 0.768, p = 0.002$). The 18% in (A) means the area where more than 18% of the participants scored ≥13 on the K6, and >8 μSv in (B) means the area where >8 μSv/h was recorded. Original maps were created by tracing copyright-free materials (http://kage-design.com/wp/?p=1061 and http://www.civilcom.co.jp/library/WhiteMapJapan/#07) and then drawing the content using Adobe Illustrator CS6 (Adobe Systems Inc., San Jose, CA).

Analytical Methods

• Propagation of uncertainty
• Addressing measurement error
  – Validation studies
  – Models for ME correction
• New approaches for dose-response modeling
Cancer Risks

• We have strong evidence on risks for some cancers (strong priors established--CLL for example).
• We can always refine risk estimates
• Surprises happen
• Some new questions will inevitably arise, but what populations for new research?
• When should studies be extended to “get the full picture”? 
Non-Cancer Risks

• ARS: can we do better with data capture and follow-up?

• CVD: a very important contributor to disease burden but MRIN

• In utero exposures: complex territory and of great potential importance; what next?

• Cataract: dose-response and risks at lower end of dose range
Neuropsychological Consequences

• The "orphan" of adverse effects
• Need to use community-based methods
• Need to approach with multi-level models that include individuals and communities
• Research needs to be tied to interventions and evaluation
INFLUENCE OF CHERNOBYL ON FUKUSHIMA?
Challenges

Chernobyl

• Initially:
  – True impact of the disaster
  – Clean-up activities: minimizing radiation exposure
  – Evacuation of people living in the 30km exclusion zone

• Three decades later:
  – Poor mental and physical health
  – Impact of resettlement
  – Economic burden
  – Containment of radiation (sarcophagus)

Fukushima

• Initially:
  – Accessing the plant
  – Controlling temperature
  – Dealing with multiple disasters at plant and offsite

• Five years later:
  – Management of contaminated water
  – Monitoring of seawater radioactivity
  – Some areas still not accessible due to radiation
  – Displaced populations
  – Medical screening
From Chernobyl to Fukushima

- Broad population survey implemented by Fukushima Medical University
- Thyroid cancer screening implemented for at-risk population
- Worker cohort study underway involving medical screening
- Dosimetry estimation
LOOKING TO THE FUTURE
New Opportunities

• 21\textsuperscript{st} century science
  – Biomarkers of dose
  – Biobanks
  – Genomics and other “omics”

• Pooling of data

• Multidisciplinary approaches supporting risk assessment
Integration of a radiation biomarker into modeling of thyroid carcinogenesis and post-Chernobyl risk assessment

Jan Christian Kaiser*, Reinhard Meckbach1, Markus Eidemüller, Martin Selmansberger2, Kristian Unger2, Viktor Shpak3, Maria Blettner4, Horst Zitzelsberger2 and Peter Jacob5

Institute of Radiation Protection, Helmholtz Zentrum München, 85764 Oberschleißheim, Germany, 1Boris-Blacher-Str.
14, 80939 München, Germany, 2Helmholtz Zentrum München, Research Unit Radiation Cytogenetics, 85764 Neuherberg, Germany, 3National Academy of Medical Sciences of the Ukraine, Institute of Endocrinology and Metabolism, 254114 Kyiv, Ukraine, 4Johannes Gutenberg Universität, Institut für Medizinische Biometrie Epidemiologie und Informatik, 55131 Mainz, Germany and 5RADRISK, 83727 Schliersee, Germany

*To whom correspondence should be addressed. Tel: +49 8931874028; Fax: +49 31873363 Email: christian.kaiser@helmholtz-muenchen.de
Logistics

• Tissue banks
• Data sharing
• Strategic agendas
• Funding
• Stakeholder engagement and communication
Research Projects - 2010 - 2019

Approved projects

EpiRadBio

Molecular specificities of radiation-induced thyroid tumors

EpiRadBio - Validation of radiation-associated gain of chromosome band 7q11

A Sequence-based Approach to Identify Genetic Determinants of Tumorigenesis in Radiation-Induced Pediatric Papillary Thyroid Carcinomas

EpiRadBio - integrative analysis of molecular data

Validation of the gene signature differentiating exposed from non-exposed PTCs, obtained in the Genrisk-T project (no.: 036495) with an independent QPCR method

A detailed study of the somatic genomics of radiation induced thyroid cancer

Assessing the impact of radiation exposure on the development of medullary thyroid carcinoma

Anaplastic lymphoma kinase (ALK) – rearrangements in radiation-induced papillary thyroid carcinomas: a study on post Chernobyl tissue samples

Comprehensive Genomic Characterization of Radiation-Related Thyroid Cancer in Ukraine

Project reference number: 001/2011

Principal Investigator: Dr K Unger, Helmholtz Centre, Munich, Germany

Email: unger@helmholtz-muenchen.de

Strategic Research Agenda
The Health Consequences of the Chernobyl Accident

ARCH is a European Commission FP7 Project to develop a strategic Research Agenda to address the health consequences of the Chernobyl accident.

The Chernobyl accident led to the most extensive and severe release of radioactive materials of any nuclear accident. It has been comprehensively studied. In some countries, detailed studies have been carried out; in others, little work has been done. The results have been mainly based on whole body exposures. However, the health consequences of low levels of radiation, particularly from internal contamination, are still of great public concern.

Questions relate to the choice of models and extrapolation of risks from external high doses to low levels of radiation. Chernobyl has an opportunity to answer these questions, and to develop a strategic research agenda to guide future research.
Planning Prospectively

• Are there templates for considering research/surveillance in any future accident situations?
• Dosimetry issues have been considered
• Is broader planning needed?
• Draw on experiences with other disaster situations?
• Stakeholder roles?
There will be a 40th Anniversary Symposium