The National Academies of
SCIENCES • ENGINEERING • MEDICINE

The Role of Companion Animals as Sentinels for Predicting Environmental Exposure Effects on Aging and Cancer Susceptibility in Humans A Hybrid Workshop

Heavy/Toxic Metal Exposures

Norman J. Kleiman, PhD

CHORNOBYL:

AN ENVIRONMENTAL, ECOLOGICAL AND RADIOLOGICAL DISASTER.

LESSONS FOR THE FUTURE?

COLUMBIA | MAILMAN SCHOOL OF PUBLIC HEALTH
ENVIRONMENTAL HEALTH SCIENCES

RADIATION


ATTACK
OF THE 50 FT.
WOMAN


SHRIEK SHOW PRESENTS
MUTANT MONSTERS
TRIPLE FEATURE
FROM THE DIRECTOR OF
KINGDOM OF THE SPIDERS!
The dark
THE ULTIMATE TERROR
HAS TAKEN FORM...
THE BEING
Creatures
From the Abyss


IF YOU HAVE HAD NO WARNING
IN AN A-BOMB ATTACK
WHEN YOU SEE A FLASH OF LIGHT
BRIGHTER THAN THE SUN —
Don't run: there isn't time.
Fall flat on your face.
GET DOWN FAST!
STAY DOWN FOR AT LEAST ONE MINUTE


FALLOUT SHELTER

1950's

25 April 2016

World Health Organization

1986-2016: CHERNOBYL at 30

An update

On 26 April 1986, an explosion and fires at the Chernobyl nuclear plant in Ukraine caused the largest uncontrolled radioactive release in the history of the civil nuclear industry. Large quantities of radioactive iodine and cesium were released into the air due to the explosion and fire at the accident site. Most of this radioactive material was deposited near the installation, but a substantial amount of these radionuclides was carried by wind currents over Belarus, the Russian Federation and Ukraine and, to some extent, over parts of Europe.

In 2006, WHO published a report "Heath Effects of the Chernobyl Accident and Special Health Care Programmes"[1] summarizing 20 years of research on the health consequences of the Chernobyl accident.

1. Updated assessments of health effects of the Chernobyl accident since 2006

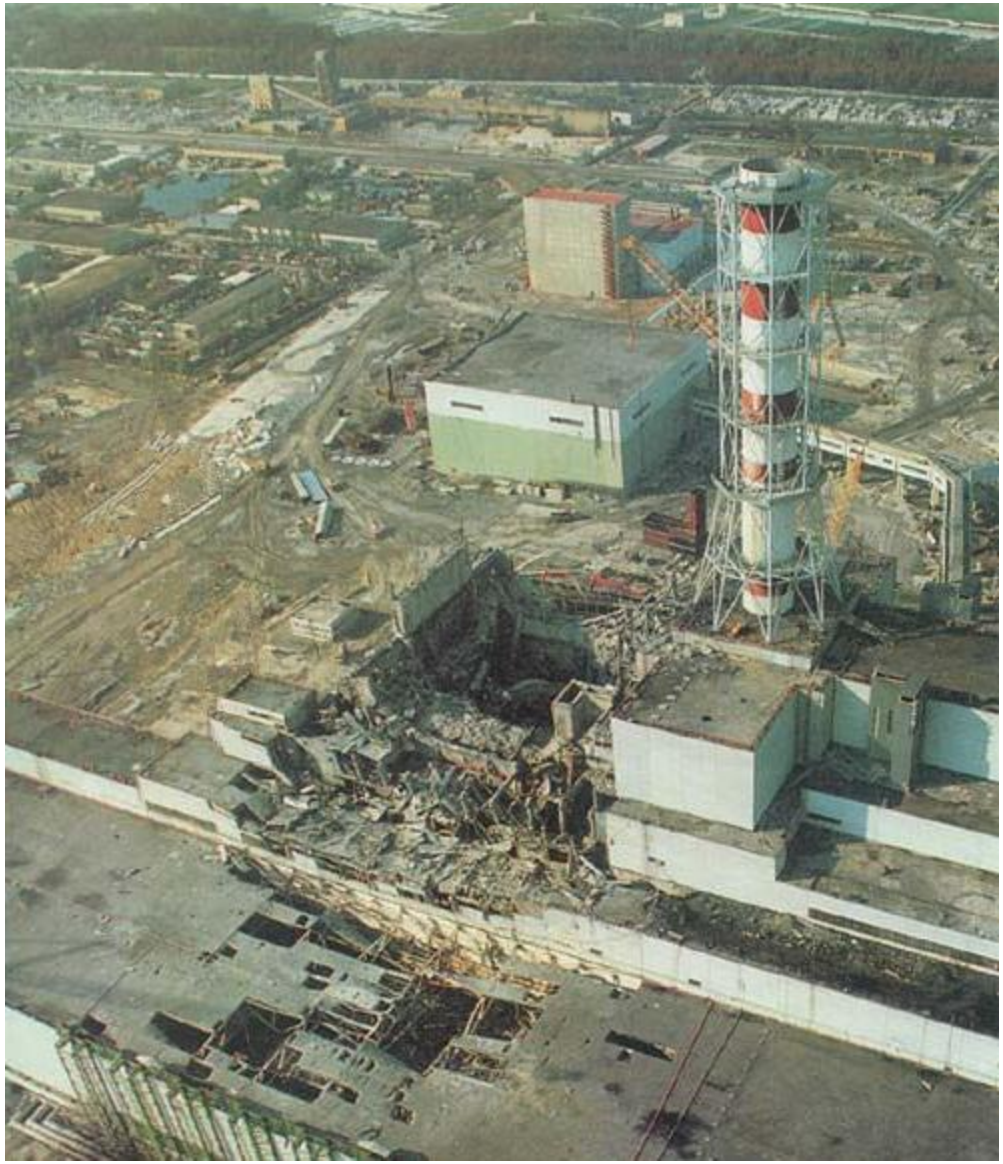
In 2011, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) published a report "Health effects due to radiation from the Chernobyl accident". The findings were based on more than two decades of experimental and analytical studies of the radiation consequences of the Chernobyl accident on the health of the exposed populations. The report is the most comprehensive evaluation to date of human exposure levels and health effects from the Chernobyl accident[2] .

Public Health Concerns

- Lingering radiation may pose continuing short and long-term health risks to workers, animals and the environment
  - Varying levels of radioactive contamination within the 30 km Exclusion Zone
  - Continuing clean-up efforts to limit chronic exposures
  - 30 yr half life of major contaminants (^{137}Cs, ^{90}Sr) $\rightarrow$ 200 year timeline for re-habitation
  - Increasing forest fire risks may pose additional concern for re-release of radioisotopes

- Health risks from a wide range of toxic contaminants in soil, water and air
  - >2,500 tons of lead may contaminate the area surrounding the damaged reactor
  - Other toxic and heavy metals from industrial activities scattered throughout environment
  - Extensive aerial pesticide spraying 1986-1992
  - Organic solvents, industrial wastes, military equipment abandoned and discarded throughout the zone
  - Little information about the full extent of toxic contamination

Chornobyl



- Extensive radioactive contamination of Northern Ukraine and Belarus.
- Cities, towns and villages evacuated to establish a 30 km "*Exclusion Zone*" surrounding the power plant complex

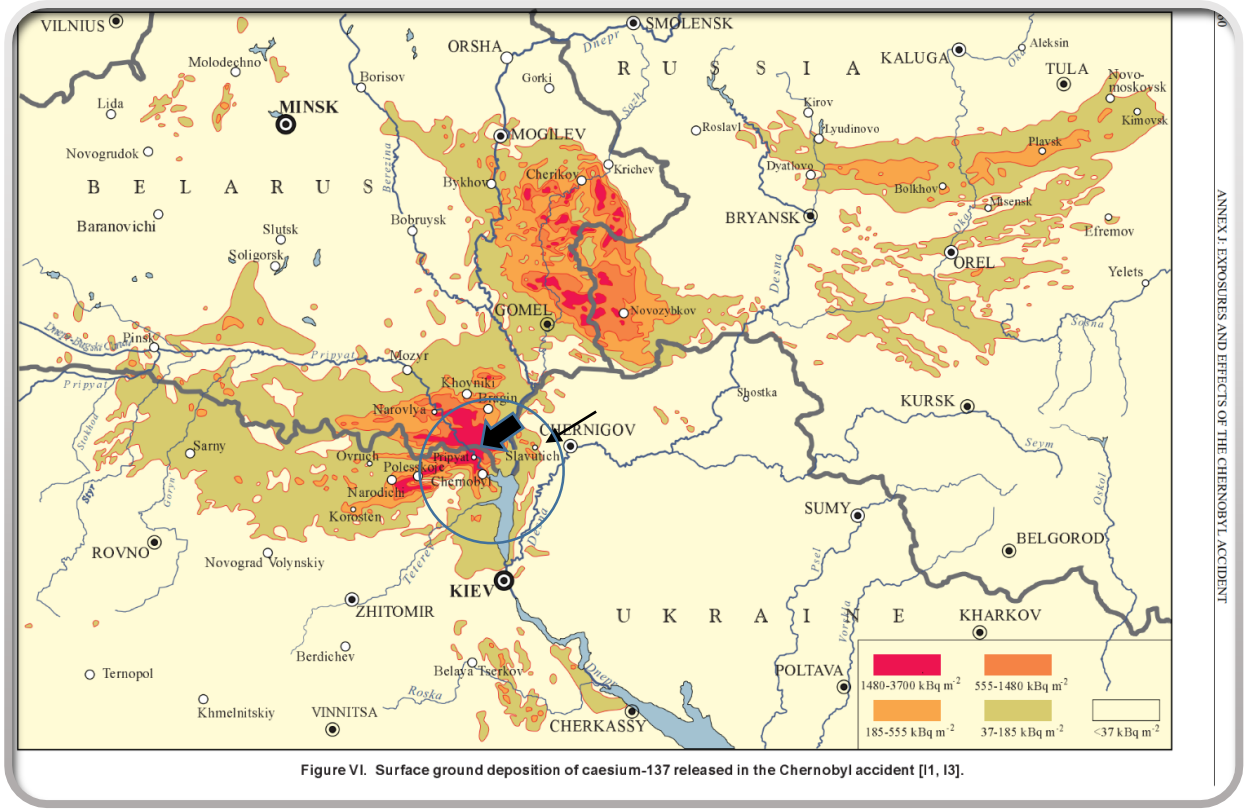


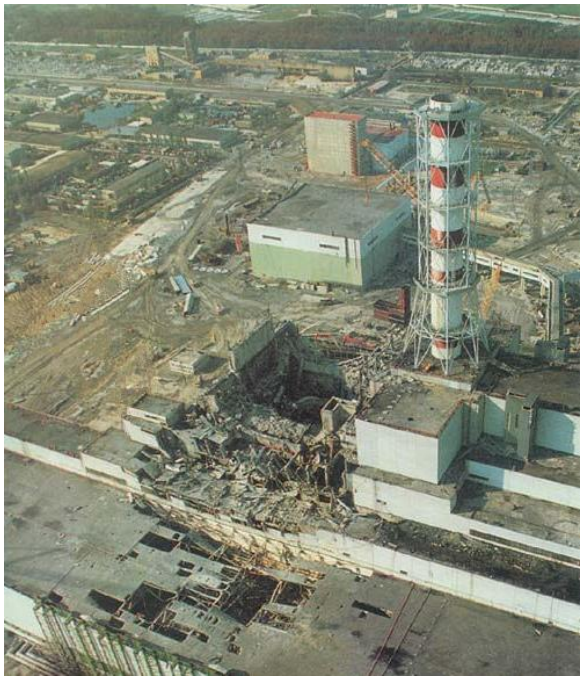
Figure VI. Surface ground deposition of caesium-137 released in the Chernobyl accident [I1, I3].

Helicopters Begin Dumping Boron, Sand, and Lead

- >5,000 tons of lead powder, boron and sand dropped by helicopter to cover the exposed reactor and limit further radiation release

Destroyed Unit 4 Reactor

- 1986-1989 – approx. 600,000 workers (*Liquidators*) employed in cleanup efforts



May, 1986


UPPA

Unit 4 Reactor with Sargophagus

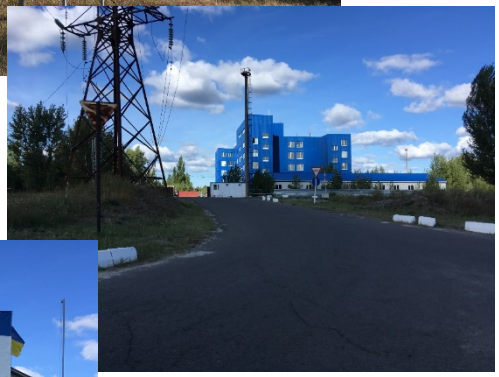
- Concrete and steel "*Sargophagus*" containment structure constructed to further shield workers and ongoing activities at the three other operating reactors.

Chernobyl Today

- 35 years later, thousands of workers travel to the Nuclear Power Plant (NPP) each day by special train from Slavutych, a city 40 km away
- Radiation levels in the immediate area surrounding the plant are no higher than that received by transatlantic air travelers
- Two new nuclear fuel storage facilities are being constructed nearby

Worker train approaching the NPP

Intermediate Storage Facility (ISF-1)



ISF2

ISF1

So, how did I end up in Chornobyl??

Catheterization and Cardiovascular Interventions 76:826–834 (2010)

Risk for Radiation-Induced Cataract for Staff in Interventional Cardiology: Is There Reason for Concern?

Olivera Ciraj-Bjelac,[1] PhD, Madan M. Rehani,[2*] PhD, Kui Hian Sim,[3] MBBS, FRACP, Houng Bang Liew,[3] MBBS, FRCP, Eliseo Vano,[4] PhD, and Norman J. Kleiman,[5] PhD

Objectives: To examine the prevalence of radiation-associated lens opacities among interventional cardiologists and nurses and correlate with occupational radiation exposure. **Background:** Interventional cardiology personnel are exposed to relatively high levels of X-rays and based on recent findings of radiation-associated lens opacities in other cohorts, they may be at risk for cataract without use of ocular radiation protection. **Methods:** Eyes of interventional cardiologists, nurses, and age- and sex-matched unexposed controls were screened by dilated slit lamp examination and posterior lens changes graded using a modified Merriam-Focht technique. Individual cumulative lens X-ray exposure was calculated from responses to a questionnaire and personal interview. **Results:** The prevalence of radiation-associated posterior lens opacities was 52% (29/56, 95% CI: 35–73) for interventional cardiologists, 45% (5/11, 95% CI: 15–100) for nurses, and 9% (2/22, 95% CI: 1–33) for controls. Relative risks of lens opacity was 5.7 (95% CI: 1.5–22) for interventional cardiologists and 5.0 (95% CI: 1.2–21) for nurses. Estimated cumulative ocular doses ranged from 0.01 to 43 Gy with mean and median values of 3.4 and 1.0 Gy, respectively. A strong dose–response relationship was found between occupational exposure and the prevalence of radiation-associated posterior lens changes. **Conclusions:** These findings demonstrate a dose dependent increased risk of posterior lens opacities for interventional cardiologists and nurses when radiation protection tools are not used. While study of a larger cohort is needed to confirm these findings, the results suggest ocular radio-protection should be utilized.

Key words: cardiac catheterization; fluoroscopy; occupational exposure; posterior subcapsular cataract (psc); lens opacity

RADIATION RESEARCH 174, 490–495 (2010)
0033-7587/10 $15.00

DOI: 10.1667/RR2207.1

Radiation Cataract Risk in Interventional Cardiology Personnel

Eliseo Vano,[a,1] Norman J. Kleiman,[b,1,2] Ariel Duran,[c,1] Madan M. Rehani,[d,1] Dario Echeverri[e] and Mariana Cabrera[f]

[a] Radiology Department, Complutense University, Madrid, Spain; [b] Department of Environmental Health Sciences, Mailman School of Public Health, Columbia University, New York, New York; [c] Invasive Cardiology, University Hospital, Montevideo, Uruguay; [d] International Atomic Energy Agency, Vienna, Austria; [e] Fundación Cardio Infantil, Bogota, Colombia; and [f] Fundación Oftalmologica Nacional, Bogota, Colombia

Vano, E., Kleiman, N. J., Duran, A., Rehani, M. M., Echeverri, D. and Cabrera, M. Radiation Cataract Risk in Interventional Cardiology Personnel. *Radiat. Res.* 174, 490–495 (2010).

The lens of the eye is one of the most radiosensitive tissues in the body, and exposure of the lens to ionizing radiation can cause cataract. Cumulative X-ray doses to the lenses of interventional cardiologists and associated staff can be high. The International Commission on Radiological Protection recently noted considerable uncertainty concerning radiation

of such changes increases progressively with dose until vision is impaired and cataract extraction surgery is required (*5, 6, 8*). The latency of such changes is inversely related to dose. During typical fluoroscopy working conditions, and if radiation protection tools are not routinely used, X-ray exposure to the eyes of interventional cardiologists, other physicians and/or paramedical personnel working in catheterization laboratories can be high (*9–14*). These individuals often remain close to patients and may therefore be within a high-scatter X-radiation field for several hours a day

entional procedures.

Commission on Radiological Pro-

Radiation-associated Lens Opacities in Catheterization Personnel: Results of a Survey and Direct Assessments

Eliseo Vano, PhD, Norman J. Kleiman, PhD, Ariel Duran, MD, Mariana Romano-Miller, MD, and Madan M. Rehani, PhD

ABSTRACT

Purpose: To estimate ocular radiation doses and prevalence of lens opacities in a group of interventional catheterization professionals and offer practical recommendations based on these findings to avoid future lens damage.

Materials and Methods: Subjects included 58 physicians and 69 nurses and technicians attending an interventional cardiology congress and appropriate unexposed age-matched controls. Lens dose estimates were derived from combining experimental measurements in catheterization laboratories with questionnaire responses regarding workload, types of procedures, and use of eye protection. Lens opacities were observed by dilated slit lamp examination using indirect illumination and retroillumination. The frequency and severity of posterior lens changes were compared between the exposed and unexposed groups. The severity of posterior lens changes was correlated with cumulative eye dose.

Results: Posterior subcapsular lens changes characteristic of ionizing radiation exposure were found in 50% of interventional cardiologists and 41% of nurses and technicians compared with findings of similar lens changes in < 10% of controls. Estimated cumulative eye doses ranged from 0.1–18.9 Sv. Most lens injuries result after several years of work without eye protection.

Conclusions: A high prevalence of lens changes likely induced by radiation exposure in the study population suggests an urgent need for improved radiation safety and training, use of eye protection during catheterization procedures, and improved occupational dosimetry.

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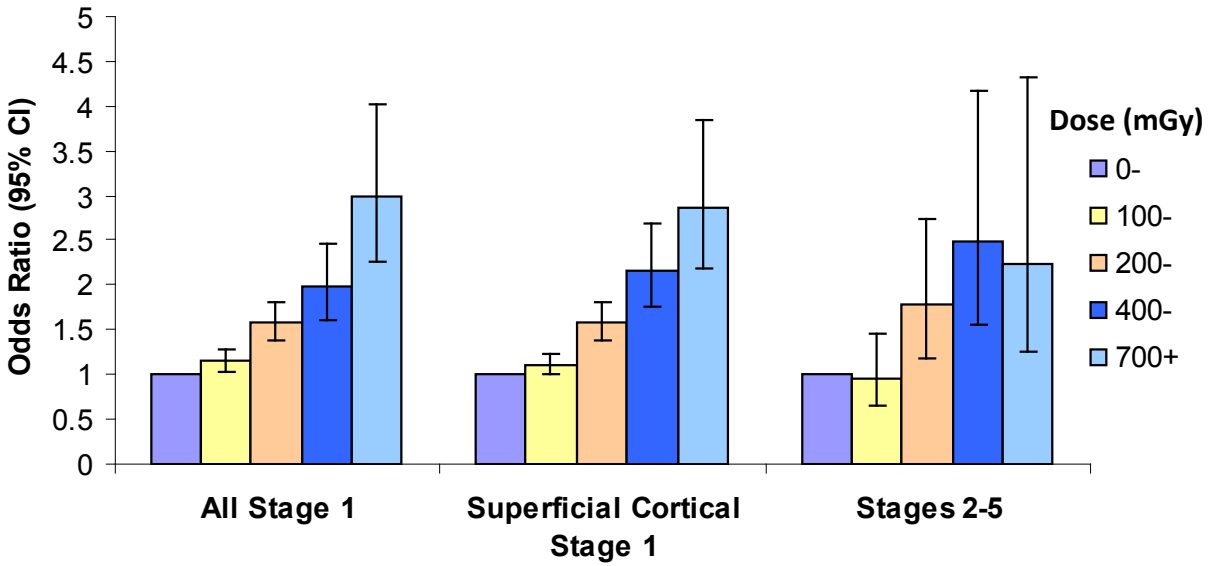
Cataracts According to Lens Radiation Dose in Chernobyl Cleanup Workers



Radiat Res 2007; 167:233-43

- 30% prevalence of pre-cataractous changes at first exam 12 years after the accident.
- Median exposure of 123 mGy
- Dose threshold estimates < 350 mGy, CI not exceeding 700 mGy
- Dose response relationships established for multiple endpoints; (e.g., stage 1 cataract; OR @ 1Gy = 1.42)

biology letters
Community ecology

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doi:10.1098/rsbl.2007.0226
Published online 14 August 2007

Species richness and abundance of forest birds in relation to radiation at Chernobyl

A. P. Møller[1,*] and T. A. Mousseau[2]

[1]*Laboratoire de Parasitologie Evolutive, CNRS UMR 7103, Université Pierre et Marie Curie, Bâtiment A, 7ème étage, 7 quai St Bernard, Case 237, 75252 Paris Cedex 05, France*
[2]*Department of Biological Sciences, University of South Carolina, Columbia, SC 29208, USA*
**Author for correspondence (amoller@snv.jussieu.fr).*

The effects of low-level radiation on the abundance of animals are poorly known, as are the effects on ecosystems and their functioning. Recent conclusions from the UN Chernobyl forum and reports in the popular media concerning the effects of radiation from Chernobyl on animals have left the impression that the Chernobyl exclusion zone is a thriving ecosystem, filled with an increasing number of rare species. Surprisingly, there are no standardized

biology letters
Evolutionary biology

Biol. Lett. (2007) 3, 414–417
doi:10.1098/rsbl.2007.0136
Published online 17 April 2007

Elevated frequency of abnormalities in barn swallows from Chernobyl

A. P. Møller[1,*], T. A. Mousseau[2], F. de Lope[3] and N. Saino[4]

UNIVERSITY OF South Carolina

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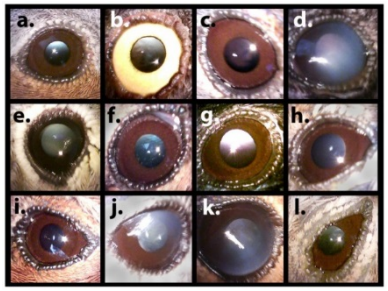
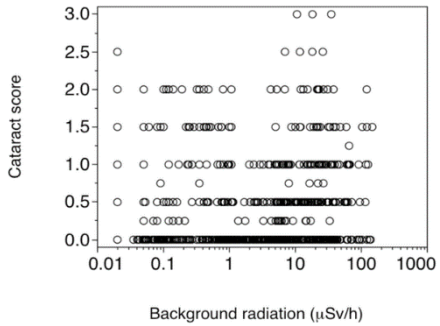
Elevated Frequency of Cataracts in Birds from Chernobyl





Mean cataracts in birds from Chernobyl in relation to background radiation level

Elevated Frequency of Cataracts in Birds from Chernobyl

Timothy Alexander Mousseau[1], Anders Pape Møller[2]*

1 Department of Biological Sciences, University of South Carolina, Columbia, South Carolina, United States of America, 2 Laboratoire d'Ecologie, Systématique et Evolution, CNRS UMR 8079, Université Paris-Sud, Orsay, France

Abstract

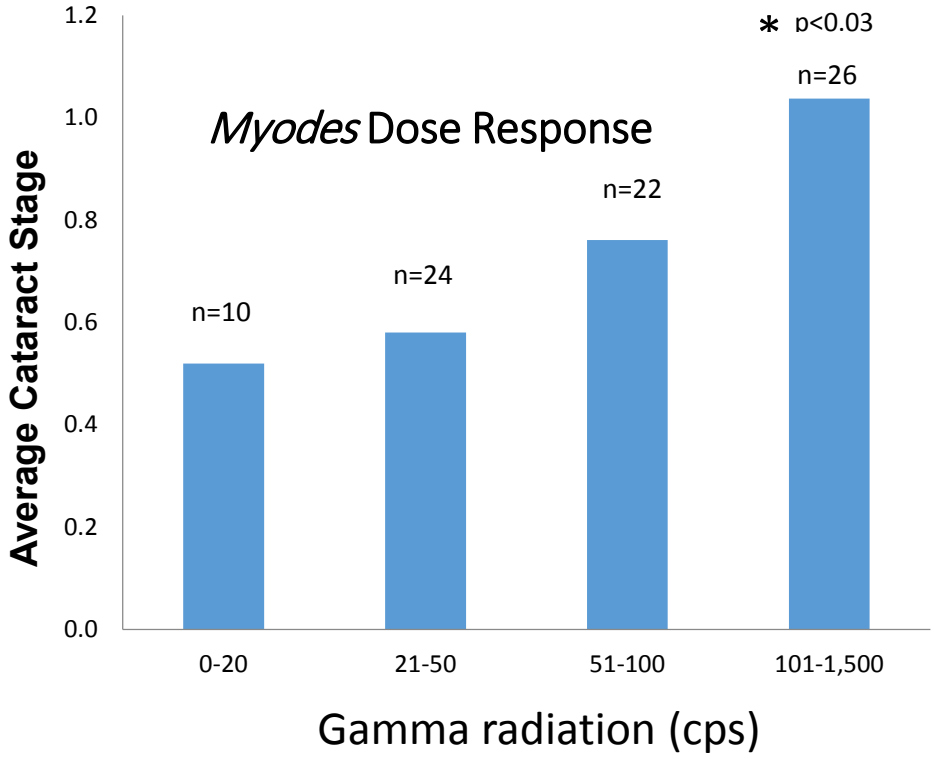
Background: Radiation cataracts develop as a consequence of the effects of ionizing radiation on the development of the lens of the eye with an opaque lens reducing or eliminating the ability to see. Therefore, we would expect cataracts to be associated with reduced fitness in free-living animals.

Methodology/Principal Findings: We investigated the incidence of lens opacities typical of cataracts in more than 1100 free-living birds in the Chernobyl region in relation to background radiation. The incidence of cataracts increased with level of background radiation both in analyses based on a dichotomous score and in analyses of continuous scores of intensity of cataracts. The odds ratio per unit change in the regressor was 0.722 (95% CI 0.648, 0.804), which was less than odds ratios from investigations of radiation cataracts in humans. The relatively small odds ratio may be due to increased mortality in birds with cataracts. We found a stronger negative relationship between bird abundance and background radiation when the frequency of cataracts was higher, but also a direct effect of radiation on abundance, suggesting that radiation indirectly affects abundance negatively through an increase in the frequency of cataracts in bird populations, but also through direct effects of radiation on other diseases, food abundance and interactions with other species. There was no increase in incidence of cataracts with increasing age, suggesting that yearlings and older individuals were similarly affected as is typical of radiation cataract.

Conclusions/Significance: These findings suggest that cataracts are an under-estimated cause of morbidity in free-living birds and, by inference, other vertebrates in areas contaminated with radioactive materials.

PLoS ONE 8(7): e66939; 2013

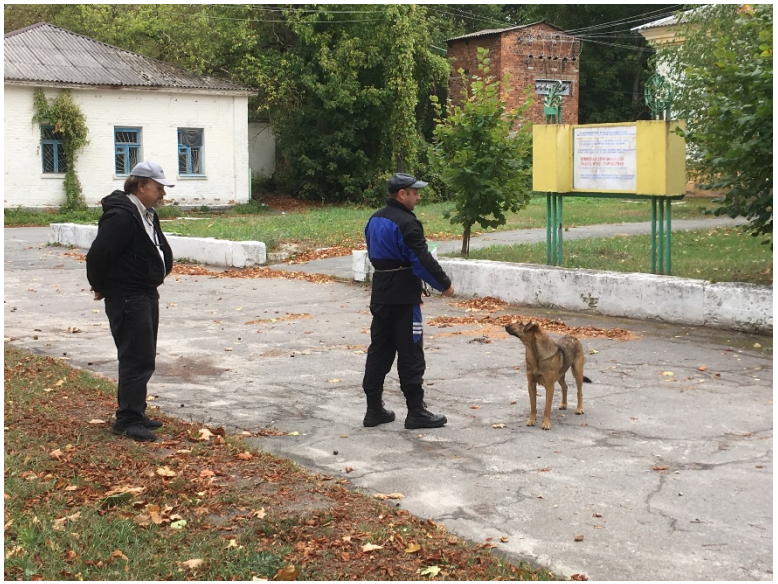
Average Merriam-Focht Radiation Cataract Stage in Chernobyl Voles



Dogs of Chornobyl

Background

- From 1986-1988, small teams of "*Liquidators*" were tasked with eliminating all agricultural animals and pets from towns and villages in the Exclusion Zone to limit the spread of radiation.
- Some managed to evade the hunters.
- 35 years later, descendants of the canine survivors have repopulated both Chernobyl City and the Nuclear Power Plant site, areas where thousands of humans continue to work today.



Dog veterinary care and biospecimen collection

Comprehensive Health Exams

- Spay/Neuter
- Vaccination
- Deworming
- Paracides
- Ocular exam
- Ear tag and biodosimeter

Biosamples

- Blood
  - PAXgene (RNA expression)
  - EDTA (DNA sequencing)
  - NaCitrate (Pedigree analysis)
  - Heparin (cytogenetics)
- Saliva
- Feces
- Ticks
- Hair

Spay/Neuter/Vaccinate Campaign

2018: Initial goal: Duplicate mouse/vole radiation cataract study in feral dog populations living within the Exclusion Zone

- Utilize ongoing capture spay/neuter/vaccinate program to examine the eyes of several hundred dogs at the Power Plant, Chornobyl City and outside the Exclusion Zone
- Use whole body gamma counting to estimate radiation body burden of dogs from various regions
- Perform dilated slit lamp examinations and intraocular pressure measurements on dogs during the course of routine veterinary care
- Analyze findings to determine if, as in rodents, a dose-response relationship exists between radiation exposure and lens opacity

Fail!! There were no radioactive dogs!

So now what to do? Is there something else we might learn from studying these animals?

Working Hypothesis:

Biomarkers from dogs may be useful surrogate indicators of human risk for environmental exposures. Feral dog populations, as well as other animals, insects and plants living in the area surrounding the Chernobyl nuclear power plant (CNPP) complex, are exposed to radiation, toxic/heavy metals, pesticides, organic compounds, and other contaminants arising from the disaster and its ongoing cleanup. They may be infected by endoparasites or carry tick borne-diseases that affect humans. In fact, they live in close proximity to several thousand human workers employed at the CNPP working on continued containment, remediation and decontamination as well as construction of two new nuclear fuel reprocessing facilities.

Environmental Contamination

Multiple industrial waste sites and abandoned buildings suggest that toxic and/or heavy metals might be of more long-term health concern than radiation exposure.

Primary Hypothesis

Elevated toxic and/or heavy metal concentrations in the environment surrounding the nuclear power plant complex, abandoned military bases and the surrounding region may pose health hazards to workers and local animal populations.

Secondary Hypotheses

- As feral dog populations living in the Exclusion Zone are exposed to toxic and/or heavy metals in air, soil, food and water, hair metal analysis may provide information about external environmental contamination as well as potential body burdens via ingestion and/or inhalation.
- Furthermore, dogs may inform us about potential human exposure since dogs live in close proximity to thousands of human workers at the power plant, Pripyat and in Chernobyl City

Methods

- Dogs were captured from multiple areas within the Exclusion Zone for spay/neuter, vaccination and medical care by trained veterinarian teams.
- Hair samples were obtained during routine surgical and/or medical care.

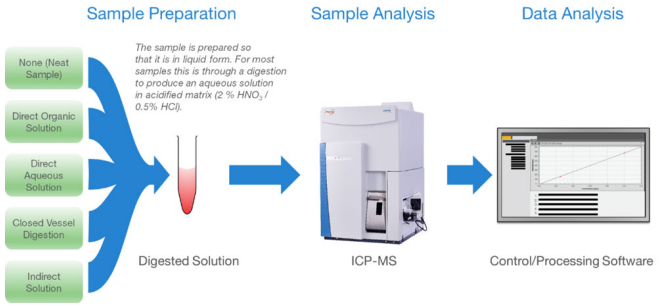
Collection

- Dr. Kleiman, students and volunteers collected hair samples from feral dog populations at the CNPP, the abandoned city of Pripyat, and the town of Chernobyl, located 10 km away within the exclusion zone.
- Hair samples were also collected from stray dogs in Slavutych and from pet owners in Ukraine and in NYC.

Slavutych

Slavutych strays

Inductively Coupled Plasma-Mass Spectroscopy (ICP-MS)



Metals Analyzed by MS-ICP

- Aluminum
- Antimony
- Barium
- Beryllium
- Calcium
- Cesium
- Chromium
- Cobalt
- Copper
- Iron
- Lead
- Lithium
- Magnesium
- Mercury
- Molybdenum
- Nickel
- Platinum
- Selenium
- Strontium
- Thallium
- Thorium
- Tin
- Tungsten
- Uranium
- Vanadium
- Zinc

Heavy Metal Analysis

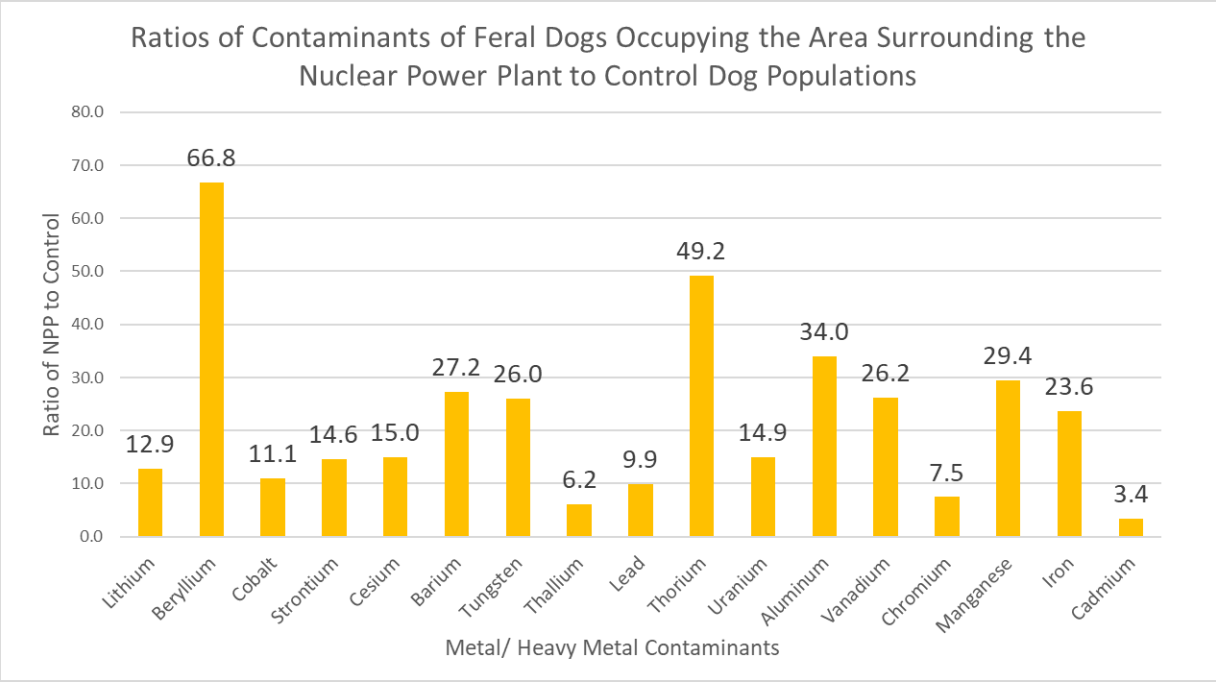
Unwashed Hair Metal Concentrations

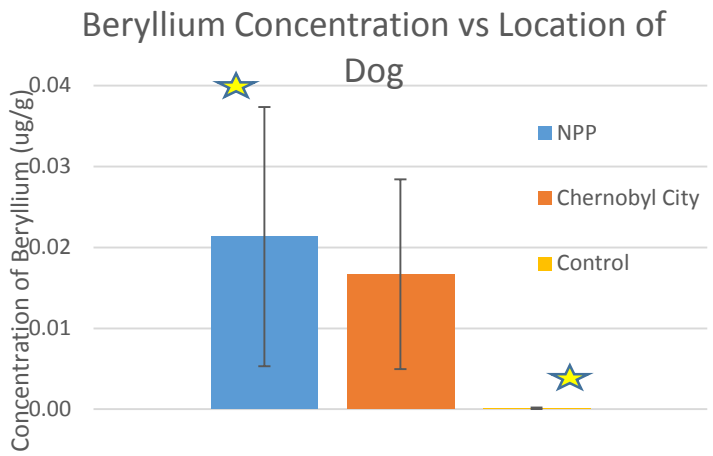
Heavy Metal	Li	Be	Co	Ni	Zn	Cu	Sr	Mo	Sn	Sb	Cs	Ba	W
Ratio NPP/CC	1.108	1.279	1.23	1.285	1.055	1.13	1.031	1.279	0.889	1.202	1.169	1.135	3.299
P-test Average NPP, CC	0.81	0.13	0.11	0.06	0.58	0.02	0.84	0.05	0.64	0.33	0.37	0.36	0.01
Ratio NPP/Control	21.315	99.963	12.631	1.068	0.941	1.054	15.763	2.333	2.002	1.654	11.789	41.143	68.119
P-test Average NPP, Cont	1.31E-10	3.41E-18	3.40E-14	9.15E-01	8.29E-01	6.06E-01	1.80E-22	2.78E-04	2.27E-02	1.22E-01	4.75E-17	4.26E-21	6.71E-05
Ratio CC/Control	19.233	78.182	10.272	0.831	0.893	0.933	15.293	1.824	2.251	1.376	10.087	36.245	20.646
P-test Average CC, Cont	0.03	0.00	0.00	0.79	0.70	0.54	0.00	0.01	0.04	0.37	0.00	0.00	0.04

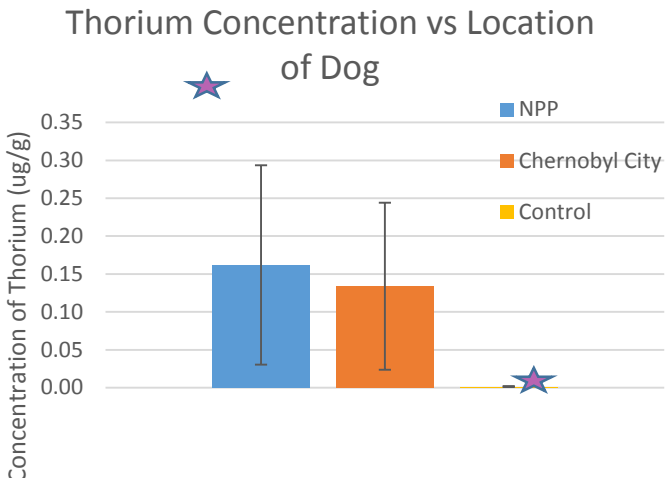
Heavy Metal	Pt	Hg	Tl	Pb	Th	U	Al	V	Cr	Mn	Fe	Se	As	Cd
Ratio NPP/CC	1.461	0.546	0.955	1.115	1.211	1.117	1.133	1.112	1.417	0.733	1.071	0.96	1.012	1.088
P-test Average NPP, CC	0.05	0.02	0.79	0.65	0.30	0.57	0.40	0.50	0.09	0.03	690.46	0.39	0.93	0.69
Ratio NPP/Control	1.42	1.735	5.621	8.036	129.166	28.433	49.631	47.648	9.098	35.52	20.007	0.935	2.167	4.18
P-test Average NPP, Control	5.36E-01	4.25E-01	2.02E-05	1.54E-06	1.20E-16	3.82E-16	3.36E-23	2.08E-21	2.68E-09	7.69E-23	4.26E-18	6.37E-01	7.75E-02	1.54E-05
Ratio CC/Control	0.972	3.179	5.884	7.207	106.659	25.455	43.788	42.846	6.422	48.433	18.677	0.974	2.143	3.841
P-test Average CC, Control	0.97	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.85	0.08	0.00

19 of 26 heavy metals have a p-value less than 0.05 and an exposed/control ratio greater than 4

Unwashed Hair



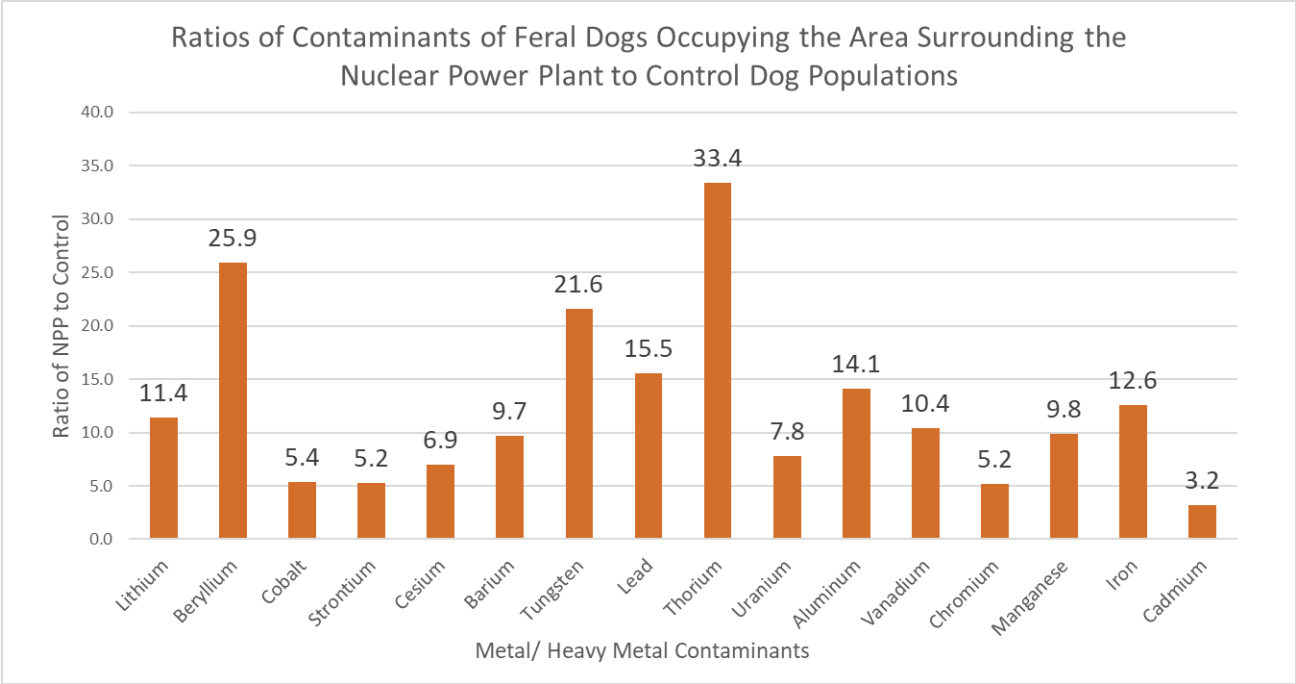




p-value between NPP and control is $3.41 * 10^{-18}$

p-value between NPP and control is $1.20 * 10^{-16}$

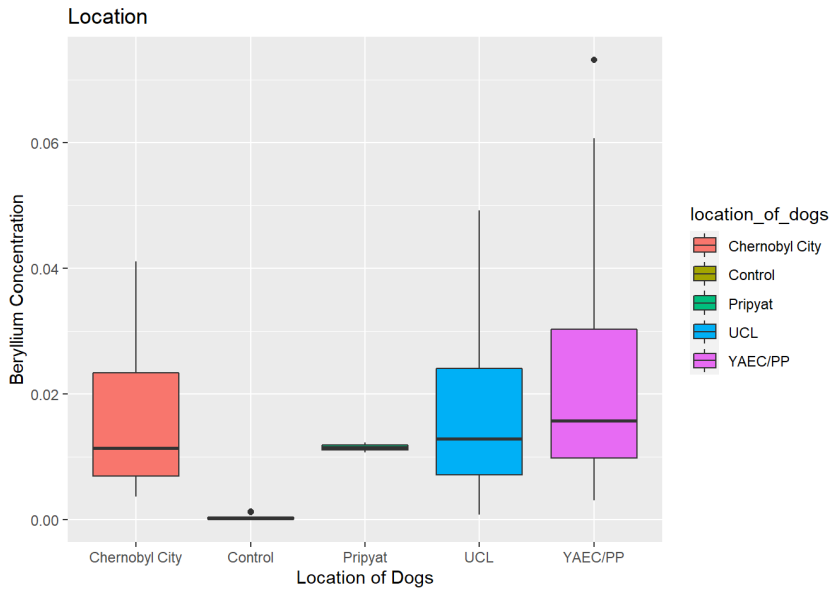
Washed Hair



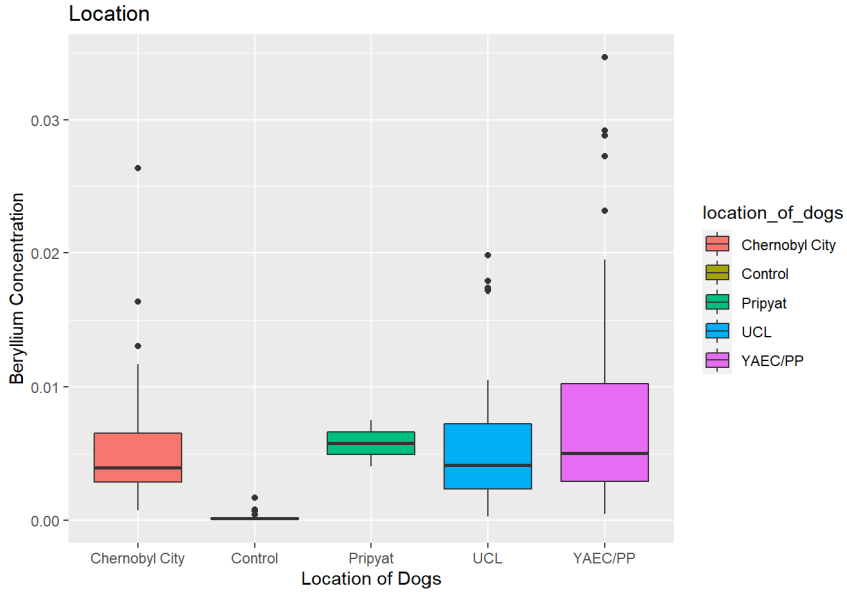
15 of 26 heavy/toxic metals have a p-value less than 0.05 and an exposed/control ratio greater than 3

Beryllium Concentration

Unwashed



Washed



Conclusions

Our data from unwashed and washed hair indicates…..

- There is a large, statistically significant difference in concentrations of a number of different heavy/toxic metals in dog hair samples from within the exclusion zone as compared to unexposed control populations.
- Washed hair samples still show significantly higher ratios for certain metals which suggests that routes of exposure are a combination of ingestion/inhalation and external contamination.
- These findings supports our initial hypothesis that high heavy/toxic metal concentrations in the environment around the CNPP pose significant health hazards to workers in the area and to the surrounding animal populations

- Findings from these studies may inform future directions for research efforts to examine the environmental and ecological factors that influence health risks to the many thousands of individuals working (and now visiting) the Exclusion Zone and, perhaps be more broadly applicable to other sites of radiological, toxic waste and chemical contamination.
- Positive findings from dog biomarker pilot studies will strengthen the concept of using dog samples as surrogate indicators for human risk for environmental exposures.
- More work is need to directly relate canine exposure assessments to biospecimens from CNPP workers, as well as other animal vectors, the surrounding environment and additional unexposed matched controls.
- If successful, we hope this effort will involve multiple collaborations among investigators with diverse expertise and interests in utilizing companion animals as sentinels for human exposure studies and adverse health effects.

TRAVEL ▶ AIR TRAVEL

Chernobyl Tourism Surges in Wake of HBO's Hit Series

Visits to the site of the world's worst nuclear disaster have never been so popular. But is that a good thing?

TIM JOHNSON • JULY 25, 2019

Pripyat's Palace of Culture has been overrun by vegetation in the years since residents were first evacuated. (Photo: Tim Johnson)

Acknowledgements

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CFF+ CLEAN FUTURES FUND

SPCA INTERNATIONAL | GLOBAL ANIMAL RESCUE

UNIVERSITY OF South Carolina

COLUMBIA | MAILMAN SCHOOL OF PUBLIC HEALTH
ENVIRONMENTAL HEALTH SCIENCES

Visiting Veterinarians International
Veterinary Care Across the Globe

Chris Lee

Sarah McLarnan

Charlene Redhead

Lauren Byrne
Andreii Simon
Artem July
Megan Dillon

Maksim Ivanenko

BREEN LAB @ NCSU

Jordan, Kayla and Jane

Gaby

The entire CleanFuturesFund and SPCAi team

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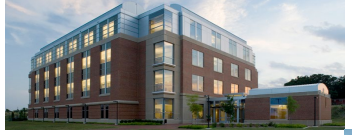
ENVIRONMENTAL HEALTH SCIENCES



NC STATE
Veterinary Medicine

Identification of inherited and somatic changes in the Chernobyl dog population

- molecular cytogenetics
  - chromosome reorganization
- SNP analysis
  - population structure
- gene expression
  - altered transcriptional activity
- whole genome and exome sequencing
  - exposure induced DNA mutations