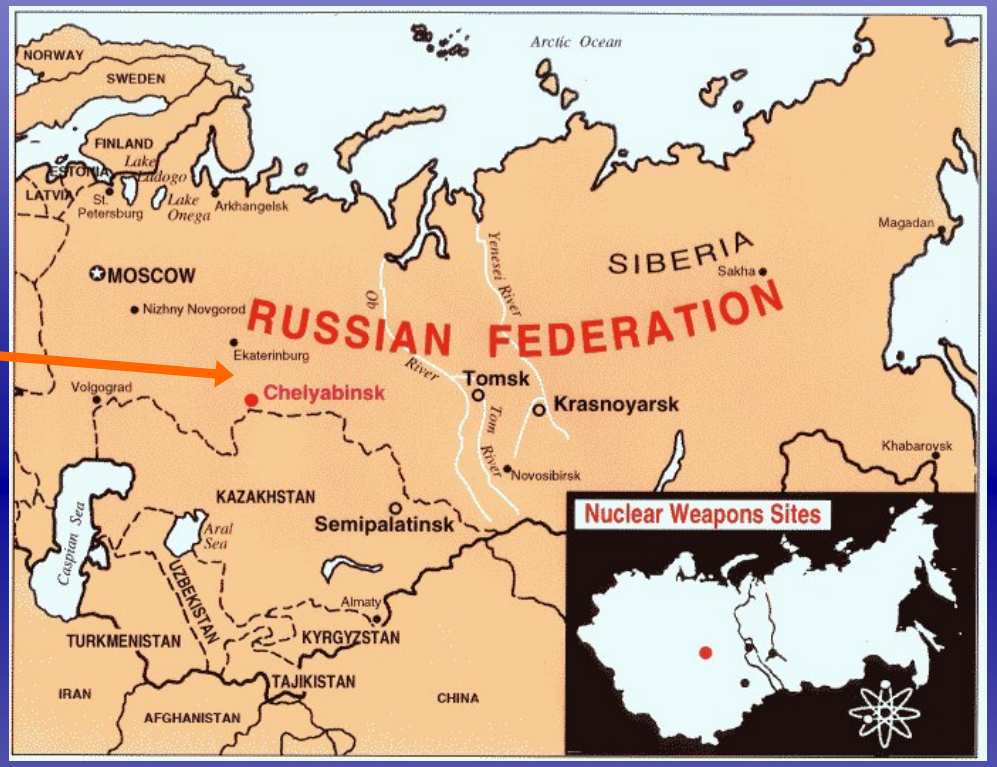
Cancer mortality among Workers at the Mayak Nuclear Complex

Natalia S. Shilnikova
Epidemiology Laboratory Southern Urals Biophysics Institute
Dale L. Preston
Hirosoft International

Outline

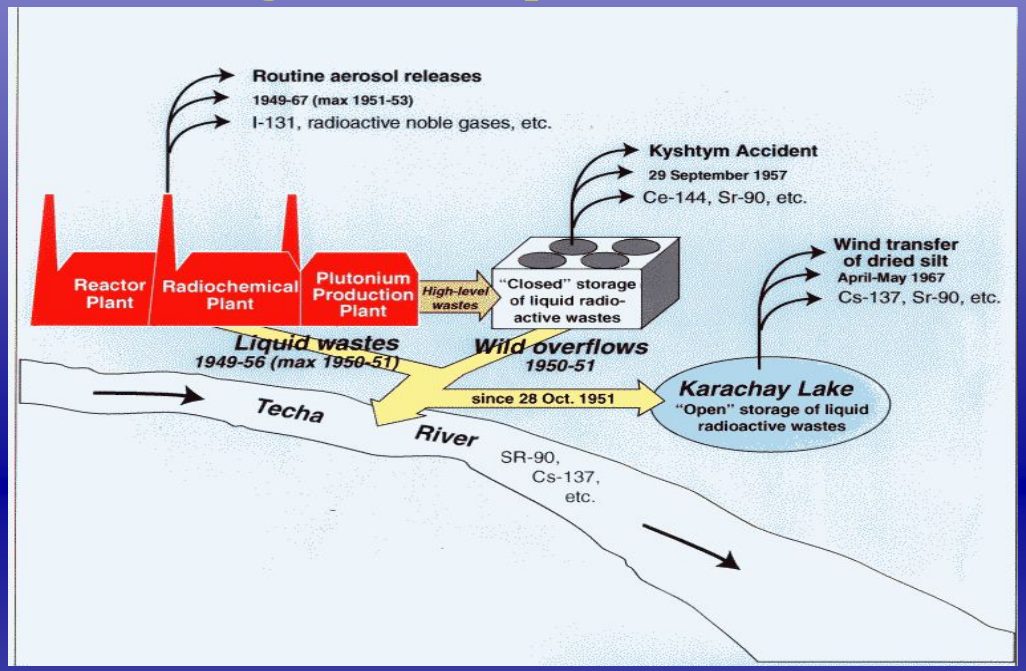
- Mayak P.A. background
- Mayak worker cohort (MWC)
- Statistical methods and risk models for cancer mortality analyses
- Summary of current findings

Mayak Production Association



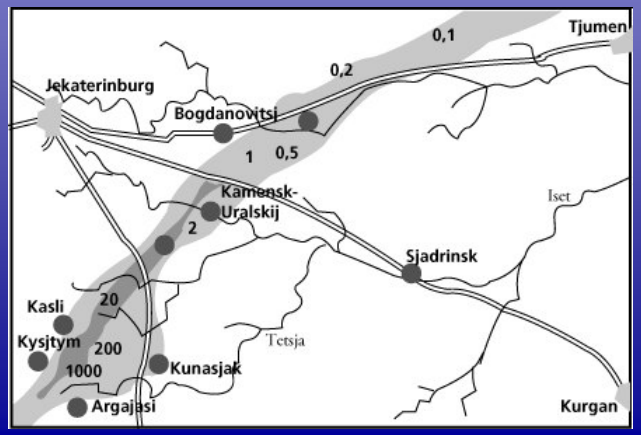
- First USSR plutonium production facility established in 1948
- In the southern Urals near the closed city of Ozyorsk (Chelyabinsk-65)

Mayak Operations



- **Three main plants with high potential for occupational exposures**
  - **Reactor complex; Radiochemical production plant; Plutonium production plant**
- **Numerous auxiliary plants**

Radiation Exposures Associated with Mayak Operations



- Occupational exposures
- Gaseous aerosol releases
  - I-131 and other isotopes
  - Primarily in the 1950's
  - Affecting residents of Ozyorsk and nearby areas
- Accidental releases
  - Releases into Techa river 1949- 56
  - Kyshtym accident 1957
  - Resuspension of contaminated soil 1967

Mayak Worker Cohort

- Cohort includes
  - All main plant workers
  - All workers from water treatment and mechanical repair plants
  - Hired between 1948 and 1982
- Follow-up
  - Vital status ascertainment based on address bureau queries
  - Cause of death base on death certificates and autopsy findings

Occupational Exposures

- Gamma radiation
  - Main plant workers and some auxiliary plant workers
  - Film badge-monitoring for all workers with potential exposure
- Plutonium aerosols
  - Radiochemical and plutonium production plant workers
  - In-vivo body burden measurement since 1970's

Basic Characteristics

	Plant				All Plants
	Auxiliary	Reactor	Radio-chemical	Plutonium production	
Workers	3,560	5,412	9,185	7,782	25,939
%Female	18%	22%	26%	27%	24%
Average age	23	24	23	24	24
Mean gamma dose (Gy)	0.13	0.55	1.05	0.39	0.69
Pu Monitoring	6%	4%	39%	40%	27%
Mean body burden (kBq)	0.6	0.21	0.96	2.57	1.63

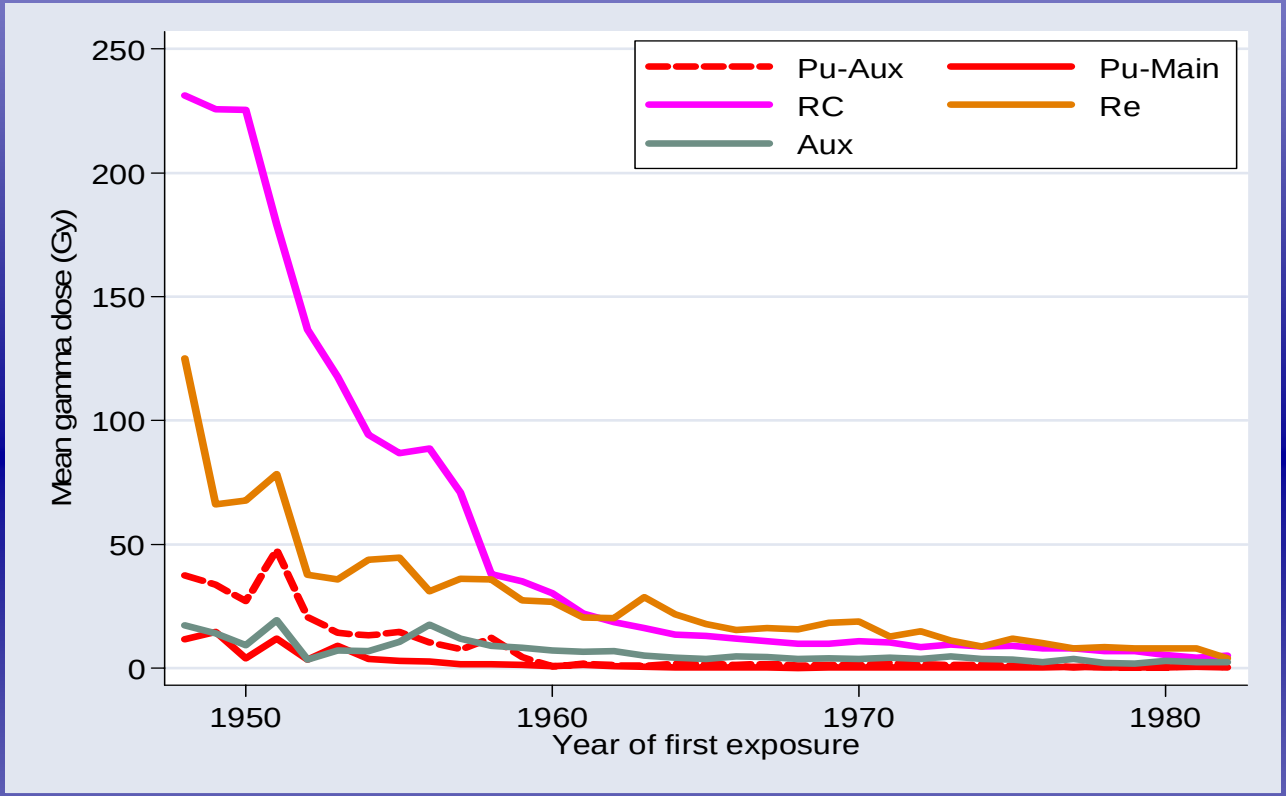
- Highest proportion of exposed women of any occupational radiation cohort
- Highest mean external doses Pu burdens and most exposed workers

Mortality Follow-up 1948-2000

Vital Status	Plant				Total	
	Auxiliary	Reactor	Radio-chemical	Plutonium production		
Alive	2,294	2,985	5,111	4,558	14,948	58%
Dead	1,001	1,960	3,206	2,662	8,829	34%
Solid cancer	*190*	*461*	*742*	*693*	*2,086*	*24%*
% Lung, liver, skeletal cancer	*34%*	*33%*	*34%*	*43%*	*37%*	
Leukemia	5	18	39	27	89	
Lost to follow-up	265	467	868	562	2,162	8%

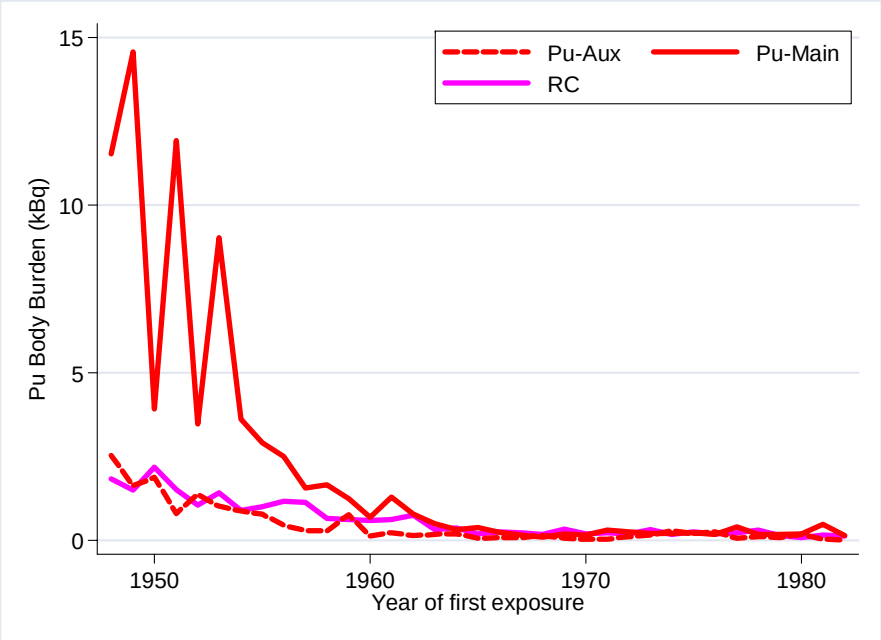
- 8% lost to follow-up
- Cause unknown for 3% of the deaths

External Gamma Dose by Plant

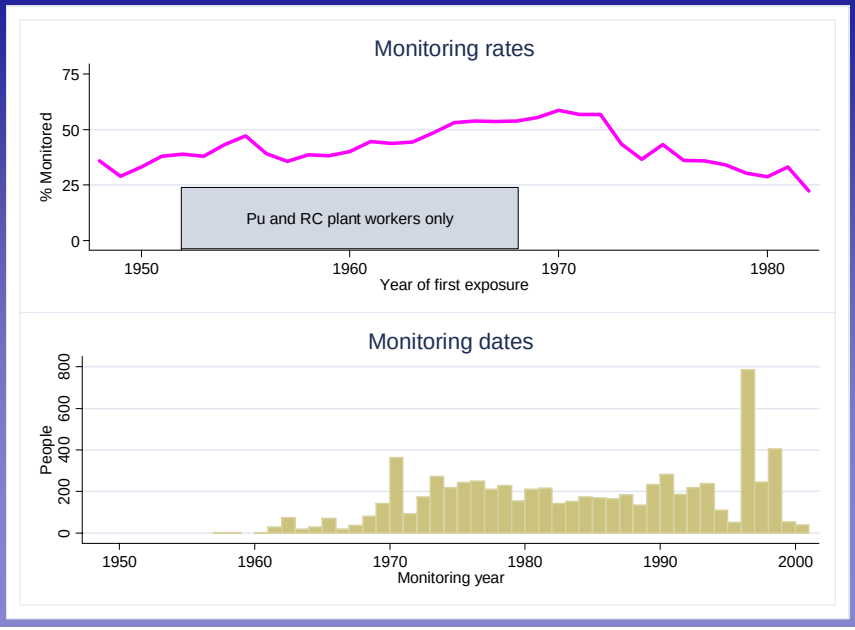


- **Extremely high doses in radiochemical plant and reactor complex throughout first decade of operation**
- **Mean doses remained above current occupational limits until 1970's**

Plutonium Exposures



- 60% of RC and Pu workers unmonitored
- Monitoring only from 1970
- Sampling more likely for
  - High potential workers
  - People with cancer or lung disease



Plutonium Surrogate

- Developed due to limitations of measurement data
  - Used to adjust gamma risk estimates for Pu exposure
- Six levels based on time period and occupation
- Mean for unmonitored workers likely to be less than that for monitored workers

Category	Period	Plants	People	Monitored	Mean Burden (kBq)
5	1948-49	Pu-main	663	33%	17.8
4	1950-53	PuMain	250	37%	14.3
3	1954-58 1948-49	Pu-Main Pu-Aux	1,702	31%	2.7
2	1959-63 1950-58	Pu-Main Pu-Aux	5,238	37%	1.6
1	1964+ 1959+ 1948+	Pu-main Pu-Aux RC	9,262	43%	0.4
0	any	RE or Aux	8,824	4%	0.4
Total			25,939	27%	1.6

Analysis Methods and Data Organization

- Cancer risks (hazard functions) estimated using Poisson regression models
- Data organized as table of cases and person years (rate table) stratified on

Time-independent factors				
Gender	Plant	Year of hire	Age at hire	Pu-surrogate
Time-dependent factors				
Pu-body-burden	Calendar time	Lagged cumulative gamma dose	Attained age	

  - Rate table has about 100,000 cells with non-zero person-years

Excess Relative Risk Model

$$\lambda_0(a,s,b)(1+ERR(d,z))$$

where $\lambda_0(a,s,b)$ is a log-linear function of attained age, sex, and birth cohort that describes the baseline rate and $ERR(d,z)$ is the excess relative risk function.

The ERR is modeled as

$$\beta_{ext} d_{ext}\ f_{ext}(z) + \beta_{pu}\, b_{pu}\, I_{pumon}\, f_{pu}(z) + \gamma_{pucat}\,(1 - I_{pumon})\, f_{pusurr}(z)$$

I_{pumon} is a time-dependent Pu-monitoring indicator and the $f(z)$ are effect modification functions

Results
Risk estimates and Fitted Values

	ERR/Gy	P	ERR/kBq	P	ERR-Cat4,5	P
Solid	0.14	<0.001	0.27	<0.001	0.83	<0.001
Lung, Liver, Skeleton	0.28	< 0.001	0.71	<0.001	2.62	<0.001
Other Solid	0.08	0.01	0.09	<0.001	0.18	0.27
	0.10	0.005	--	--	--	--

Outcome	Observed Cases	Fitted Background	Fitted Excess		
			External	Internal	Total
Solid	2086	1663.9	180.3	241.8	422.1
Lung, Liver, Skeleton	770	460.3	107.8	201.9	309.7
Other Solid	1316	1198.7	70.4	46.9	117.3
		1224.3	91.7	--	91.7

Results

- Strong evidence of effects of low dose-rate chronic gamma radiation exposures
  - Significant effects for lung. liver, and skeletal cancers and for all other solid cancers
- Internal exposure accounts for almost 60% of excess cases for Pu deposition sites (lung, liver, and bone)
- Internal exposure seems to have a significant effect on risk for solid cancers at sites little or no Pu dose

Summary

- Unique opportunity to study effects of chronic low dose rate exposures
- Best data for risks of Pu exposure in humans
  - Results suggest possibility of indirect effects of Pu exposure in organs other than those with significant Pu accumulation
- Analyses present interesting statistical challenges
  - Multiple exposures
  - Joint use of time-dependent surrogate and measured PU exposure estimates
  - Assessment of time-since-dose-received effects
  - Interpretation of variation in site-specific estimates

Contributors

- Southern Urals Biophysics Institute
  - N. Koshurnikova
  - M. Sokolnikov
  - P. Okatenko
  - I. Kusnetsova
  - V.F. Khokhryakov
- US National Cancer Institute
  - E. Ron
  - E. Gilbert
- Mayak P.A.
  - E. Vassilenko