

# Dosimetry for the Techa River population

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# Brief historical background

**The Mayak plutonium facility began operating in 1948, in the Southern Urals, Russia.**

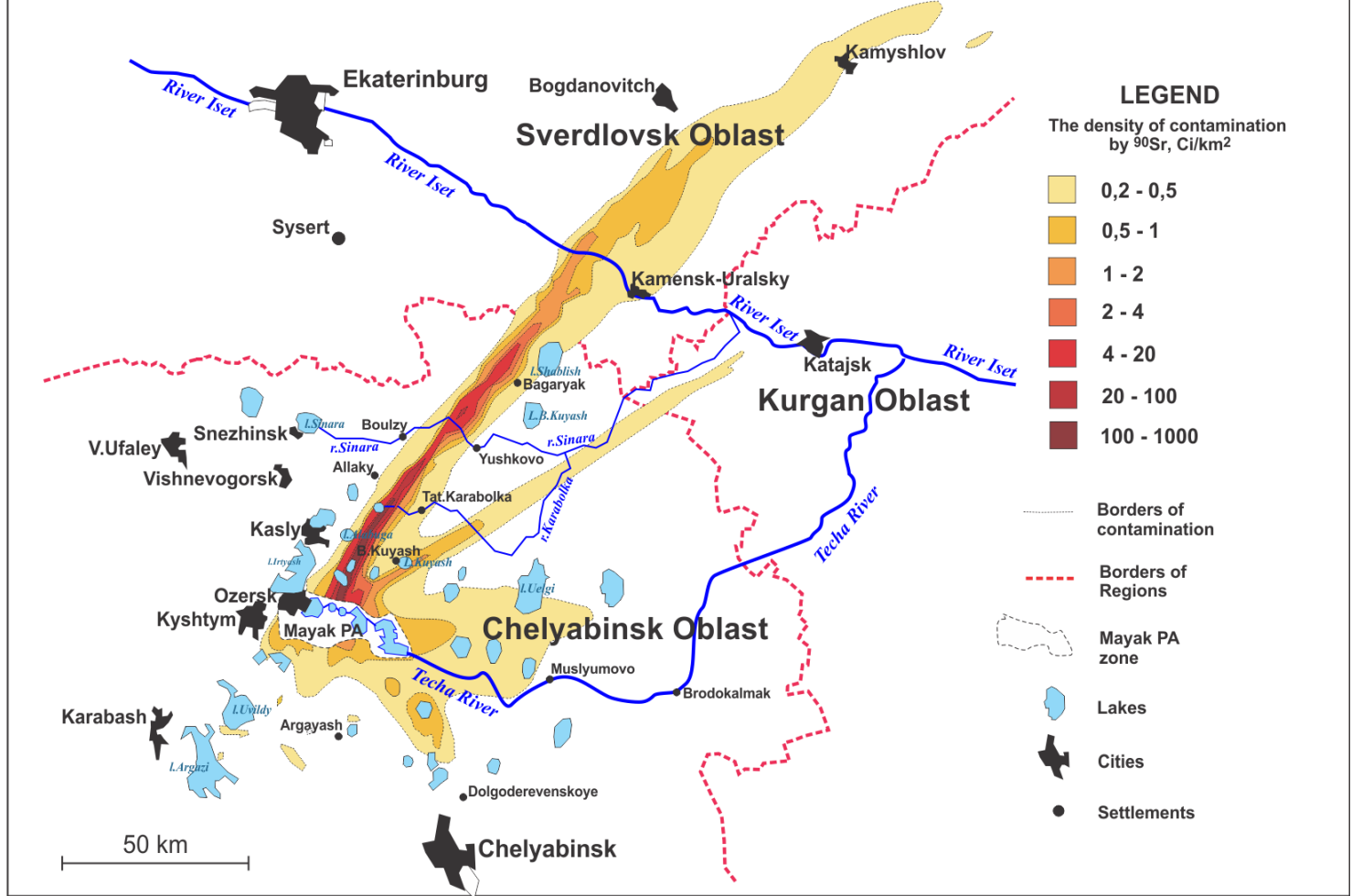
**Failures in the operation of the waste-storage resulted in several releases of uranium fission products ( $^{90}\text{Sr}$ ,  $^{89}\text{Sr}$ ,  $^{137}\text{Cs}$ ,  $^{95}\text{Zr}$ ,  $^{95}\text{Nb}$ ,  $^{144}\text{Ce}$ ,  $^{104}\text{Ru}$  etc.) into the environment:**

**1949-1956:  $1.15 \times 10^{17}$  Bq of liquid wastes were released into the Techa River;**

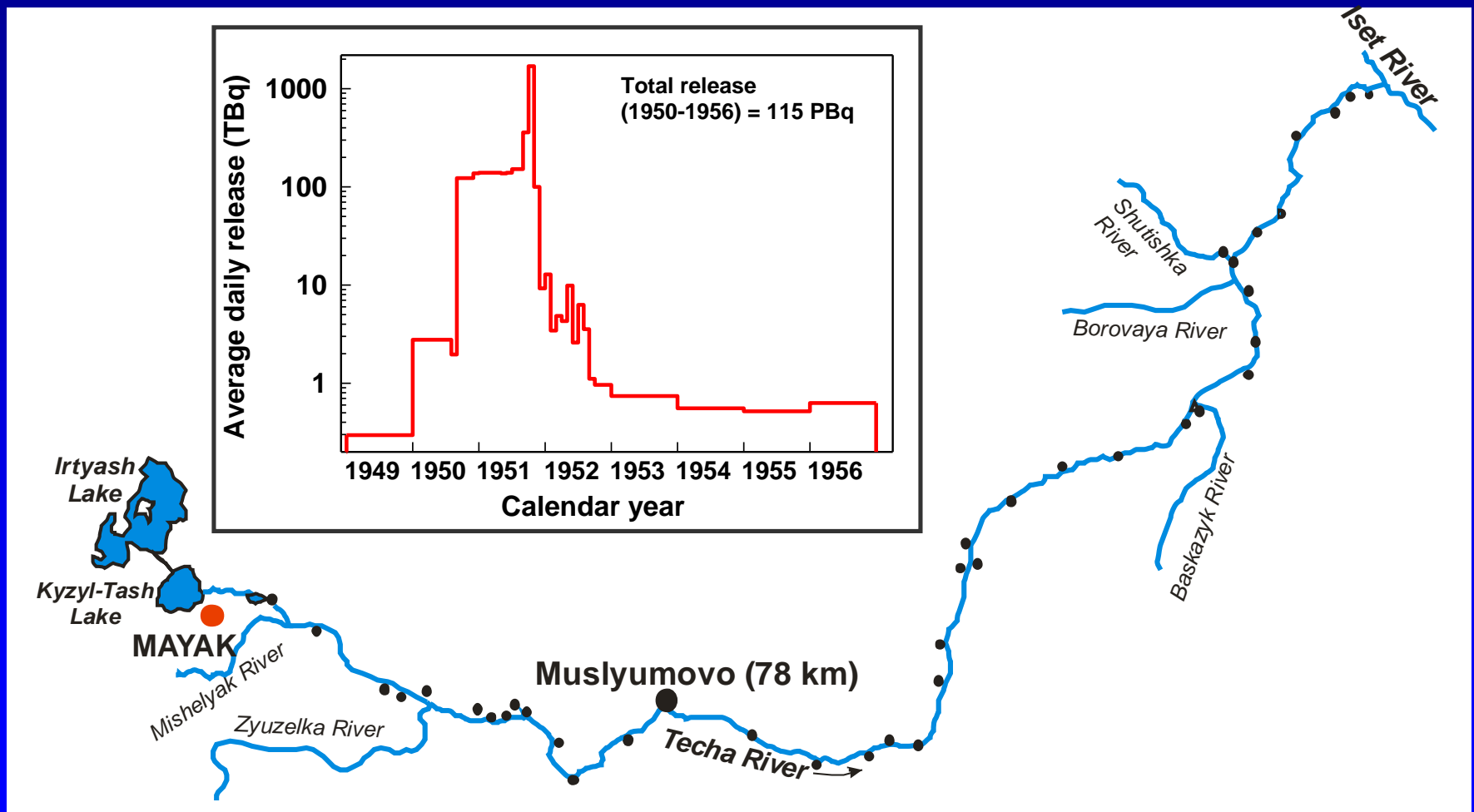
**1957:  $7.4 \times 10^{16}$  Bq were accidentally discharged into the atmosphere and formed the East Urals Radioactive Trace (EURT);**

**1967:  $2.2 \times 10^{14}$  Bq were windblown from Lake Karachay (served as open repository of radioactive waste).**

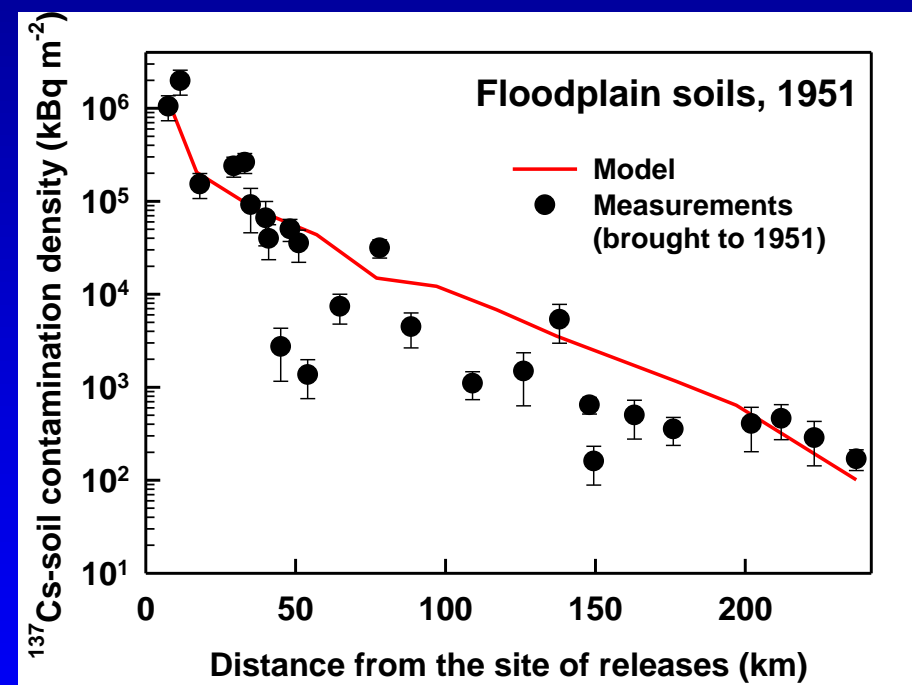
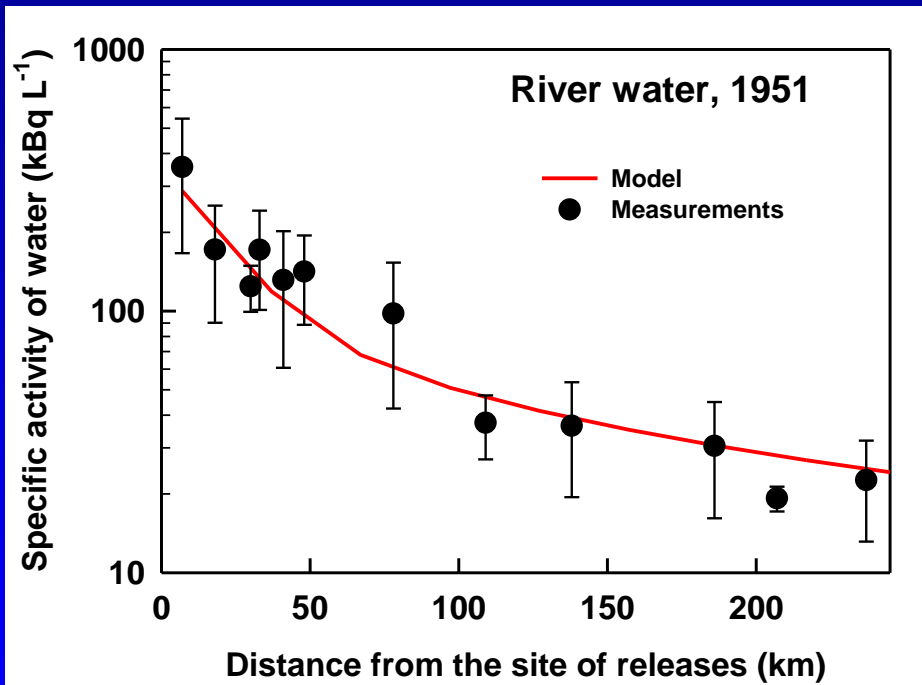
# SCHEMATIC MAP OF DENSITY CONTAMINATION BY STRONTIUM-90 (ON 1997) OF THE TERRITORIES OF THE SOUTHERN URALS REGION



# Releases into the Techa River resulted in chronic exposure of 30,000 persons who lived in downstream settlements

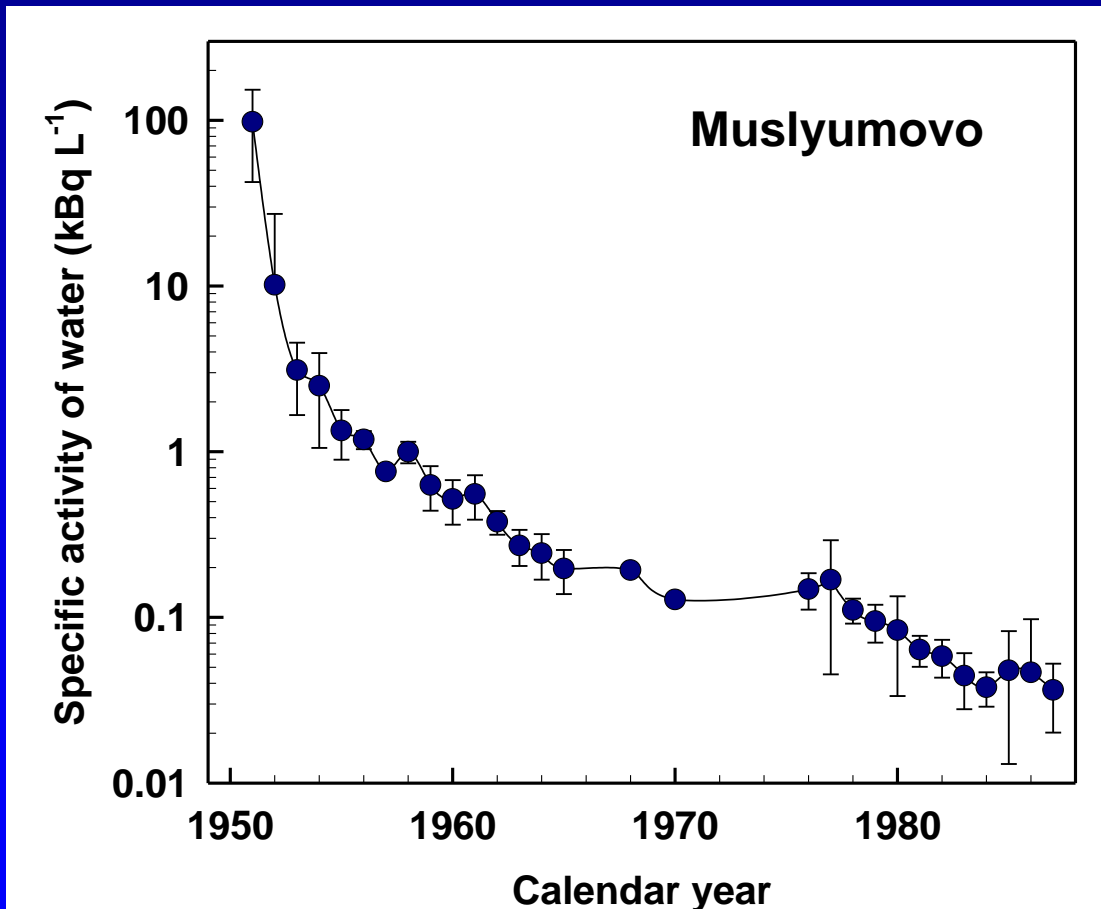


# Contamination of the Techa River water and floodplain soils decreased with the distance from the site of releases



The Techa River model was created to reconstruct the contamination in 1949-1951 (Shagina et al Radiat Environ Biophys 2012).

# Contamination of the Techa River water after 1951 decreased with the time



**Regular monitoring of environmental contamination started July 1951.**

# **The main routes of radiation exposure of the Techa River Cohort:**

**Internal exposure** due to drinking water drawn from the river and consumption of foods contaminated by river water;

**External exposure** from the contaminated flood-plain soils.

**The Techa River Dosimetry System (TRDS)** was created to support epidemiological studies using individual dose estimates.

# **Techa River Dosimetry System (TRDS)**

**The TRDS has been developed to provide estimates of internal and external doses for the Techa Riverside villagers.**

**The reconstruction of internal doses from intake of radionuclides is based primarily on a large number of measurements of radionuclide burden in humans.**

**The traditional approach of analyzing all steps of the pathway of exposure is only used as a backup when other approaches have been exhausted.**

**This methodology is rather unique in the worldwide practice of environmental dose reconstruction.**



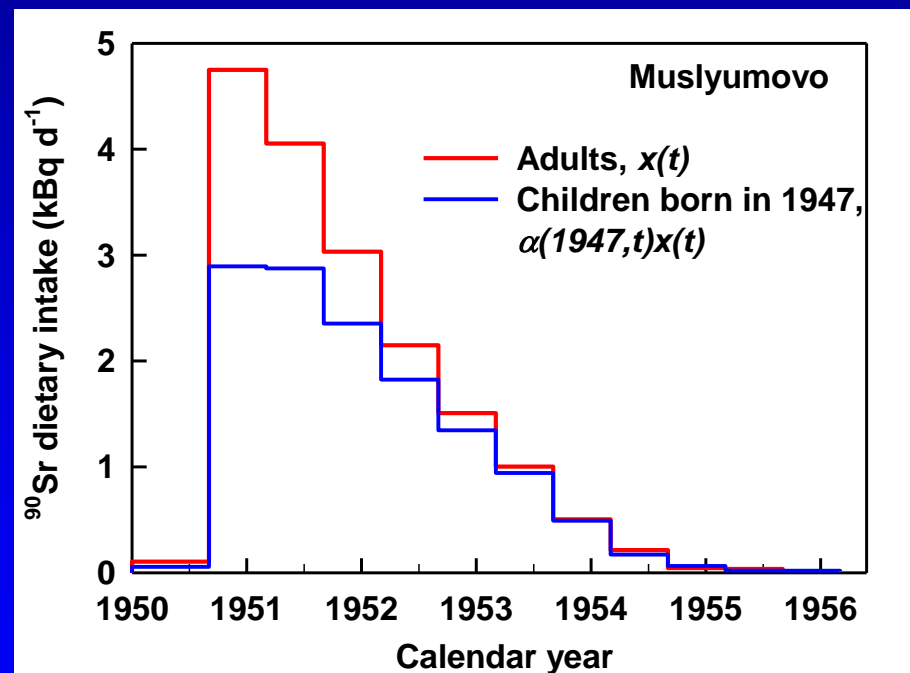
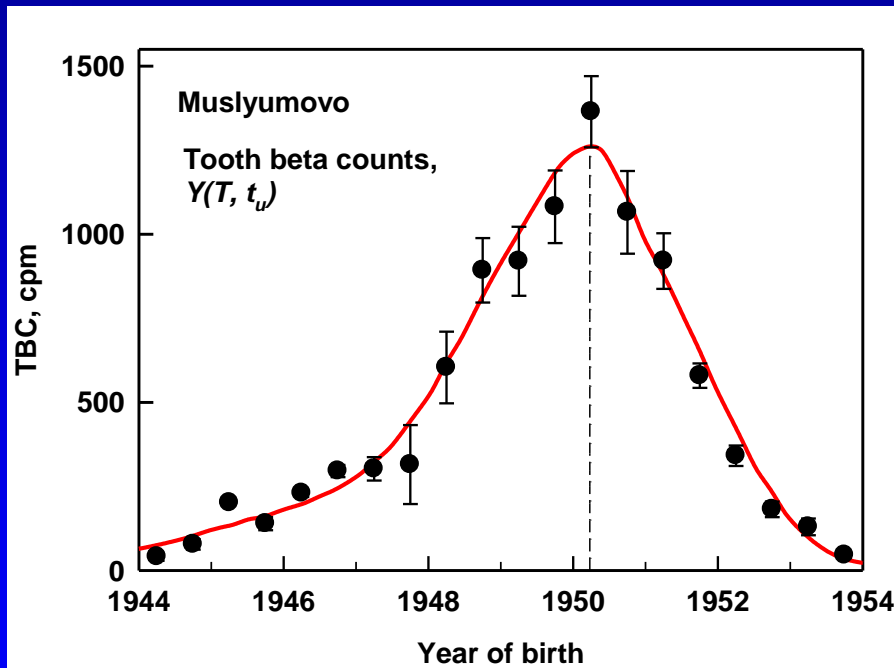
# Measurements of $^{90}\text{Sr}$ in the Techa River residents.

Dataset	Period of measurements	Number of people *	Number of measurements
<i>Postmortem</i> measurements of $^{90}\text{Sr}$ in bones	1951-1989	240	1,110
<i>In vivo</i> measurements of $^{90}\text{Sr}$ in front teeth with tooth beta counter (TBC)	1959-1997	11,000	23,000
<i>In vivo</i> measurements of $^{90}\text{Sr}$ in body with whole body counter (WBC)	1974-1997	12,200	28,000
	2006-present	2,200	2,800

\* Lived in Techa Riverside settlements any time in 1950-1960

# A reference age-dependent $^{90}\text{Sr}$ -intake function was evaluated from TBC data.

$$Y(T, t_u) = \beta \int_{t_{init}}^{t_u} \alpha(t - T, t) x(t) k(t - T) R(t - T, t_u - t) dt$$

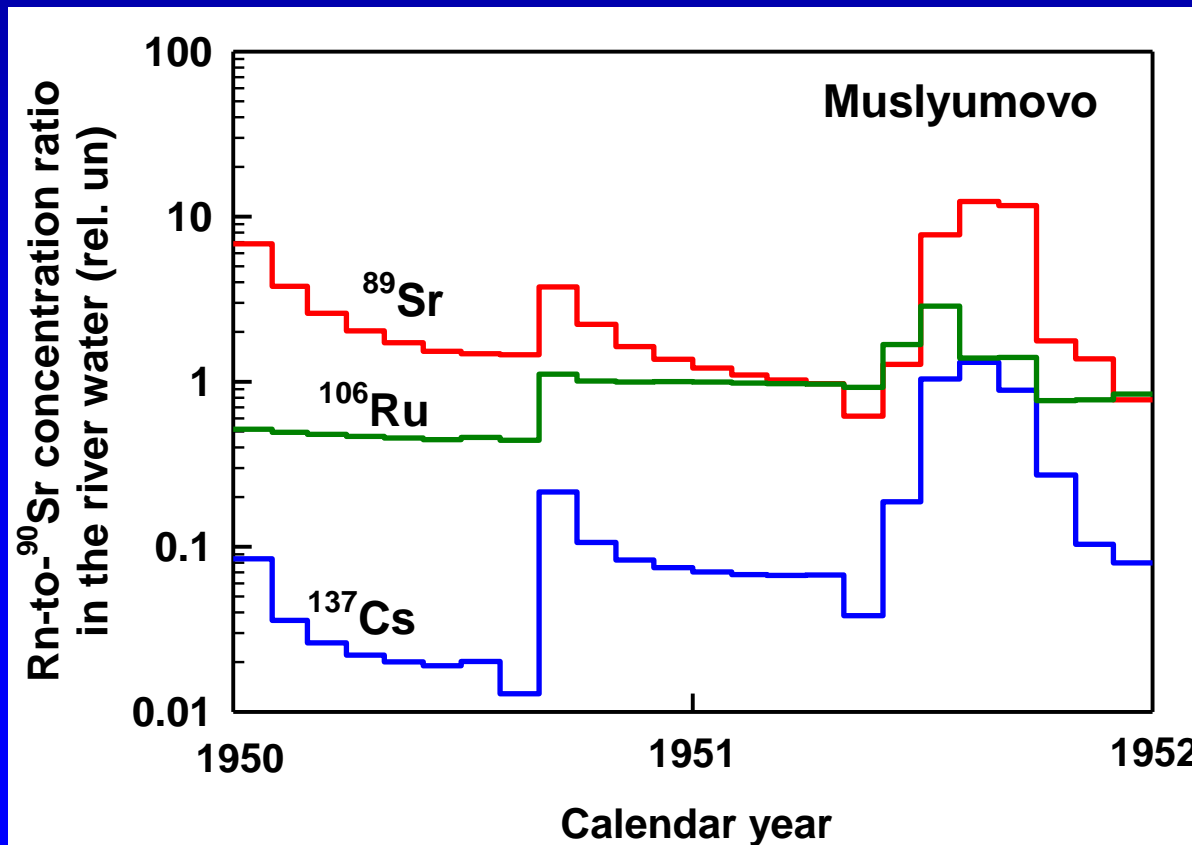


Tolstykh et al. *Health Phys* 2011

The  $^{90}\text{Sr}$ -intake function is a basic function used to reconstruct non- $^{90}\text{Sr}$  intakes with river water.

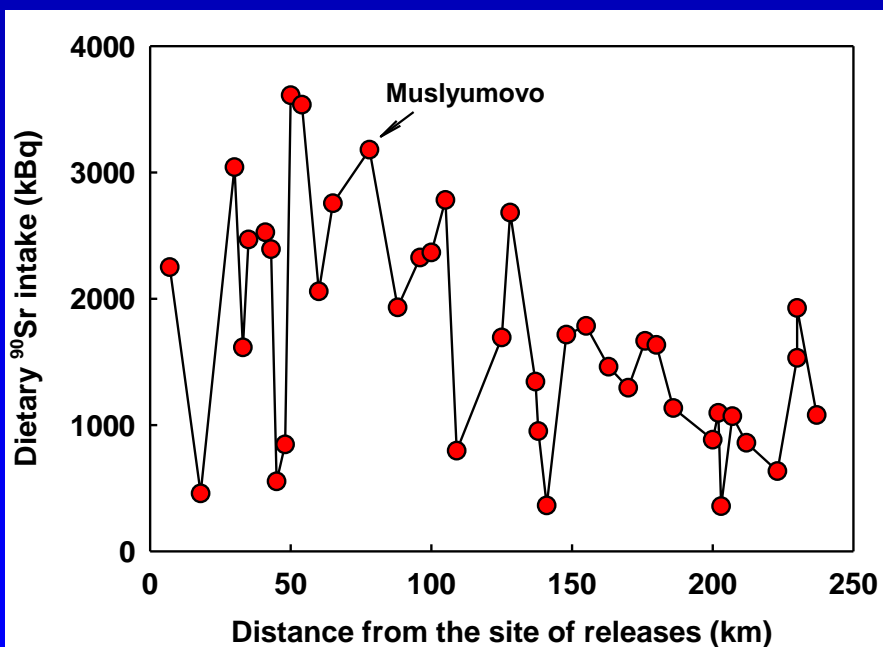
# Approach to reconstruct intake of non- $^{90}\text{Sr}$ radionuclides with river water

Based on evaluation of radionuclide-to- $^{90}\text{Sr}$  ratios in river water and the reference  $^{90}\text{Sr}$ -intake function

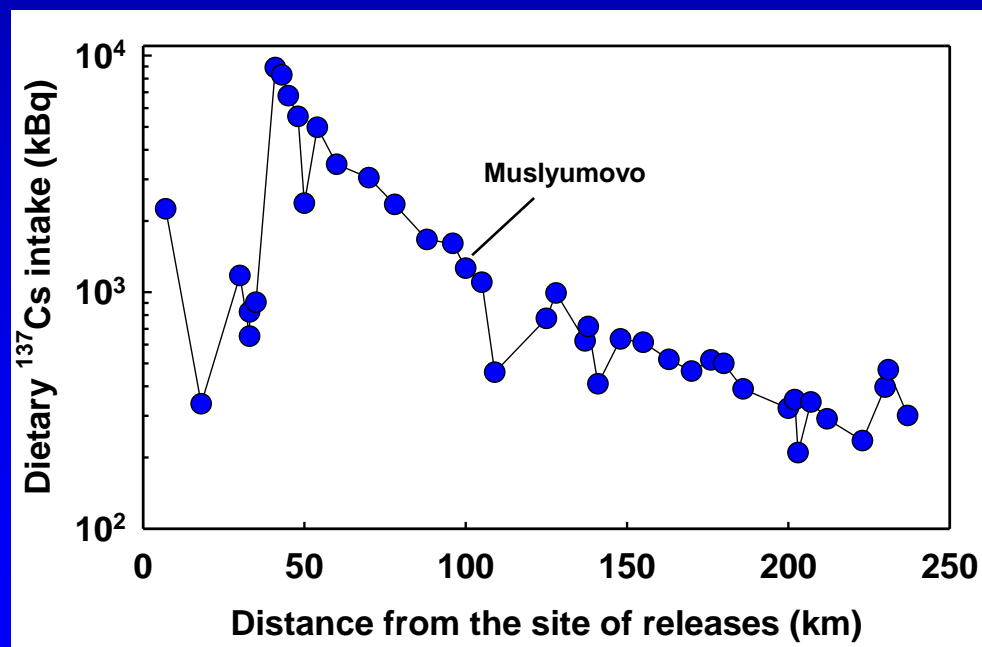


# Intakes of long-lived radionuclides by adults in the Techa River villages located at different distances

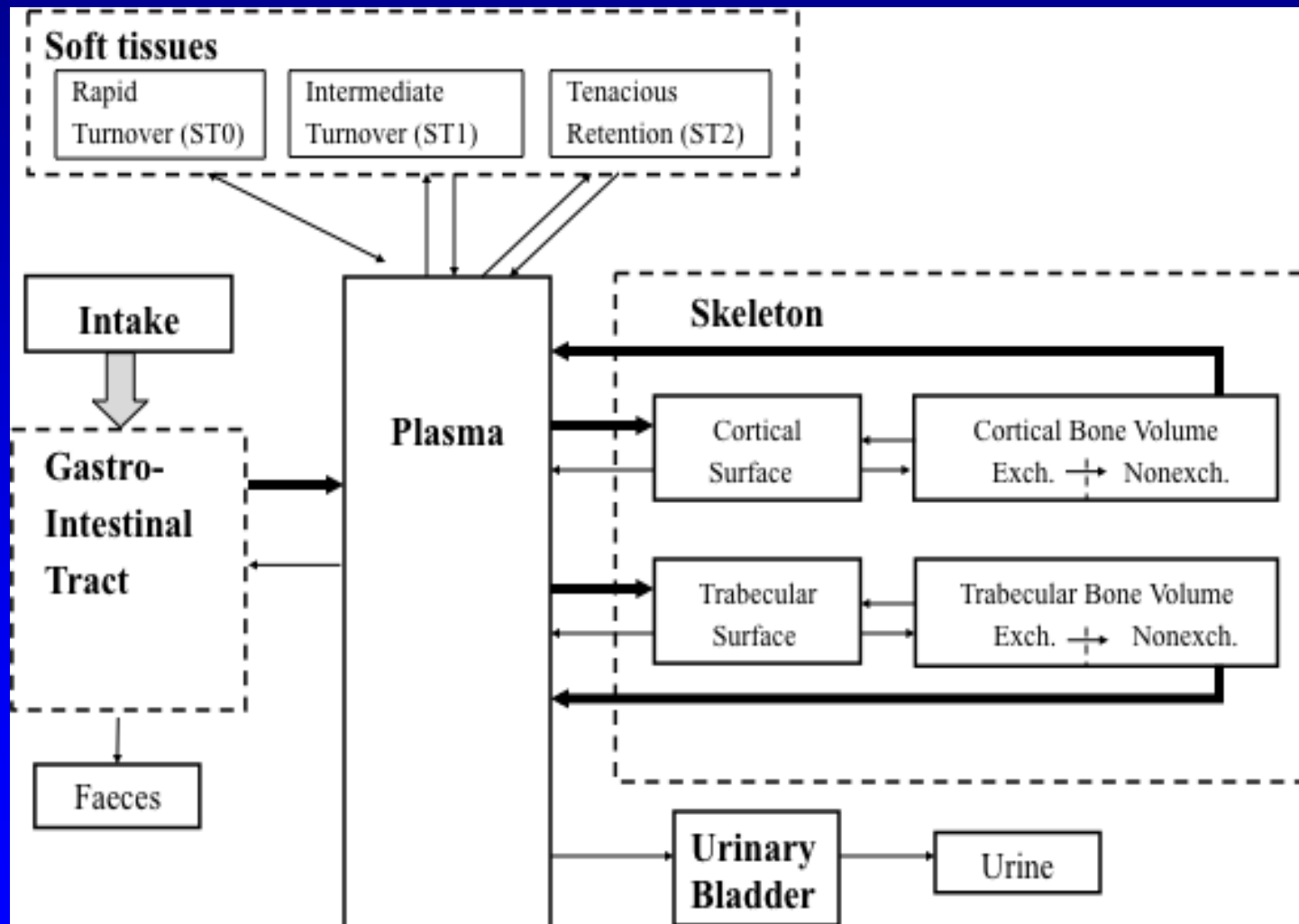
## Strontium-90



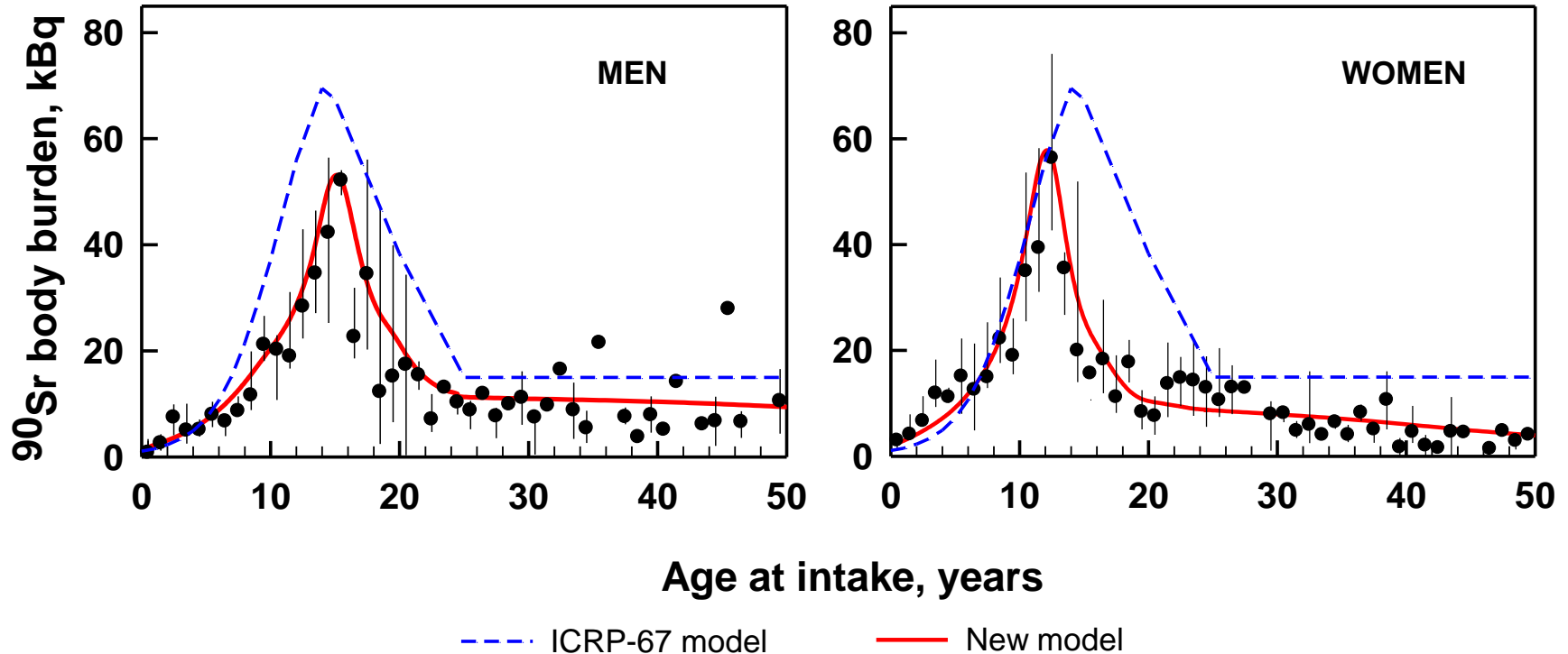
## Cesium-137



# Age- and gender-dependent biokinetic model was developed to evaluate Strontium retention in human tissues

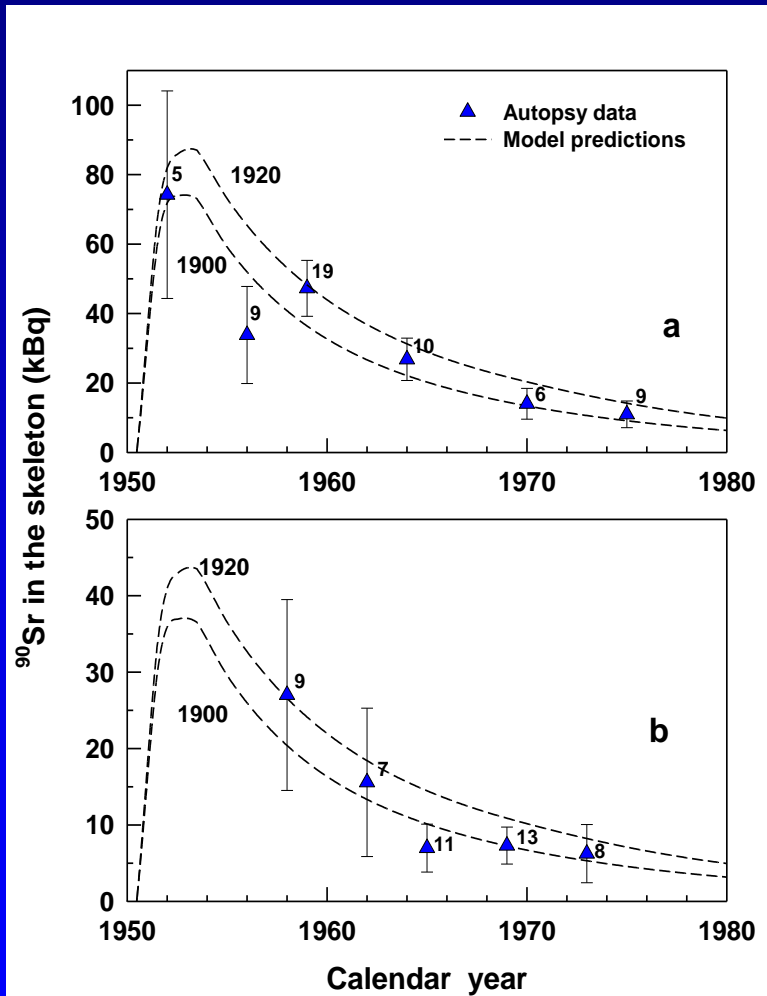


# Sr-AGe model satisfactorily describes the Techa River data on measured $^{90}\text{Sr}$ -body burden 30 years after beginning of intake

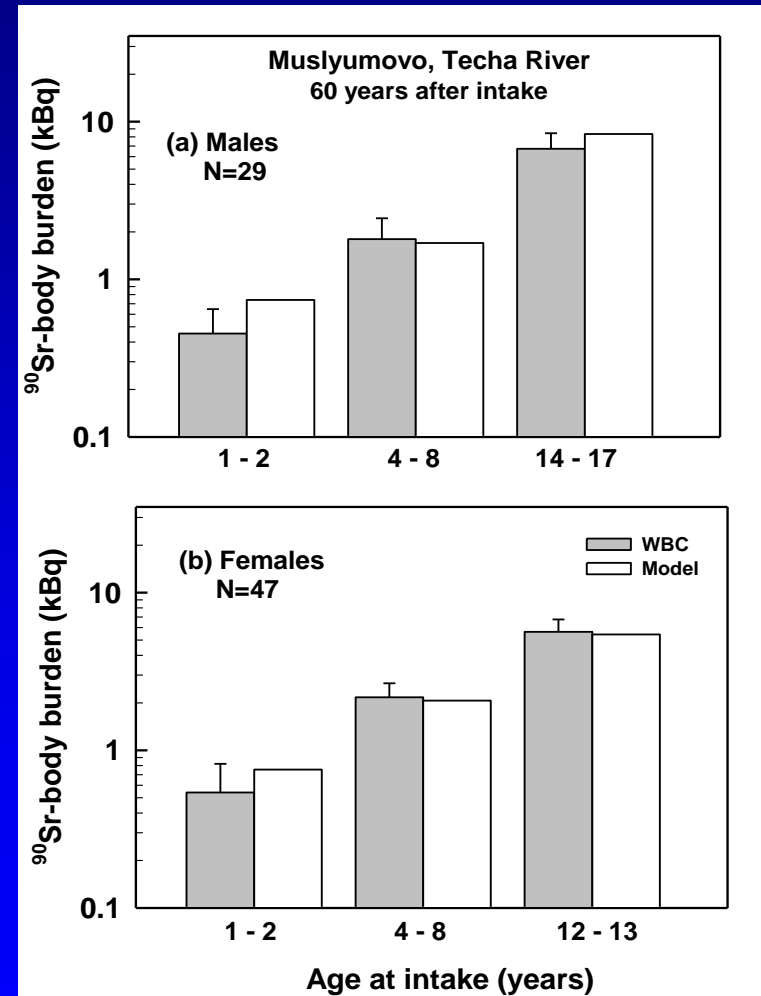


According to Shagina et al 2015

# Sr-AGe model predictions also agree with $^{90}\text{Sr}$ content measured in Techa Riverside residents in different calendar periods



Adult residents of the upper and middle Techa (a) and lower Techa (b)

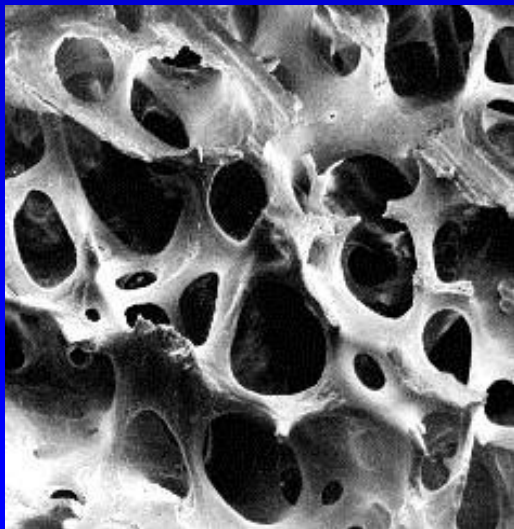


WBC measurements 60 years after beginning of  $^{90}\text{Sr}$  intake

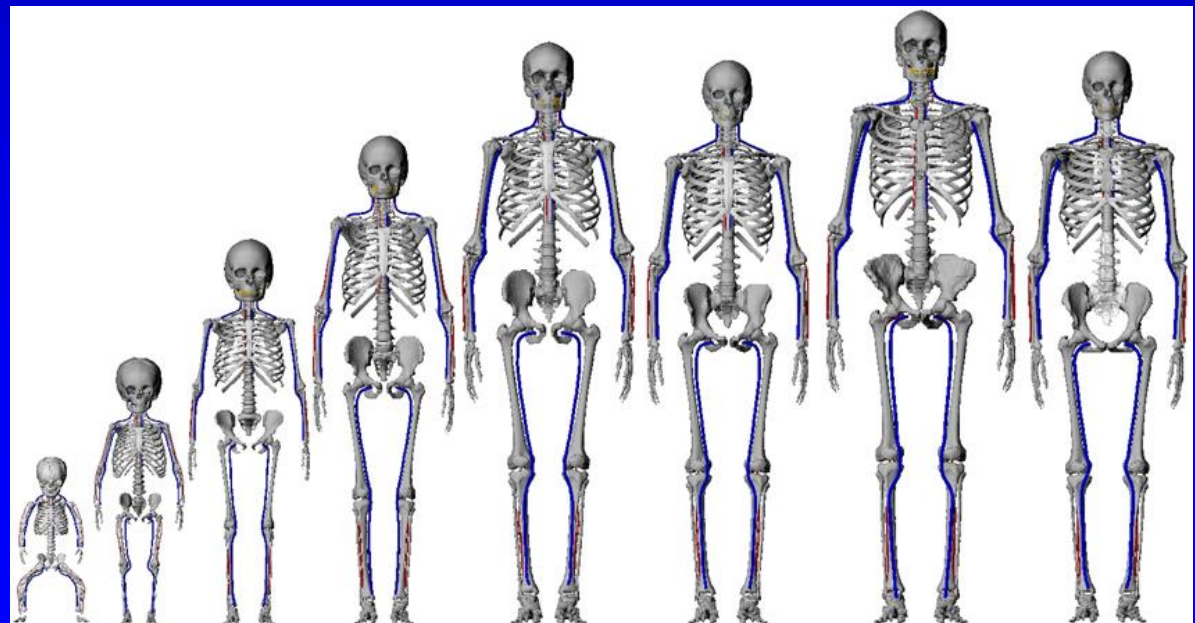
# Dosimetric models of skeleton describe energy deposition in target-tissue from radiation emitted by source-tissues

Phantom series was developed by University of Florida group led by Prof. Wesley Bolch

Microstructure of trabecular bone



Macrostructure of human skeleton



UFH00MF

UFH01MF

UFH05MF

UFH10MF

UFH15M

UFH15F

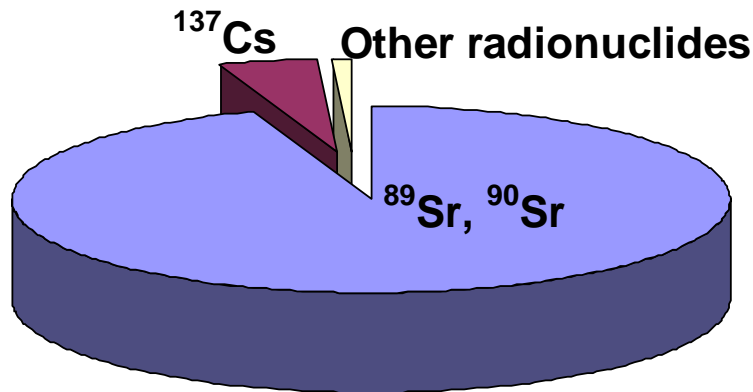
UFHADM

UFHADF



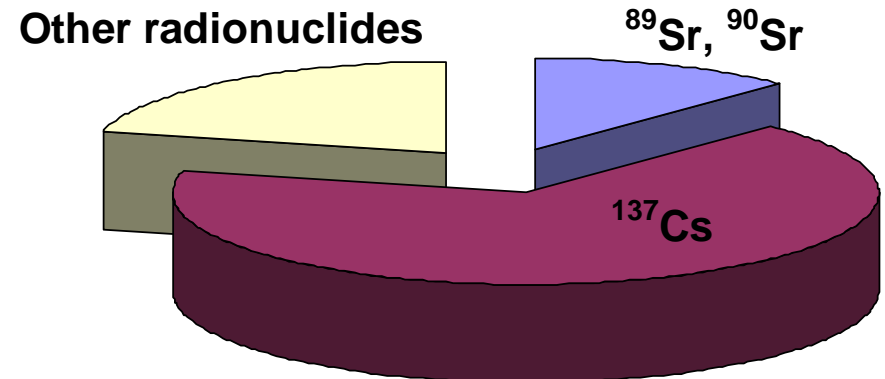
# Structure of internal doses for the Techa Riverside residents was different for bone marrow and extraskeleton tissues

**Bone marrow**



**670 mGy**

**Stomach**



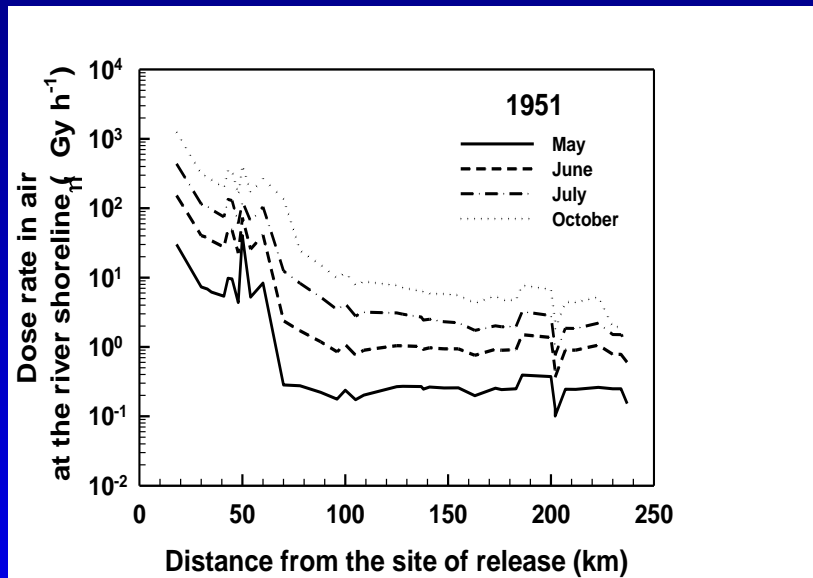
**50 mGy**

# Organ doses from external exposure

were derived from dose rate in air on the  
Techa River banks

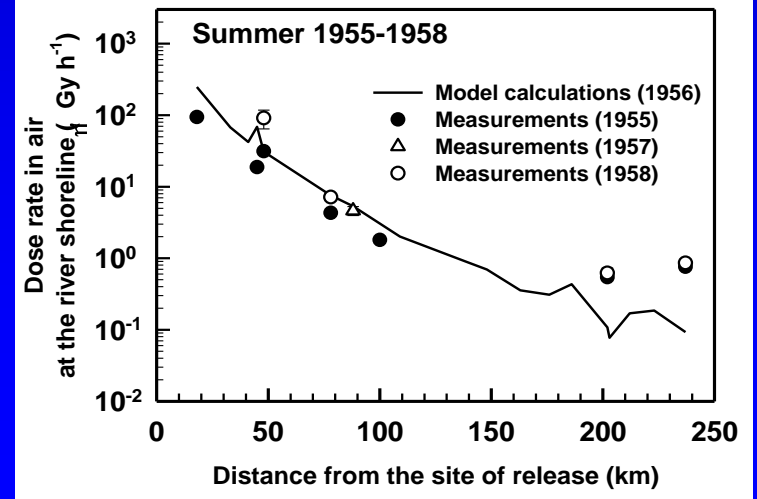
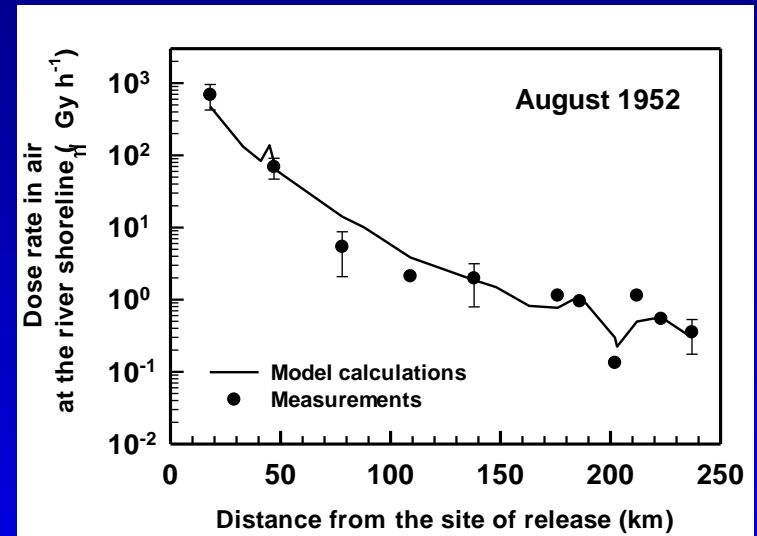
Individual doses were calculated in accordance  
with historical records of individuals'  
residence histories, observational data of  
typical lifestyles for different age groups and  
age-dependent conversion factors from air  
kerma to organ dose.

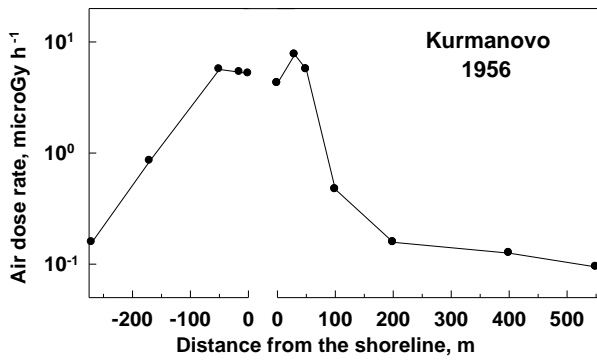
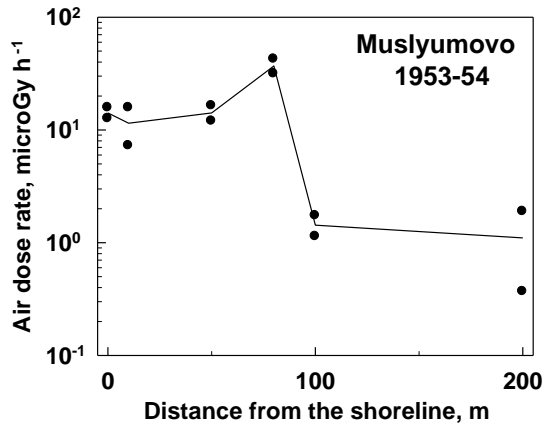
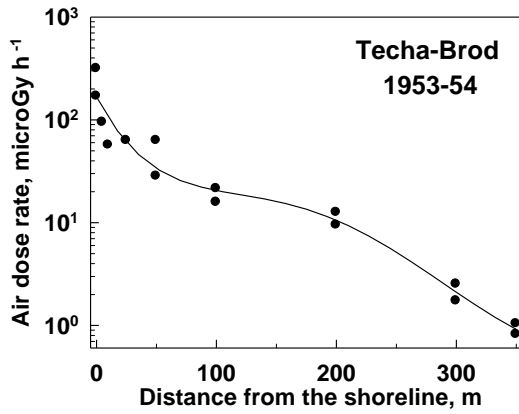
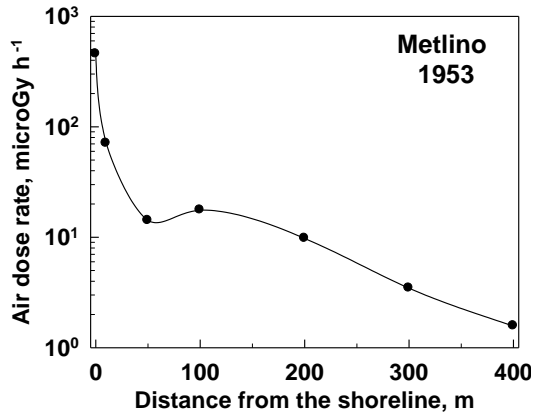
# Dose rates on the Techa River banks sharply decreased with distance from the release site.



In 1951 the dose rate increased with time month by month; after 1952 the decrease was slow because dose rate was due to long-lived  $^{137}\text{Cs}$ .

According to Degteva et al Radiat Environ Biophys 2015





**Dose rates sharply decreased with distance from the water edge**

**Historical measurements were performed at different distances from the shoreline in different locations.**

**Integral air kerma above Techa  
shoreline was checked by comparison  
with  
TL/OSL measurements of brick  
samples**

**Monte Carlo calculations of photon  
transport were performed to provide the  
link of air kerma to doses absorbed in  
bricks for different exposure conditions.**

# Metlino sampling site

was located at 7 km from the site of radioactive releases and included



constructed in 1867



constructed in 1861

# Muslyumovo sampling site

was located at 78 km from the site of releases  
and included the mill constructed in 1895



# Comparison of integral air kerma above Techa shoreline derived from TL/OSL measurements and reconstructed from the floodplain contamination

Location, time period	Building, wall orientation	Kerma derived from TL/OSL measurements, Gy	Kerma calculated from floodplain contamination, Gy
<b>Metlino, 1949-1956</b>	Mill, SW	23 <sup>a</sup> (15 – 32)	21 (11 - 42)
	Church, SW	26 (17 – 35)	
	Church, SE	45 (35 – 45)	
<b>Muslyumovo, 1949-2007</b>	Mill, West	2.2 <sup>b</sup> (0.2 – 1.5)	1.9 (0.9 – 3.8)

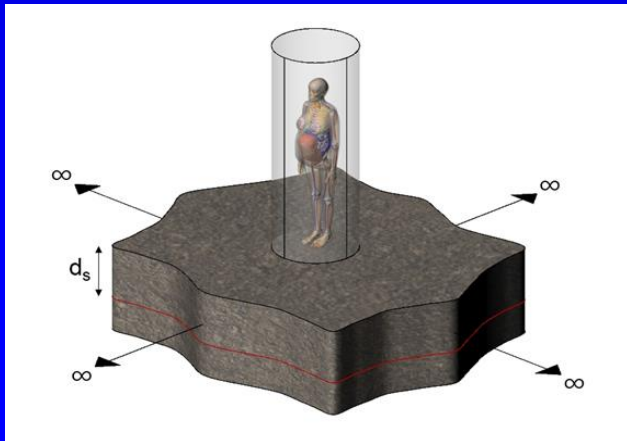
According to: (a) Taranenko et al 2013; (b) Ulanovsky et al 2009



# Conversion factors for human exposure on the floodplain were calculated using University of Florida hybrid phantoms.

Organ absorbed dose-to-air kerma ratios

Enamel	Active bone marrow (age-dependent)				
All ages	1 yr	5 yr	10 yr	15 yr	$\geq 20$ yr
0.95	0.89	0.87	0.83	0.78	0.73



Idealized geometry of exposure to contaminated soil on the floodplain where the residents spent 0.3 – 1.0 hours per day.

**EPR and FISH methods were used for validation of external dose estimates**

**Detection limit for EPR with human teeth was estimated as 100 mGy (Fattibene and Callens 2010);**

**Detection limit for FISH with human lymphocytes was estimated as 300 mGy (IAEA 2011).**

**Expected doses in the upper Techa Riverside residents could exceed the detection limits for EPR and FISH**

**The issue in EPR and FISH application for external dose validation on the Techa River was  $^{90}\text{Sr}$  incorporated in human bones and teeth where it served as a source of confounding exposure of bone marrow and tooth enamel.**

**To quantify this exposure source,  $^{90}\text{Sr}$ -body burdens were determined for persons who were measured by FISH, and  $^{90}\text{Sr}$  concentrations were determined in tooth samples.**

**Then, the contributions of  $^{90}\text{Sr}$  were subtracted from translocation yield and enamel dose.**

# EPR- and FISH-based dose estimates were comparable for residents of the upper Techa

Cluster/ Settlements	Distance from the release site, km	Number of FISH donors	FISH- based dose, mGy	Number of EPR donors	EPR- based dose, mGy
1. Metlino	7	23	510±72	11	547±170
2. Asanovo, Techa-Brod, M Taskino, Gerasimovka	18-45	13	390±102	24	223±83
3. Nadyrov Most, Nadyrovo	48-50	12	480±120	10	569±250
4. Ibragimovo, Isaevo, PHT	54-70	23	130±75	34	160±60

The basic equation for dose calculations in the Techa River Dosimetry System (TRDS) includes 5 sources of population exposure:

External and internal exposure on the Techa River

External and internal exposure on the EURT area

Medical exposure at the URCRM clinics

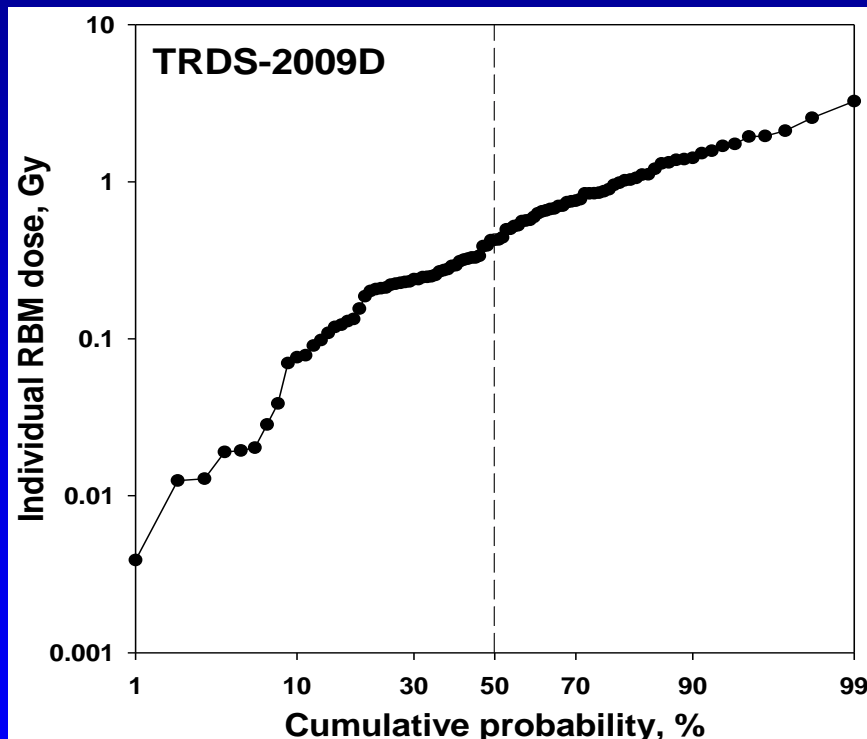
The absorbed dose  $D_{o,Y,i}$  to organ  $o$  of individual  $i$ , accumulated through calendar year  $Y$  is

$$D_{o,Y,i} = \sum_{y=y_{\min}}^{P \leq Y} \left[ \sum_L M_{y,L,i} \left[ \left( \sum_r I_{y,r,L}^*(\tau_i) DF_{r,o,Y-y}(\tau_i) \right) + A_o(\tau_i) D_{Riv,L,y} (T_1(\tau_i) + R_{out/Riv,L} (T_2(\tau_i) + R_{in/out} T_3(\tau_i))) \right) + \sum_{s=1}^2 \sum_r G_{s,r,L} \delta_{s,y} \left\{ E_{s,r,y}(\tau_i) DF_{r,o,Y-y}(\tau_i) + A_o(\tau_i) D_{s,r,y} (1 - T_3(\tau_i) + R_{in/out} T_3(\tau_i)) \right\} + \sum_{e_i} X_{o,i}(e_i, y, \tau_i) \right] \right]$$

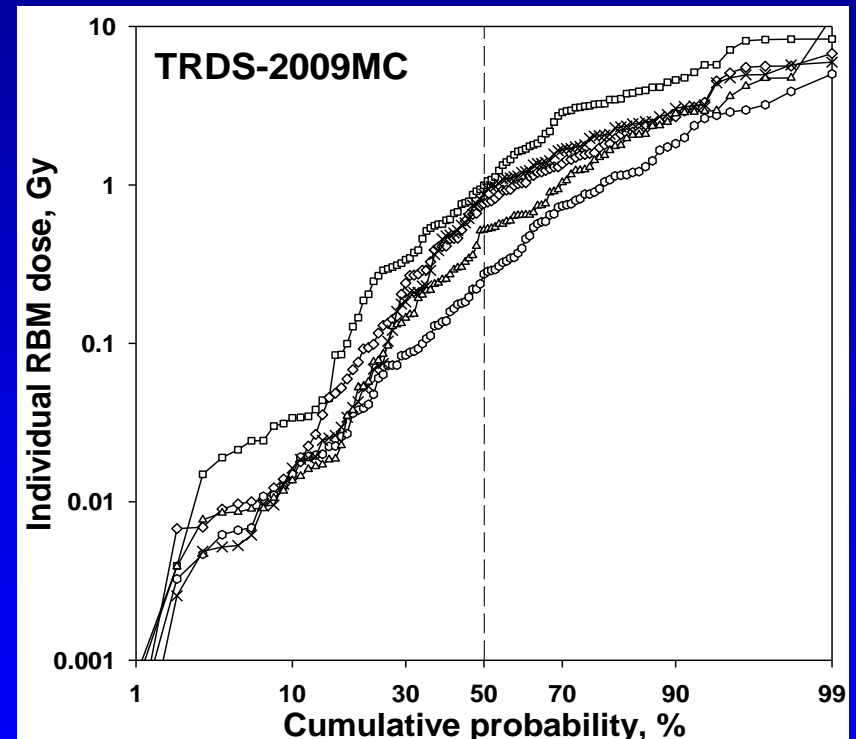
# Estimation of Uncertainty in the TRDS (Napier et al 2013)

- All individual doses are being estimated with uncertainties
- Uncertainty estimates:
  - Consider shared uncertainties
  - Consider unshared uncertainties
  - Consider Berkson and Classical error types
  - Consider individual autocorrelations
  - Are saved for epi studies as complete correlated cohort files

# Distributions of individual bone marrow dose estimates for the Techa River Cohort (30,000 persons)

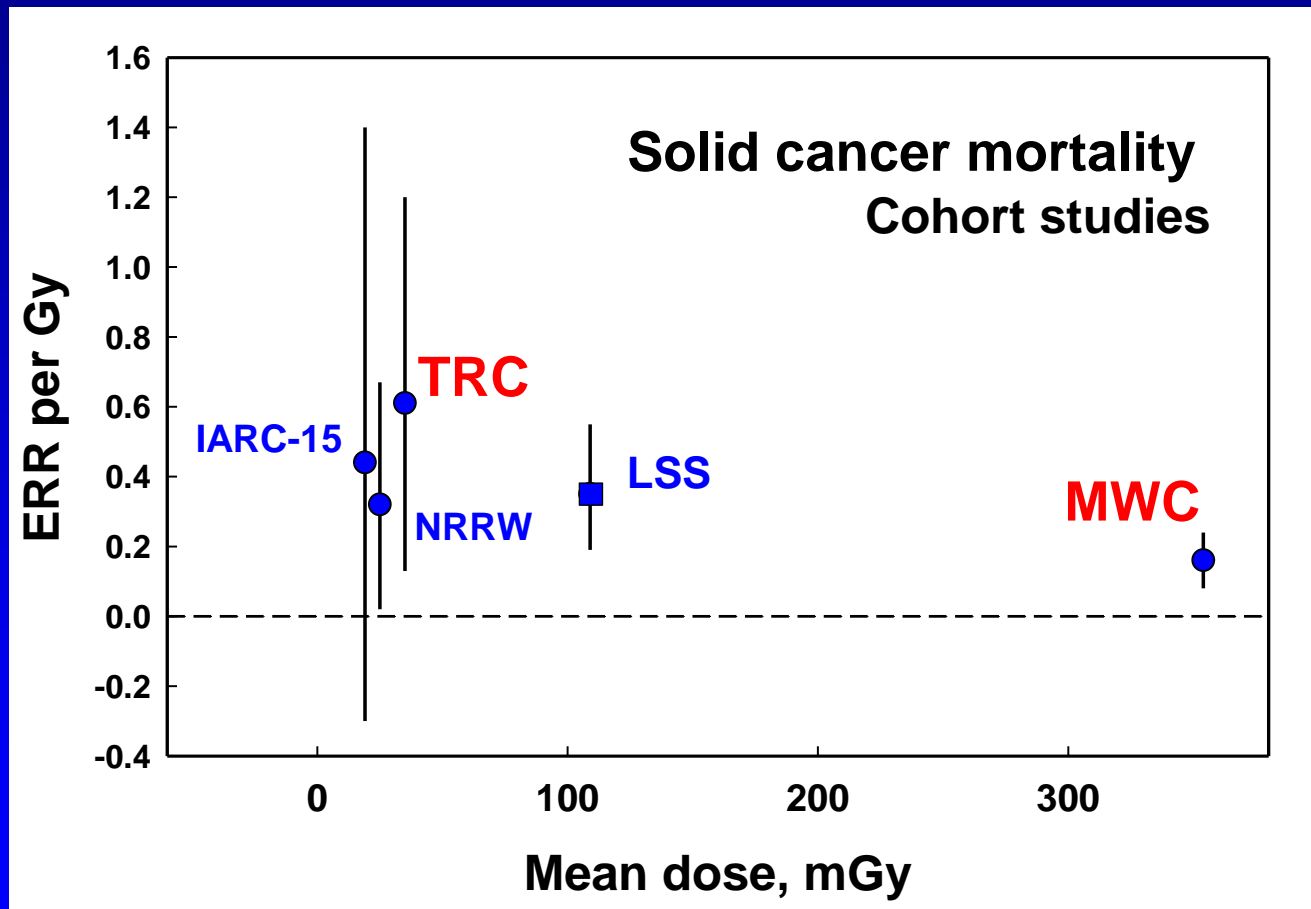


Deterministic estimates  
calculated used TRDS-2009D



5 realizations (from 15000)  
generated by stochastic TRDS-  
2009MC

# Excess relative risk estimates from the Techa and Mayak worker studies in comparison with other cohorts



According to Sokolnikov et al PLOS One 2015



**Thank you!**

Dosimetric studies on the Techa River were supported by the EC under the SOLO and SOUL projects, the US DoE Office of International Health Programs and the Federal Medical-Biological Agency of the RF.