INTERNAL AND EXTERNAL DOSIMETRY OF THE EARLY NUCLEAR WEAPONS WORKERS

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Data Sources

NIOSH Radiation Dose Reconstruction Program

- Some information publicly available in site profiles and coworker studies.
- http://www.cdc.gov/niosh/ocas/
- Electronic databases from sites.
- Historical hard copy records.

Comprehensive Epidemiologic Data Resource (CEDR)

- DOE's electronic database containing health studies of DOE contract workers.
- Derived from epidemiologic studies.

ORAU Center for Epidemiologic Research (CER)

Early Exposure Limits

1934

- U.S. Advisory Committee on X-ray and Radium Protection proposed limit of 0.1 R/day.

1941

- Maximum radium body burden of 0.1 µCi (3.7 kBq)

1944 - 1945

- Maximum plutonium body burden of 0.3 µCi (3.7 kBq),
- Manhattan Engineer District reduced this to 0.06 µCi (22 kBq)

1946 – 1948

- NCRP formed from Advisory Committee on X-Ray and Radium Protection and agreed on main conclusions.

Early Exposure Limits

1953

- *NBS Handbook 52* Produced by NCRP.
- 1st official national guidelines on air concentrations, body burdens.

1956

- ICRP and NCRP recommended limit of 5 rem (50 mSv) per year for whole body, gonads, lens of the eye, and bone marrow of occupational workers.

1957

- AEC drew on recommendations of NCRP and issued its 1st regulations on radiation protection.

Internal Dosimetry 1943-1963

- Methodologies and techniques were being developed during this time.
- Gross techniques often applied to *in vitro* bioassay.
  - Chemical separations performed.
  - Total activity measured.
- *In vivo* bioassay began around 1960 so it won't be primary focus of discussion.
- H-3 doses typically reported with external dose.

External Dosimetry 1943-1963

- Pocket Ionization Chambers were the first dosimeters used (1943)
- Primitive film dosimeters (photographic films) with only 2 windows (1944)
- Film augmented with nuclear track emulsion, type A (NTA) film for neutron (1945)
- Film ring dosimeter (1944)

Sites

Oak Ridge National Laboratory

- Oak Ridge, TN

Mound Plant

- Miamisburg, OH

Hanford Site

- Richland, WA

Los Alamos National Laboratory

- Los Alamos, NM

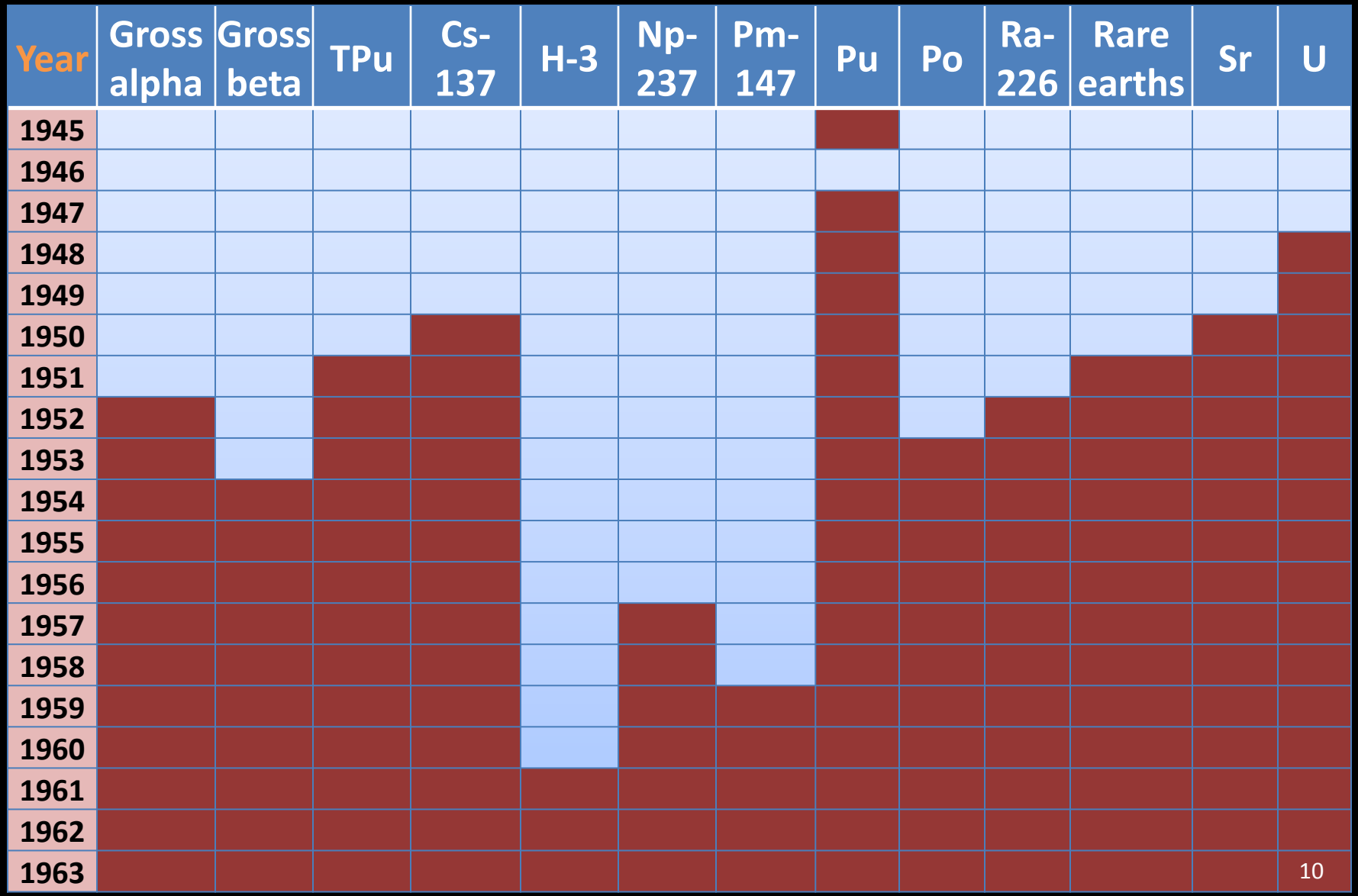
Oak Ridge National Laboratory

- Began operations in 1943.
- Operation of Graphite Reactor for producing plutonium and other radioisotopes (1943-1963).
- Development of new reactor technologies.
- Operation of facilities for separation, packaging, distribution of radioisotopes for government and commercial use.
- Development/refinement of chemical processes to separate plutonium, uranium, and thorium from irradiated fuel.

ORNL Bioassay

- Urine and fecal samples collected beginning in 1945.
- Separated trivalent alpha actinides as a group and analyzed by zinc-sulfide scintillation counting.
- 1945 memo regarding the building of a special laboratory for urinalysis of plutonium.
- Hardcopy records for 164 plutonium urine samples in 1945.
- Electronic data begin 1951.

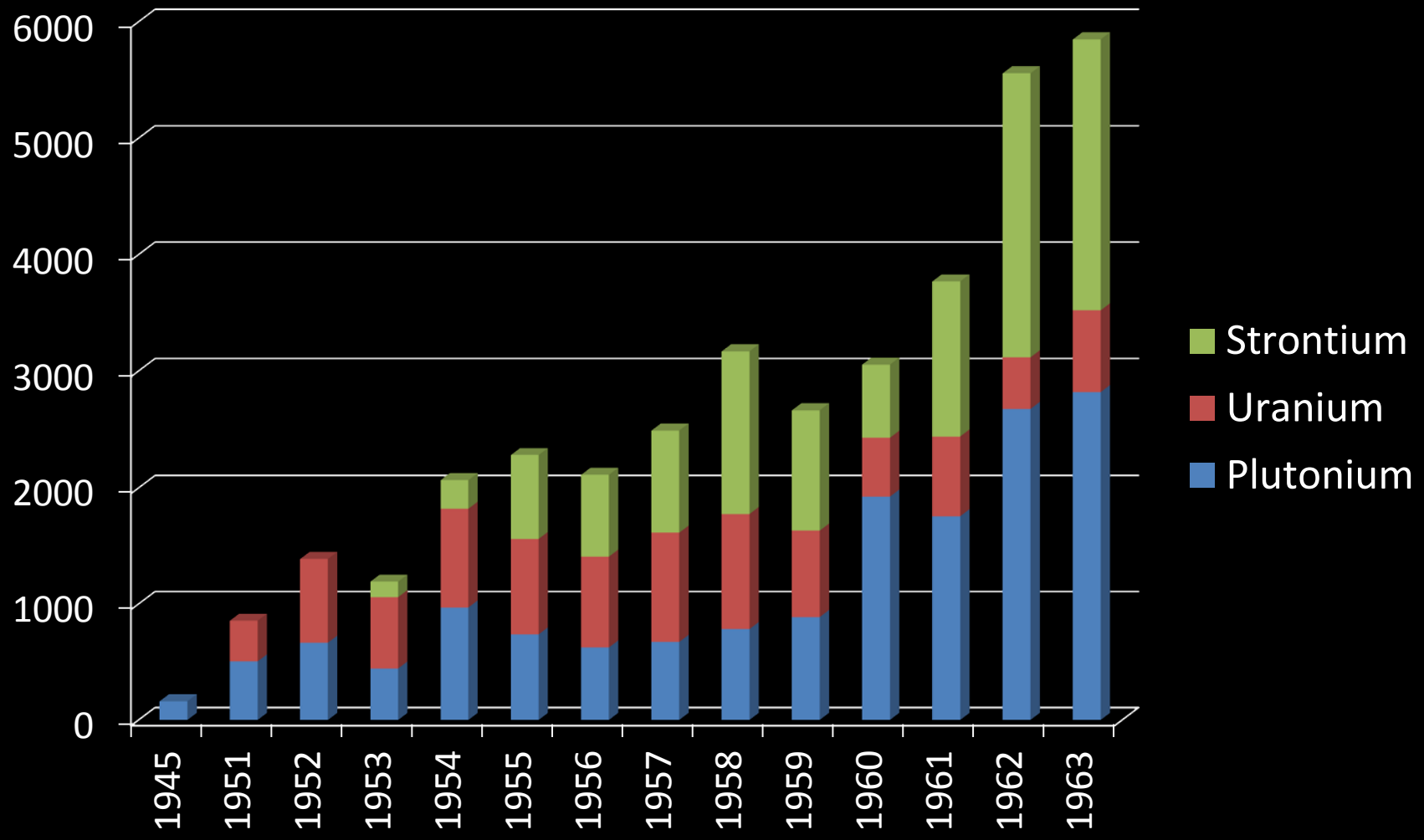
ORNL Urine Samples



ORNL Fecal Samples

Year	Pu	Th-232
1945		
1946		
1947		
1948		
1949		
1950		
1951		
1952		
1953		
1954		
1955		
1956		
1957		
1958		
1959		
1960		
1961		
1962		
1963		

ORNL Urinalysis: Samples/yr



ORNL Urinalysis: People Sampled/yr

ORNL *In Vivo* Bioassay

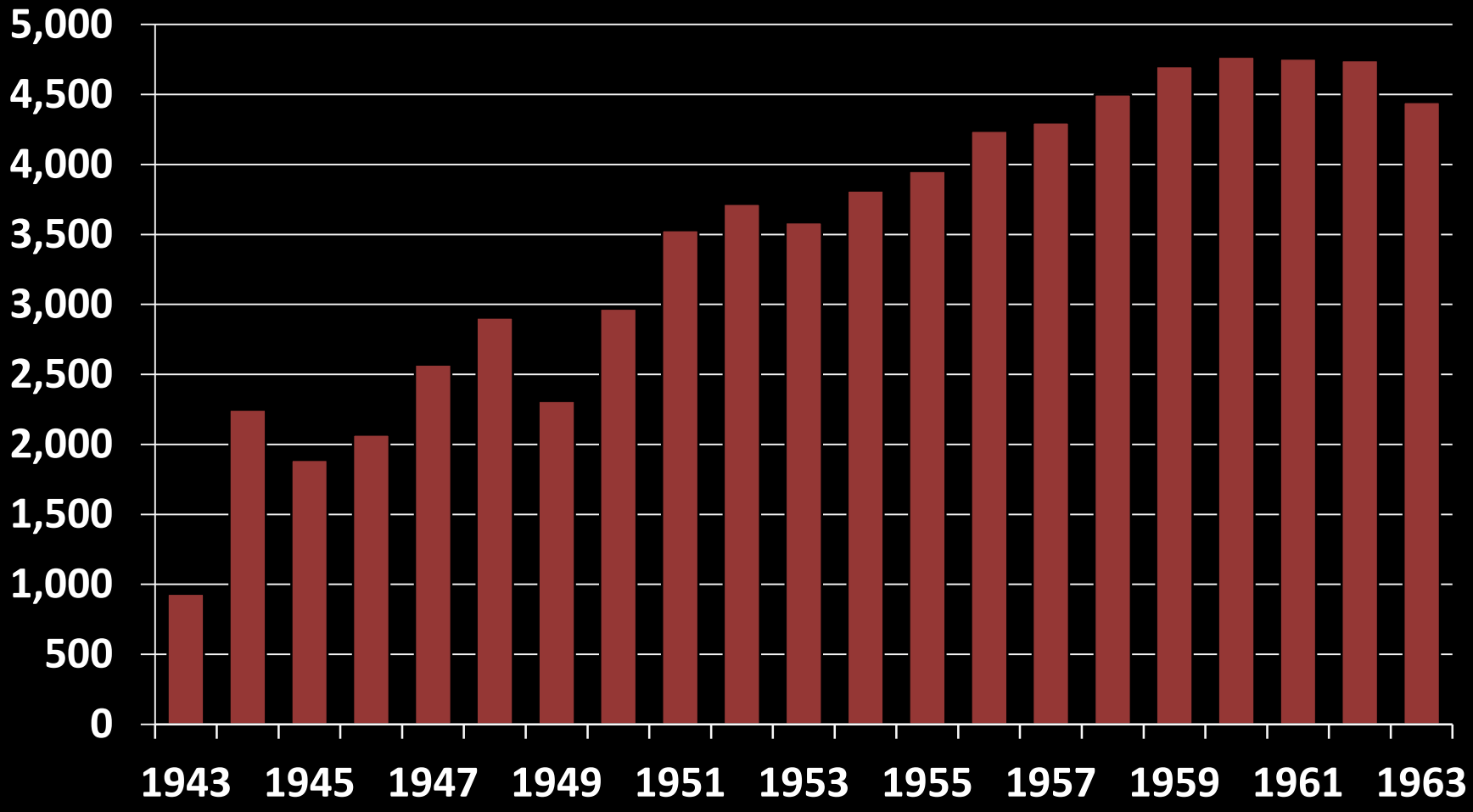
Whole body counter began operation around 1960.

Thyroid and chest counts for iodine (0.4-0.8 MeV) in 1944 for a particular (unspecified) project.

- Results reported in counts/minute.
- Background rate reported (count with “no one around”)
- Gamma counter placed as close as possible to the thyroid.
- Third count against lower chest to check clothing contamination and shielding effect of body.

ORNL External Dosimetry

No. of Workers Monitored



ORNL External Dosimetry

October 1943	ORNL issued 2 PICs to workers assigned to the entries into restricted areas associated with Graphite Reactor more than 3 times/wk.
June 1944	Film with two emulsions as the primary β-γ dosimeter of record. It used 2 windows: Open, & under a 900 mg/cm^2 Cd filter. Initially assigned only to employees required to work in restricted areas ≥ 3 days/wk.

ORNL External Dosimetry

Sept 1953	Film dosimeter with 4 shields (plastic, Cu, Pb, & Cd) to enable depth-dose measurements per NBS Handbook 59 (1954). However, no routine determination of skin dose was made because the element was behind an effective density-thickness of ~80 mg/cm^2.
1961	Model II Film Dosimeter: Only the skin (or superficial) dose and the critical organ dose measured. Techniques developed for skin dose based on extrapolation of the response of the film element under the OW of the dosimeter.

ORNL Neutron Dosimetry

February 1945	NTA film was apparently used on a limited basis to supplement field measurements.
1949	Neutron monitoring using NTA film: Neutron dose data recorded for both the open window and behind the Cd shield. The readings recorded as a fraction of tolerance values for fast & thermal neutron exposures and tolerance expressed in terms of number of tracks per field.

Mound Laboratory

- Began operations in September 1943 as Dayton Laboratories.
- Separation and processing of Po-210.
- Manufacture of PoBe neutron sources.
- Plutonium activities included fabrication of initiators, neutron sources, and fuel for RTGs.
- Ac-227 research.

Mound Bioassay

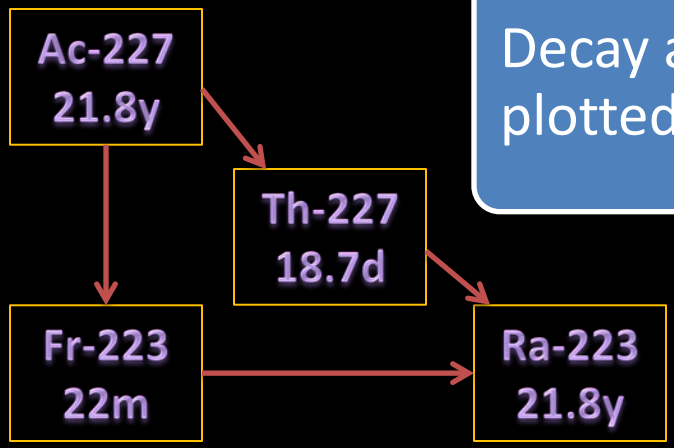
Program	Period	Monitored personnel	Frequency
Po-210 processing	1944–1974	Operations	Weekly spots, weekly 24h
Ac-227, Ra-226, Th-228	1951–1960	Research	Weekly 24h
Th-232 sludge, redrumming	1955–1975	Th refinery	Monthly 24h
Th-230 (ionium) research	1956–1959	Research	Biweekly 24h
Pa-231 extraction	1956–1960	Research	Monthly 24h
U-233 research	1958–1960	10 research	Weekly 24h
Tritium (hot gas) production	1957–close	Recovery	Weekly spots, weekly 24h
Pu-239 neutron source	1957–close	Processing	Quarterly
Pu-238 heat source	1960–close	Processing	Quarterly

Ra-226, Ac-227, Th-228 Bioassay

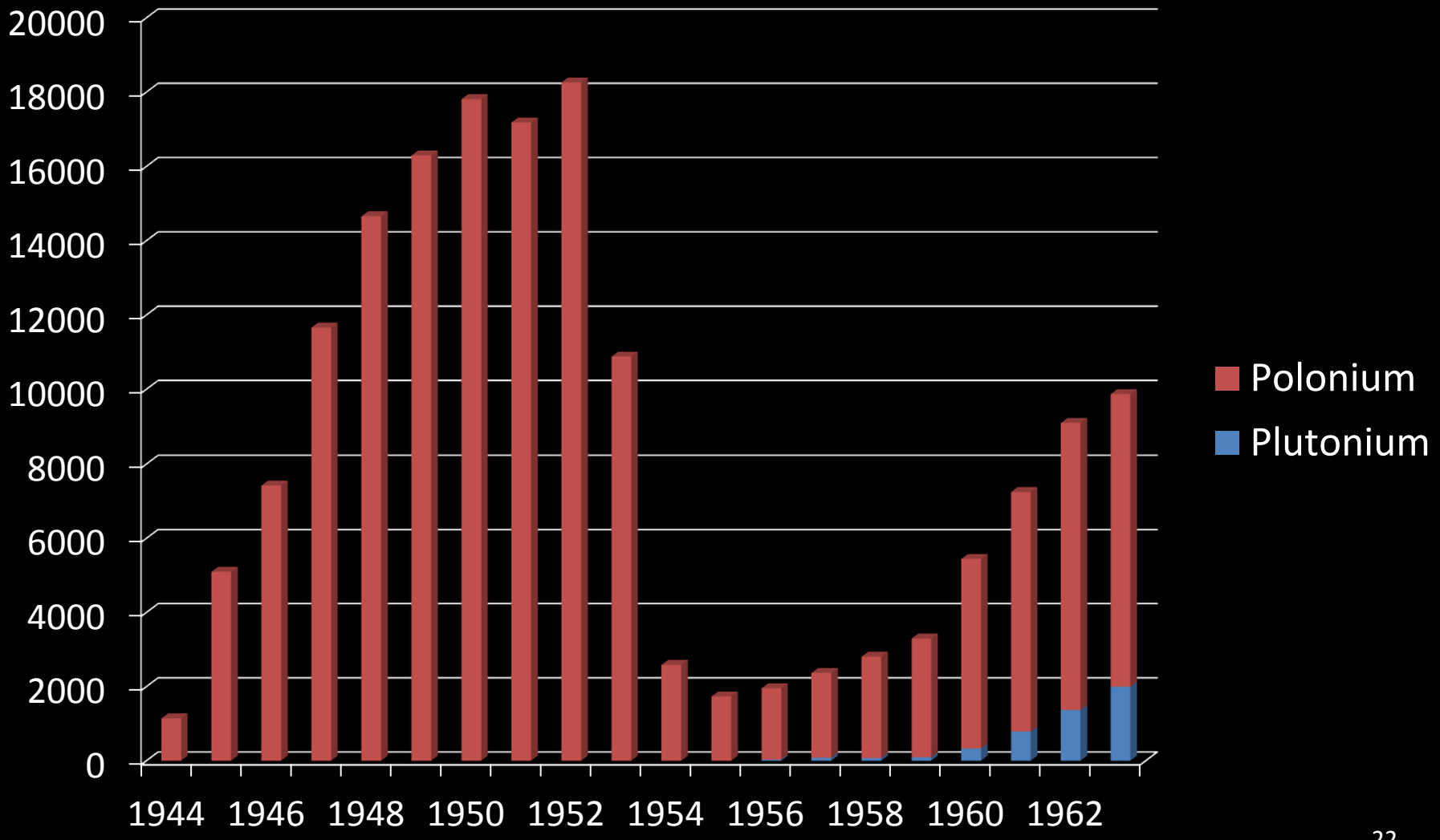
Th and Ra chemically separated from urine samples

Ra fraction counted periodically for several weeks (alpha activity)

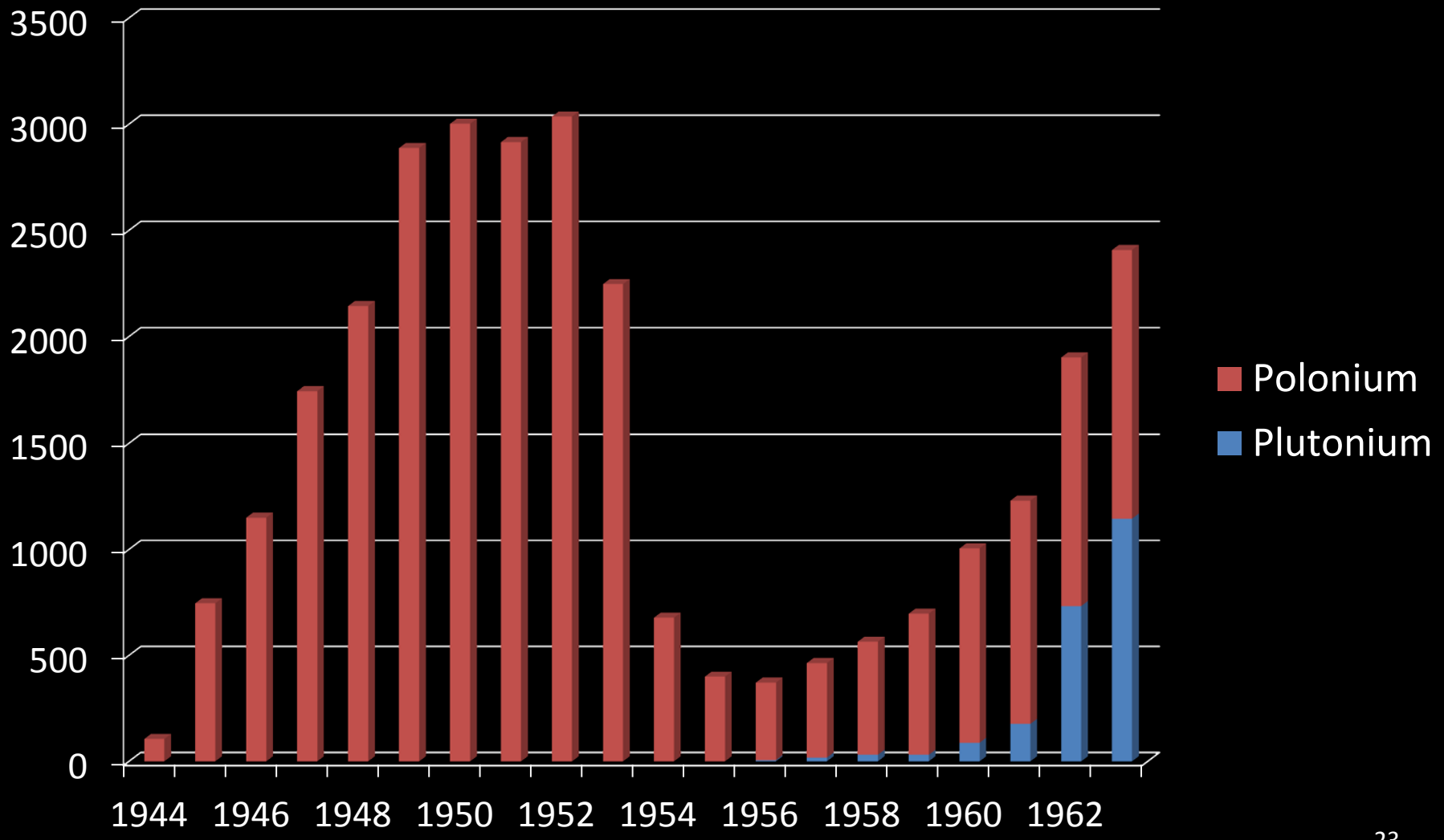
Decay and in-growth curves plotted, activities calculated



Mound Urinalysis: Samples/yr



Mound Urinalysis: People Sampled/yr



Mound Dosimeter Assignment Policies Photon

Feb. 1944	Finger ring (β) and whole-body film badges provided to some workers. Weekly limits & reports.
Aug. 1946	Wrist film badges provided to production employees.
Feb. 1949	Film badges, one sensitive and one insensitive film, with 1-mm Cd filter read weekly and 2 pocket ion chambers read daily. β-window was not read.
Dec. 1951	Film badges read every 2 weeks.
May 1966	Use of pocket ion chambers discontinued.

Mound Dosimeter Assignment Policies Neutron

Sept. 1949	NTA track etch film for fast neutrons. Read 10 fields for neutron tracks at 980-power magnification and averaged readings.
Sept. 1956	Began reading 10 fields at 430-power magnification with projection microscope and averaged values.
Dec. 1957	Returned to using 980-power projection microscope to read NTA film.
March 1963	Began using 400-power projection microscope. Reading 64 fields and averaging.

Hanford Site

- Began operations in 1943.
- Nuclear fuel fabrication.
- Reactor operations.
- Radiochemical separations.
- Refining, finishing and storing plutonium.

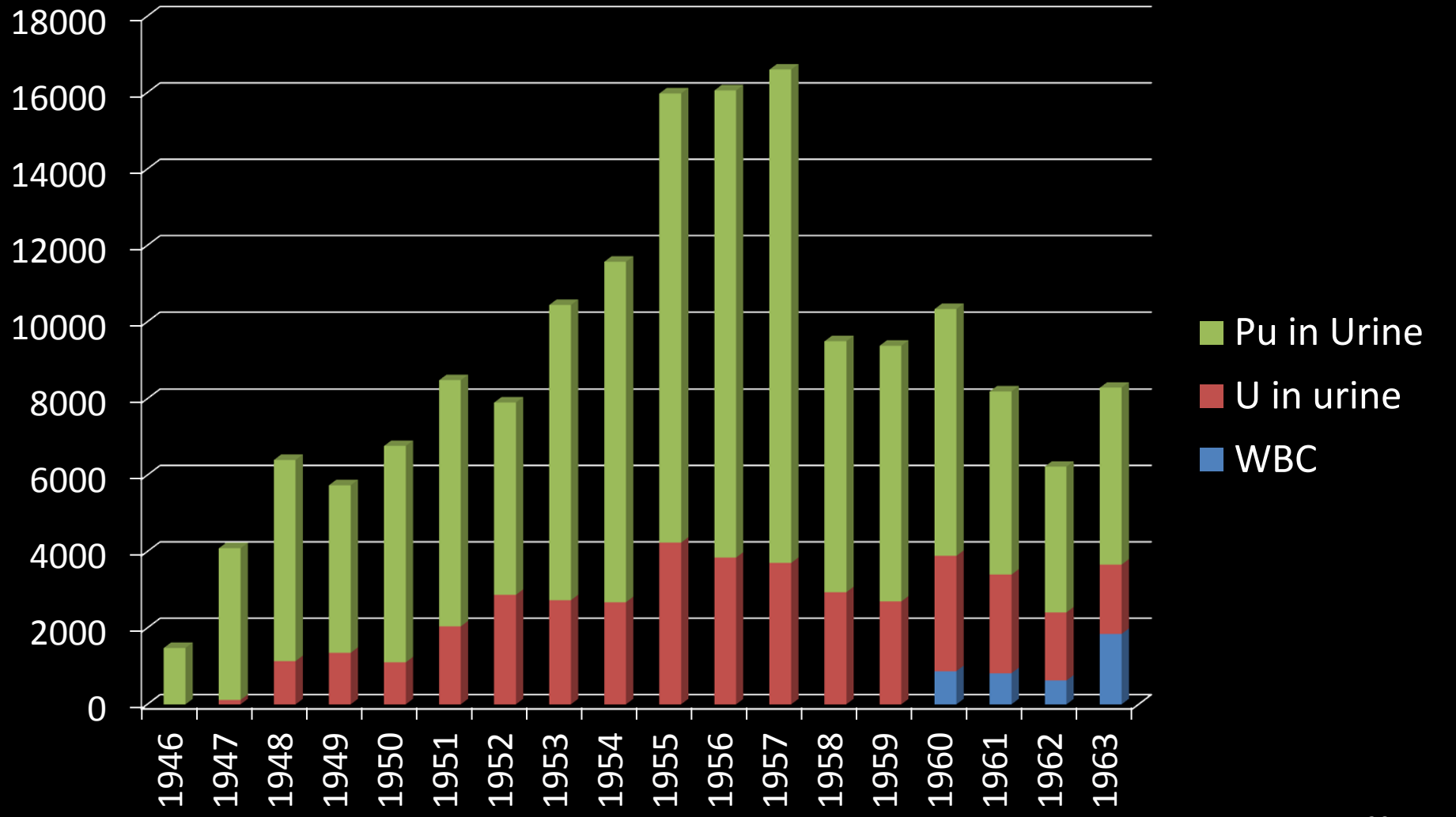
Hanford Bioassay

- Bioassay program began in 1946.
- Plutonium bioassay analysis:
  - Initially LaF_3 precipitation, thenoyl trifluoroacetone (TTA) extraction, followed by gross alpha counting.
  - December 1952: Electrodeposition on a stainless-steel disk in combination with nuclear track emulsion (autoradiography).
- H-3 bioassay began 1949.
- Uranium analysis by fluorometric method beginning 1948.

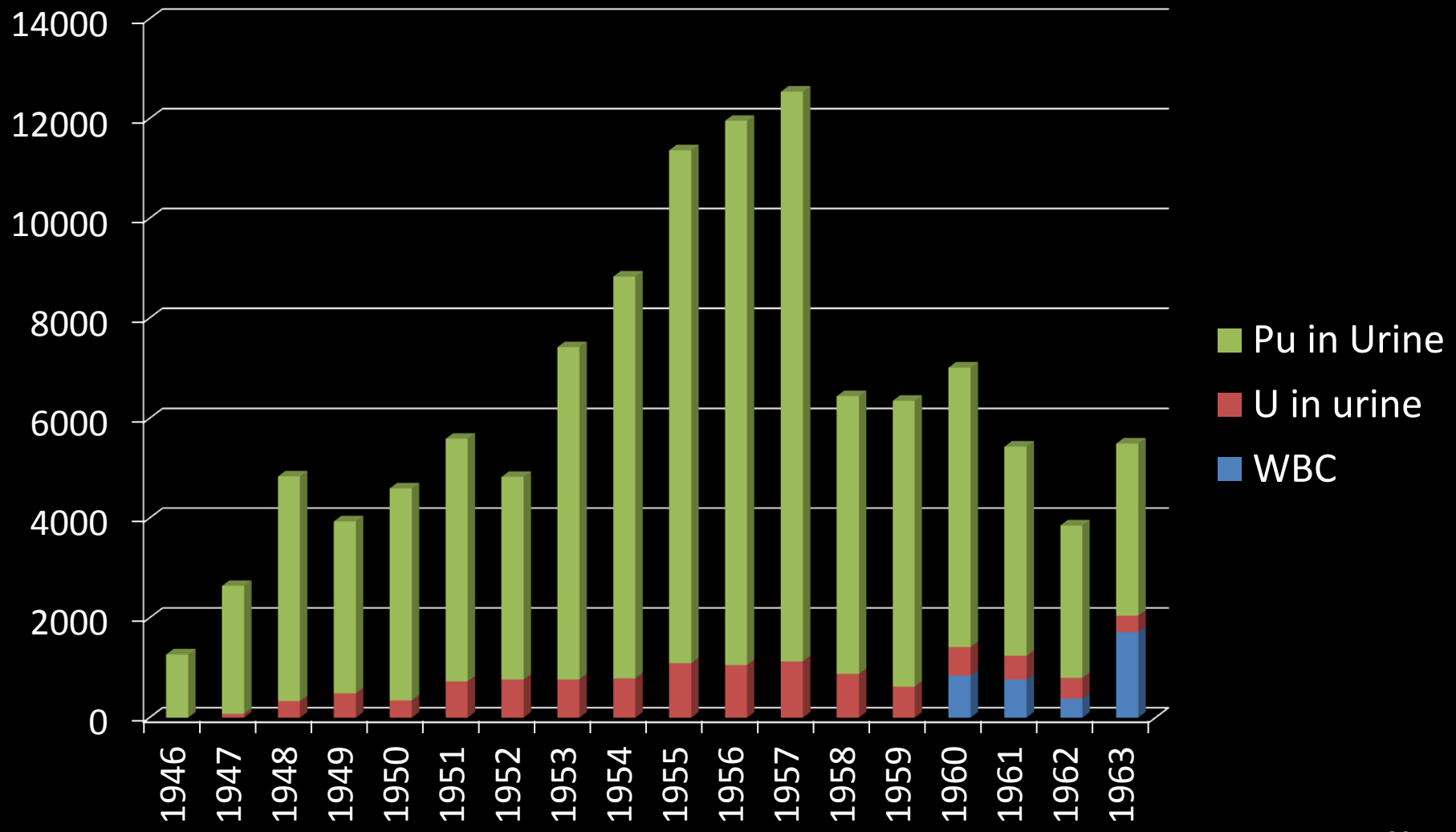
Hanford Bioassay: Fission Products

- Routine urinalysis began Jan. 1947
  - $Fe(OH)_2$ precipitation was used on the supernatant from the plutonium LaF_3 procedure.
  - Results were erratic with occasional breakthrough of ^{40}K.
- 1948 saw the addition of Sr carrier to the Al_2O_3 solution for the Pu procedure
  - Gas-flow proportional counter introduced in 1958.
  - Extracted alkaline and rare earths such as Sr, Y, Ba, La, Ce, Eu, Pm, Zr, Nb.
  - Did not include Ru, Cs, Co, Zn, Mn.
- Whole body counts beginning 1960.

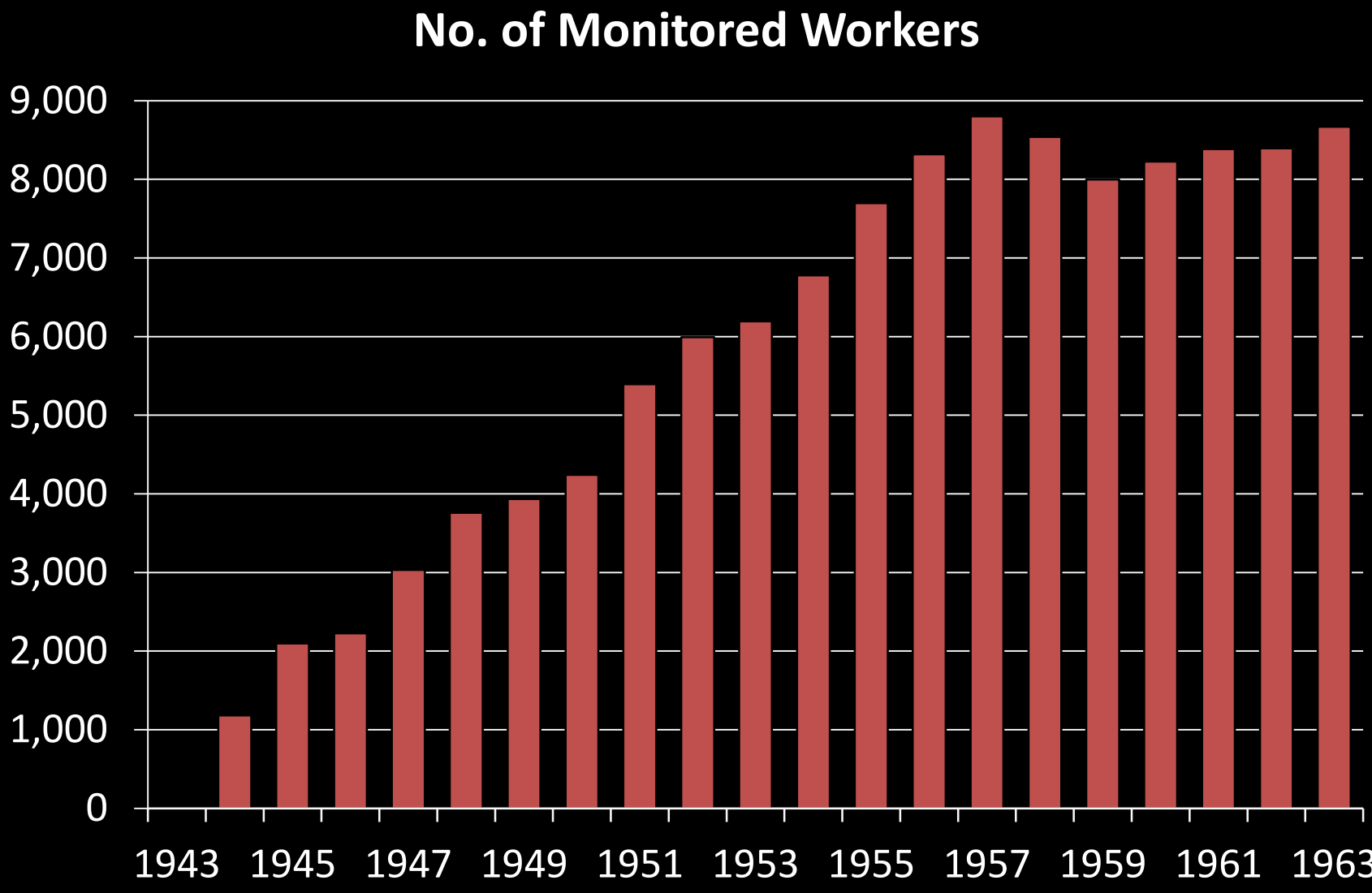
Hanford Internal Monitoring: Samples/yr



Hanford Internal Monitoring: People Sampled/yr



Hanford External Dosimetry



Hanford External Dosimetry

1944-1947	β, γ: 2-element β/γ film dosimeter
	OW = open window (mrep*)
	S = “shielded filter” dosimeter response (mR)
	WB = S
	Skin = OW + S
1948-1950	β, γ: 2-element β/γ film dosimeter
	β = open window (mrep*)
	γ = “shielded filter” dosimeter response (mR)
	WB = γ
	Skin = β + WB

(* rep = roentgen-equivalent-physical, from 83 to 95 ergs/g of tissue)

Hanford External Dosimetry

1950-1957	β, γ, n: 2-element β/γ film + NTA dosimeter
	β = open window (mrep)
	γ = “shielded filter” dosimeter response (mR)
	WB = γ + n
	Skin = β + WB
1957-1958	β, γ, X, n: Multi-element β/γ film + NTA dosimeter
	WB = γ + 0.35% X + n
	Skin = β + γ + 65% X + n

Hanford External Dosimetry

1959-1971	β, γ, X, n_f & n_s:
	Multi-element β/γ film + NTA dosimeter
	WB = γ + n + 35% X-ray
	Skin = β + WB + 65% X-ray

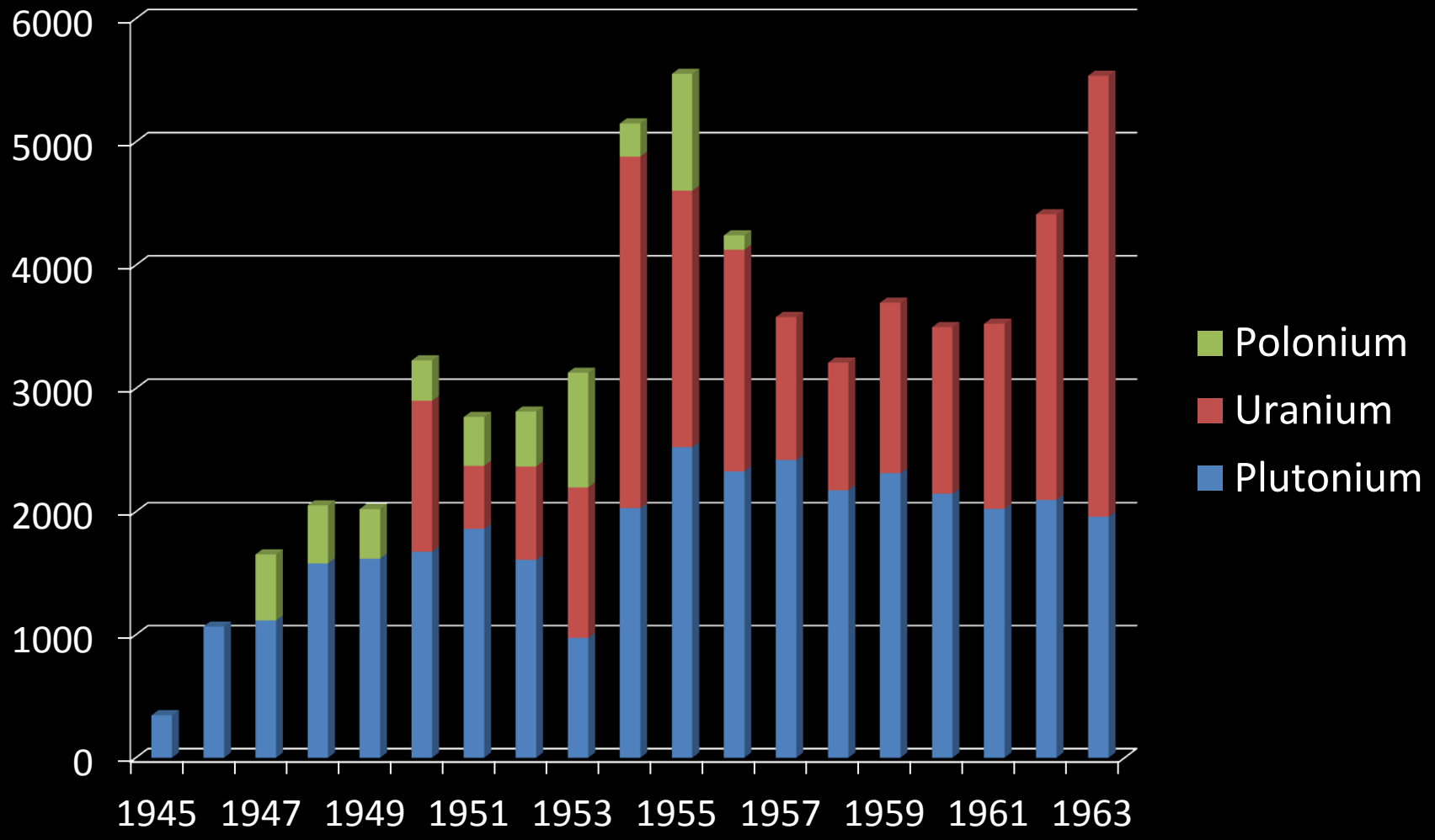
Los Alamos National Lab

- Began operations in 1943.
- Design and manufacture of the first nuclear weapons.
- Refining, finishing and storing plutonium.
- Cyclotron, Van de Graaff accelerator.
- Nuclear criticality experimentation.

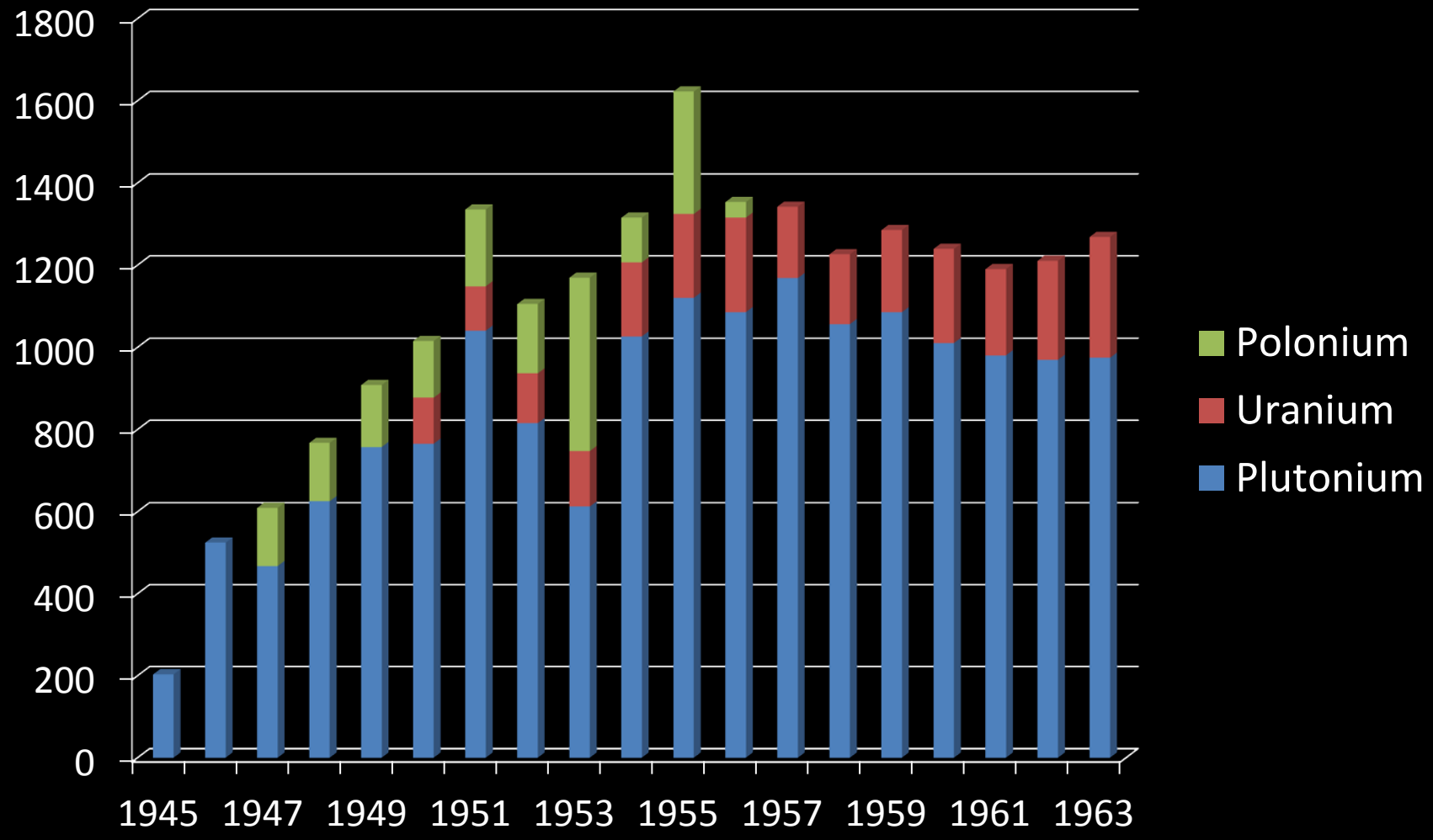
LANL Collection Procedures

Onset of program	Collected in clean area after decon shower
Spring 1945	One day to clean up
	2nd day in hospital to collect sample
1948	One day off to collect sample
1952-1958	Collection of equivalent 24-h sample while off site
	Samples collected in 3 bottles carried in a kit

LANL Urinalysis: Samples/yr



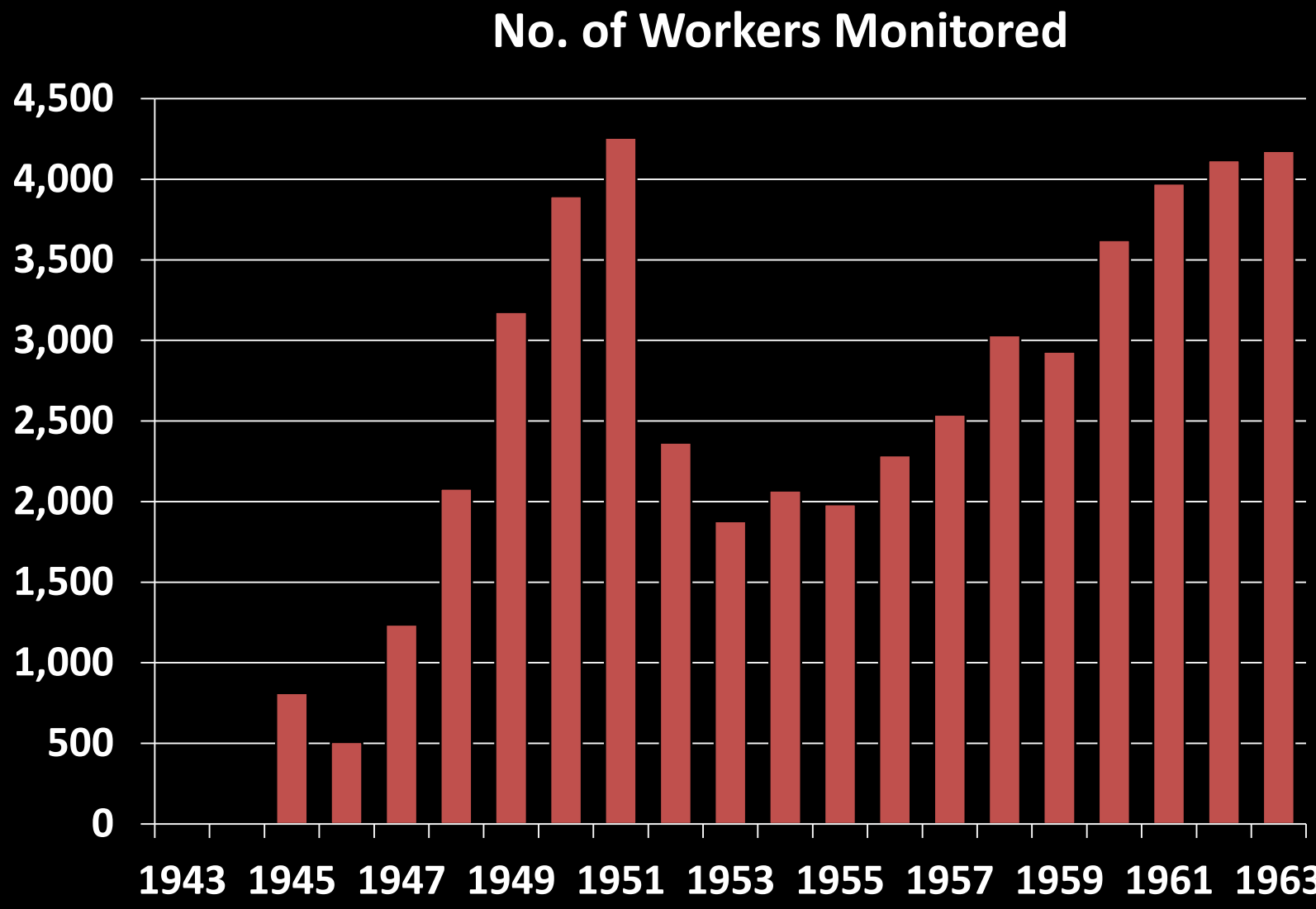
LANL Urinalysis: People Sampled/yr



UPPU Club

- Formed by Wright Langham in early ’50s.
- Study of individuals with significant Pu intakes (i.e., measurable body burdens by the bioassay methods of the time).
- Exposures primarily occurred in mid ’40s.
- Follow-up, including extensive medical exams, at 2-, then 5-, year intervals.

LANL External Dosimetry



LANL External Dosimetry

1943	Some workers were monitored with PICs alone in the beginning.
	PICs were assigned to persons with the highest potential for receiving ‘tolerance’ limit” of 0.1 R/d
1943	The phase-in of film dosimetry methods.
	Only workers with the “higher exposure potentials” dosimeter.
	More and more groups started using film badges for photon dosimetry.

LANL External Dosimetry

1943 - 1945	Brass film badges (film placed directly in a brass container, with no window of any sort or filters of any other metal).
	Only γ exposure in R was evaluated.
October 1948	The need for film monitoring at the DP West plutonium facilities was recognized because of spontaneous fission in plutonium and the possibility of a criticality accident.
	AEC regulations required that film badges be worn in any area where RAM were handled.

LANL External Dosimetry

1949	The following values were recorded on personnel exposure sheets:
	- PIC reading in (R) ; γ (R); β (rep)
	- β exposure reported only when significant
	New badge introduced for β exposures evaluation.
1950-1970	β/γ film badge designs changed several times through the 1950s, 1960s, and 1970s as filters of various types were used to address the energy-dependent response of film.

LANL Neutron Dosimetry

1945	Workers not provided dosimeters at earliest criticality experiments and accidents at LANL. Worker exposures calculated from activation measurements and area film badges.
Prior to 1949	Neutron dosimetry for selected workers with the use of PICs w/ Bakelite chambers and graphite coatings. Results recorded in 'n' units, defined as “the quantity of neutron radiation that will produce the same ionization in a 100-R Victoreen chamber (red Bakelite) as 1 R of γ”. N-unit data were recorded in medical records of some individuals, but were apparently never converted to the computerized database.

LANL Neutron Dosimetry

1949	Nuclear Track Plates (NTPs) were first used.
1951	Badges w/ Eastman Kodak Type A (NTA) film used.
February 1956	NTPs evaluated by assuming all 10- to 100-µm tracks represented 3.75-MeV neutrons and all longer tracks represented the E_{max} of the higher E neutrons in the workplace.
1960	The following external radiation dose data recorded: • γ dose (rem); • β dose (rad); • WB = γ + 0.35% X + n; • N_{th} dose (Cd O.D. - Brass O.D. in rem); • N_f dose (from NTA film in rem)

LANL External Dosimetry

Period	Values recorded in exposure records
1943 – 1948	PIC reading: • γ exposure
1949 – 1950	PIC reading: • γ exposure • β exposure
1951 – 1959	PIC reading: • γ exposure • β exposure • n_f dose
1960 – 1979	PIC reading: • γ exposure • β exposure • n_f dose

Data Sources

- NIOSH Radiation Dose Reconstruction Program
  - Site profiles
  - http://www.cdc.gov/niosh/ocas/
- Comprehensive Epidemiologic Data Resource (CEDR)
  - De-identified monitoring data.
  - Health studies of DOE contract workers and environmental studies of areas surrounding DOE facilities.
  - https://apps.orau.gov/cedr/