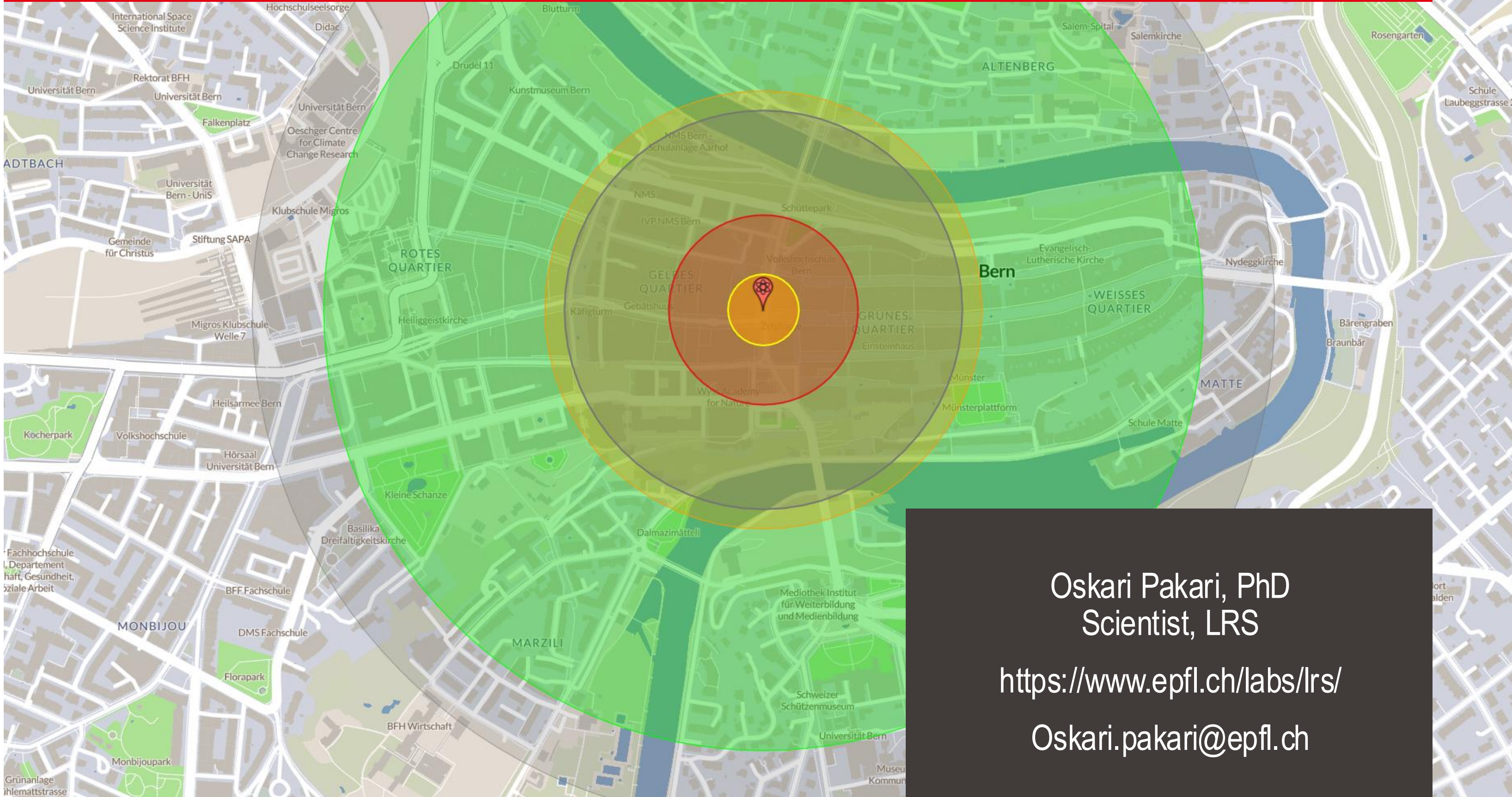
Radiation Biology, Protection and Applications
Accident and Emergency Dosimetry



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Content Warning

This presentation contains medical images, including depictions of injuries, which some viewers may find distressing. Viewer discretion is advised.

Accidents: workers vs public

- High levels of exposure of accidentally exposed workers might be associated with nuclear or radiological emergencies
  - Emergency at a nuclear power plant
  - Criticality accident
  - Emergency at an industrial irradiation facility
  - Emergency involving a lost or stolen source
  - Emergency at a medical facility
- dosimeter should be present in normal cases
- Can include workers that are normally not occupationally exposed
  - No dosimeter present!
- Accidents can also involve public and patients: no dosimeter present!

Need for dosimetry in accidents

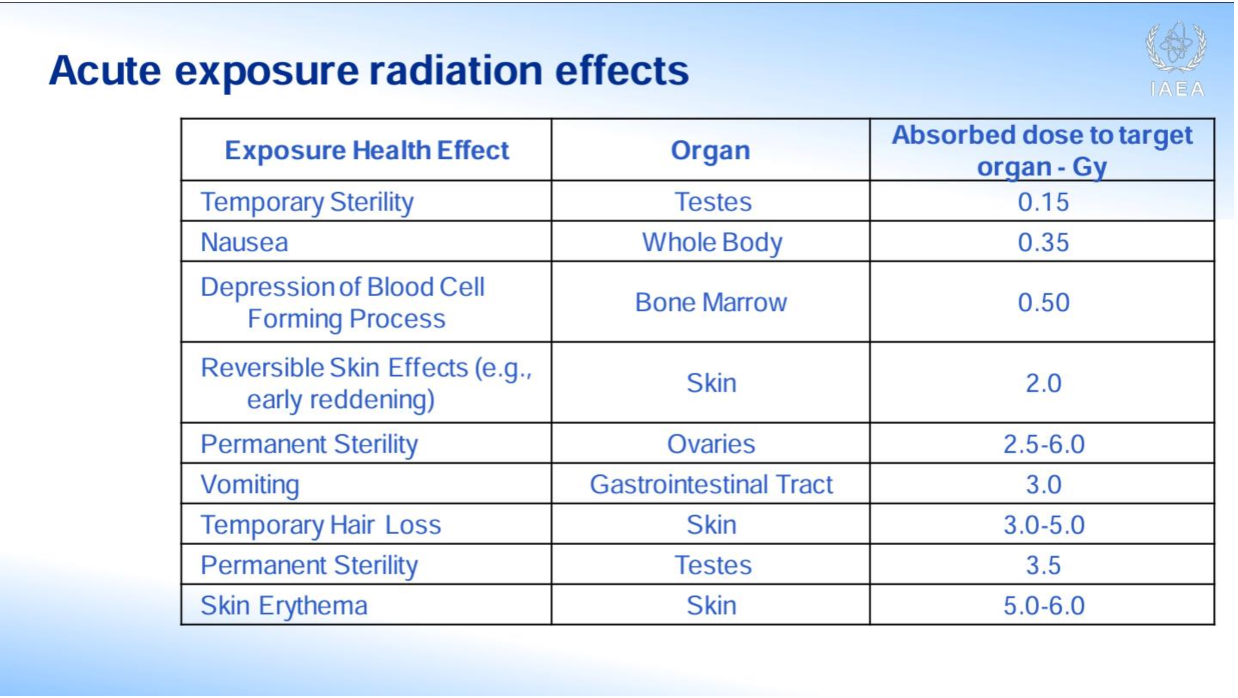
- Dosimetry is needed for medical purposes
- Different kind of accidents
  - Small-scale accidents involving just a few people
  - Large-scale events, either accidental or intentional, that may involve thousands of individuals.
- The numbers of people potentially exposed and requiring dosimetry, including the “worried well”, may vary from small to large

Medical questions after accident

- Immediately after the event: What adverse health effects should be expected?
  - The need for initial-phase dose assessment to identify those in need of medical intervention due to deterministic, tissue effects
  - The assessed doses may also later become part of epidemiologic and long-term risk assessment
- Years after the event: What were the actual health consequences?
  - primarily for epidemiology
- Long-time-after-the-event dosimetry: related to stochastic injury for epidemiologic studies
- short-time-after the event dosimetry: related to deterministic, tissue injury (e.g., acute radiation syndrome)
- Good dosimetry is essential to answering these questions.

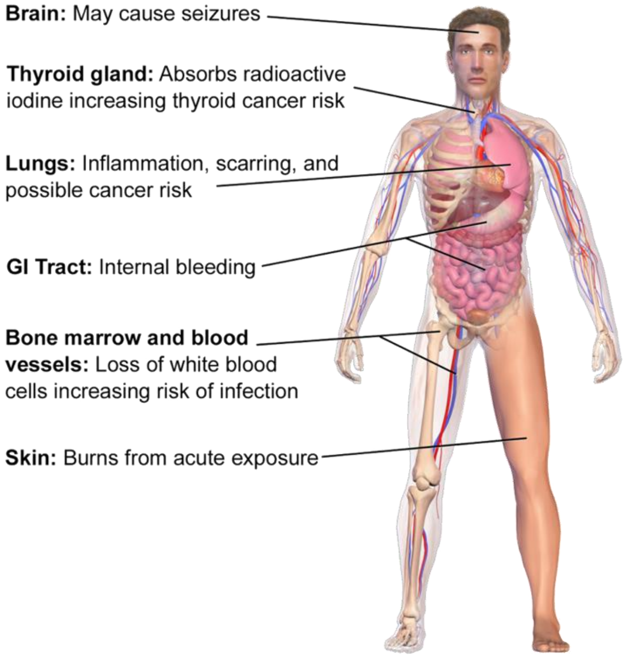
Biological effects of short term radiation

Dose Gy	Effect
< 0.2	No detectable effects
0.2-1.0	Measurable transient blood changes. Temporary decrease in white blood cell count.
1.0-2.0	Acute radiation sickness - nausea, vomiting, longer term decrease in white blood cells.
2.0-3.0	Vomiting, diarrhea, loss of appetite, listlessness, death in some cases.
3.0-6.0	Vomiting, diarrhea, hemorrhaging, deaths occurring in 50% of cases at 3.5 Gy or above without medical treatment.
Above 6.0	Eventual death in almost all cases



Acute exposure radiation effects

Exposure Health Effect	Organ	Absorbed dose to target organ - Gy
Temporary Sterility	Testes	0.15
Nausea	Whole Body	0.35
Depression of Blood Cell Forming Process	Bone Marrow	0.50
Reversible Skin Effects (e.g., early reddening)	Skin	2.0
Permanent Sterility	Ovaries	2.5-6.0
Vomiting	Gastrointestinal Tract	3.0
Temporary Hair Loss	Skin	3.0-5.0
Permanent Sterility	Testes	3.5
Skin Erythema	Skin	5.0-6.0



Selected Risks from Radiation Sickness

Phase	Symptom	Whole-body absorbed dose (Gy)				
		1–2 Gy	2–6 Gy	6–8 Gy	8–30 Gy	> 30 Gy
Immediate	Nausea and vomiting	5–50%	50–100%	75–100%	90–100%	100%
	Time of onset	2–6 h	1–2 h	10–60 min	< 10 min	Minutes
	Duration	< 24 h	24–48 h	< 48 h	< 48 h	— (patients die in < 48 h)
	Diarrhea	None	None to mild (< 10%)	Heavy (> 10%)	Heavy (> 95%)	Heavy (100%)
	Time of onset	—	3–8 h	1–3 h	< 1 h	< 1 h
	Headache	Slight	Mild to moderate (50%)	Moderate (80%)	Severe (80–90%)	Severe (100%)
	Time of onset	—	4–24 h	3–4 h	1–2 h	< 1 h
	Fever	None	Moderate increase (10–100%)	Moderate to severe (100%)	Severe (100%)	Severe (100%)
	Time of onset	—	1–3 h	< 1 h	< 1 h	< 1 h
	CNS function	No impairment	Cognitive impairment 6–20 h	Cognitive impairment > 24 h	Rapid incapacitation	Seizures, tremor, ataxia, lethargy
Latent period		28–31 days	7–28 days	< 7 days	None	None

Phase	Symptom	Whole-body absorbed dose (Gy)				
		1–2 Gy	2–6 Gy	6–8 Gy	8–30 Gy	> 30 Gy
Illness		Mild to moderate Leukopenia Fatigue Weakness	Moderate to severe Leukopenia Purpura Hemorrhage Infections Alopecia after 3 Gy	Severe leukopenia High fever Diarrhea Vomiting Dizziness and disorientation Hypotension Electrolyte disturbance	Nausea Vomiting Severe diarrhea High fever Electrolyte disturbance Shock	— (patients die in < 48h)
Mortality	Without care	0–5%	5–95%	95–100%	100%	100%
	With care	0–5%	5–50%	50–100%	99–100%	100%
	Death	6–8 weeks	4–6 weeks	2–4 weeks	2 days – 2 weeks	1–2 days

Overview radiological accidents

- More than 600 incidents occurred since 1945, resulting in over 200 deaths
    - 41% industrial
    - 19% research
    - 4% military
    - 11% medical
    - 11% nuclear
    - Rest not defined
- 84% external
    - 12% whole body
    - Rest localized
- 10% internal
- Rest mixed
- Chernobyl, Fukushima not included

#1: Demon core incident

Three Pu cores were created by August 1945:
1) Gadget: Trinity test
2) Fat Man: Nagasaki bombing
3) ‘Third shot’, never used for bombing

May 21st 1946:
Criticality experiment with Pu core using Be reflector

‘Nuclear cowboy’ Louis Slotin performed an approach to criticality experiment by lowering the top Be half onto the Pu core – by hand and with a screwdriver (the flat end of the screwdriver was supposed to ensure minimal spacing between the spheres, thereby ensuring no super-criticality)

Re-creation of Slotin’s fatal experiment with the third core. (Source: Los Alamos)

Clip from 1989 Movie

Fat Man and Little Boy

Demon core incident aka Pojarito accident

- Screwdriver slips, core goes supercritical
- Flash of blue
- Slotin grab the sphere top half and removes it
- Slotin tells everone in the room to remain where they stood, gives them chalk to mark their locations

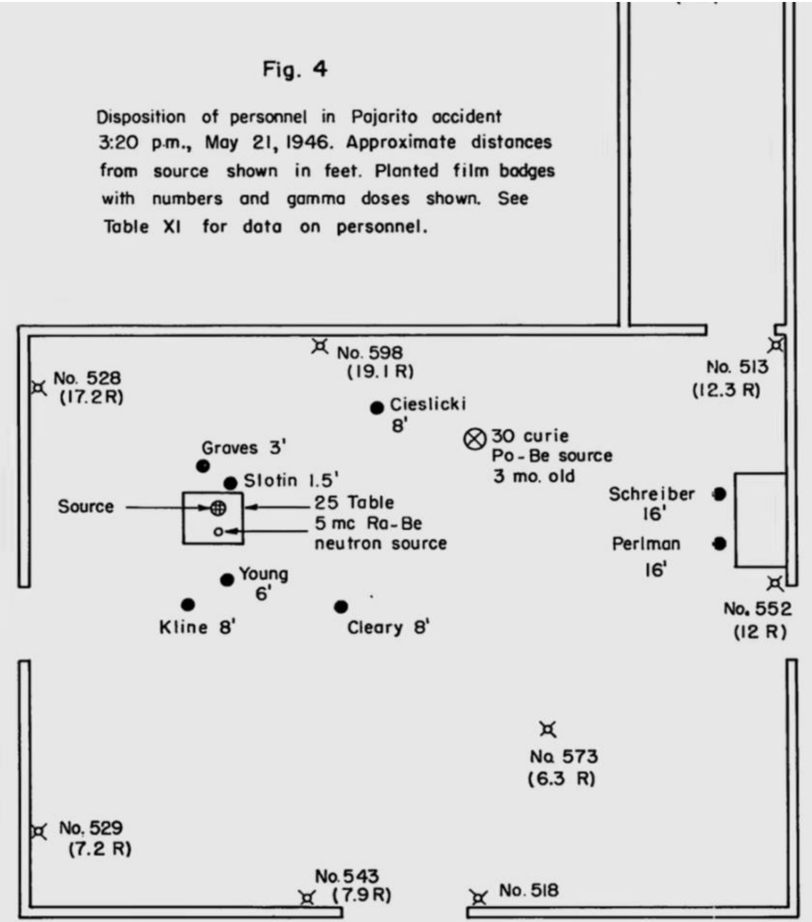


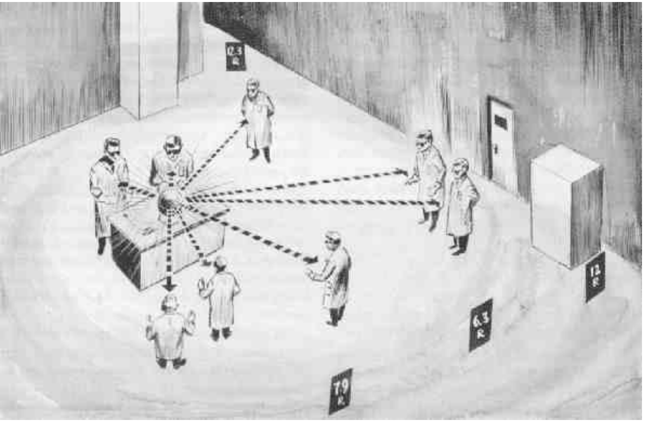
Fig. 4

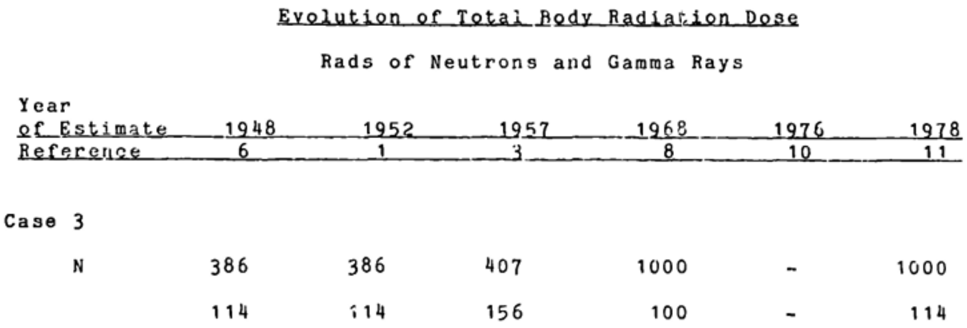
Disposition of personnel in Pojarito accident 3:20 p.m., May 21, 1946. Approximate distances from source shown in feet. Planted film badges with numbers and gamma doses shown. See Table XI for data on personnel.

How to determine the dose?

No dosimeters were worn!

Gamma dose was estimated based on total amount of fissions in the core and the distance of the individuals



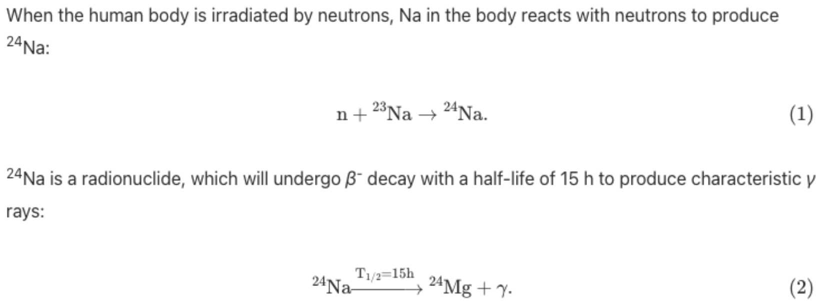


Evolution of Total Body Radiation Dose

Rads of Neutrons and Gamma Rays

Year of Estimate	1948	1952	1957	1968	1976	1978
Reference	6	1	3	8	10	11
Case 3						
N	386	386	407	1000	-	1000
	114	114	156	100	-	114

Neutron dose was estimated via Na24 activity in blood:



When the human body is irradiated by neutrons, Na in the body reacts with neutrons to produce ^{24}Na:

$$\mathrm{n} + {}^{23}\mathrm{Na} \rightarrow {}^{24}\mathrm{Na}. \qquad (1)$$

^{24}Na is a radionuclide, which will undergo β^- decay with a half-life of 15 h to produce characteristic γ rays:

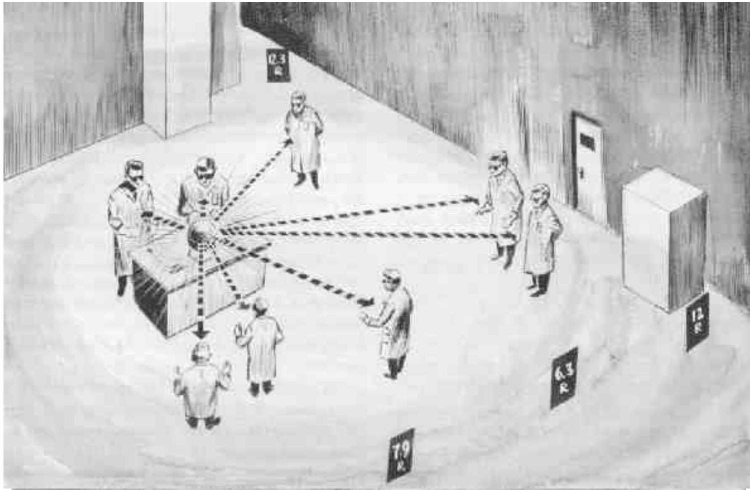
$$^{24}\mathrm{Na} \xrightarrow{\mathrm{T}_{1/2}=15\mathrm{h}} {}^{24}\mathrm{Mg} + \gamma. \qquad (2)$$

1966: Energy of n emitted in fission was measured

Aftermath

Name	Age at accident	Profession	Dose	Aftermath
Louis Alexander Slotin	32	Physicist	1,000 rad (10 Gy) neutron 114 rad (1.14 Gy) gamma	Died 9 days after the accident of acute radiation syndrome, gastrointestinal focus.
Alvin C. Graves	36	Physicist	166 rad (1.66 Gy) neutron 26 rad (0.26 Gy) gamma	Died in 1965 from heart attack. Heart problems exacerbated by radiation.
Marion Edward Cieslicki	23	Physicist	12 rad (0.12 Gy) neutron 4 rad (0.040 Gy) gamma	Died of leukemia in 1965.
Dwight Smith Young	54	Photographer	51 rad (0.51 Gy) neutron 11 rad (0.11 Gy) gamma	Died in 1975.
Raemer Edgar Schreiber	36	Physicist	9 rad (0.090 Gy) neutron 3 rad (0.030 Gy) gamma	Died in 1998.

⋮



What kind of dosimeters are used nowadays?

Luminescence dosimeters: advantages

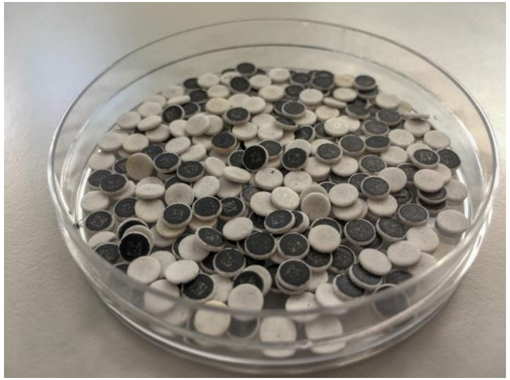
- Small detectors
- No cables
- Precision and accuracy
- Convenience (easy to read, cheap)
- Similar to tissue or water
- Minimal influence of magnetic field
- Supposedly minimal influence of dose rate

Most detectors use:

- **Thermally stimulated luminescence (TL)**
- **Optically stimulated luminescence (OSL)**
- **Radio-Photo-Luminescence (RPL)**

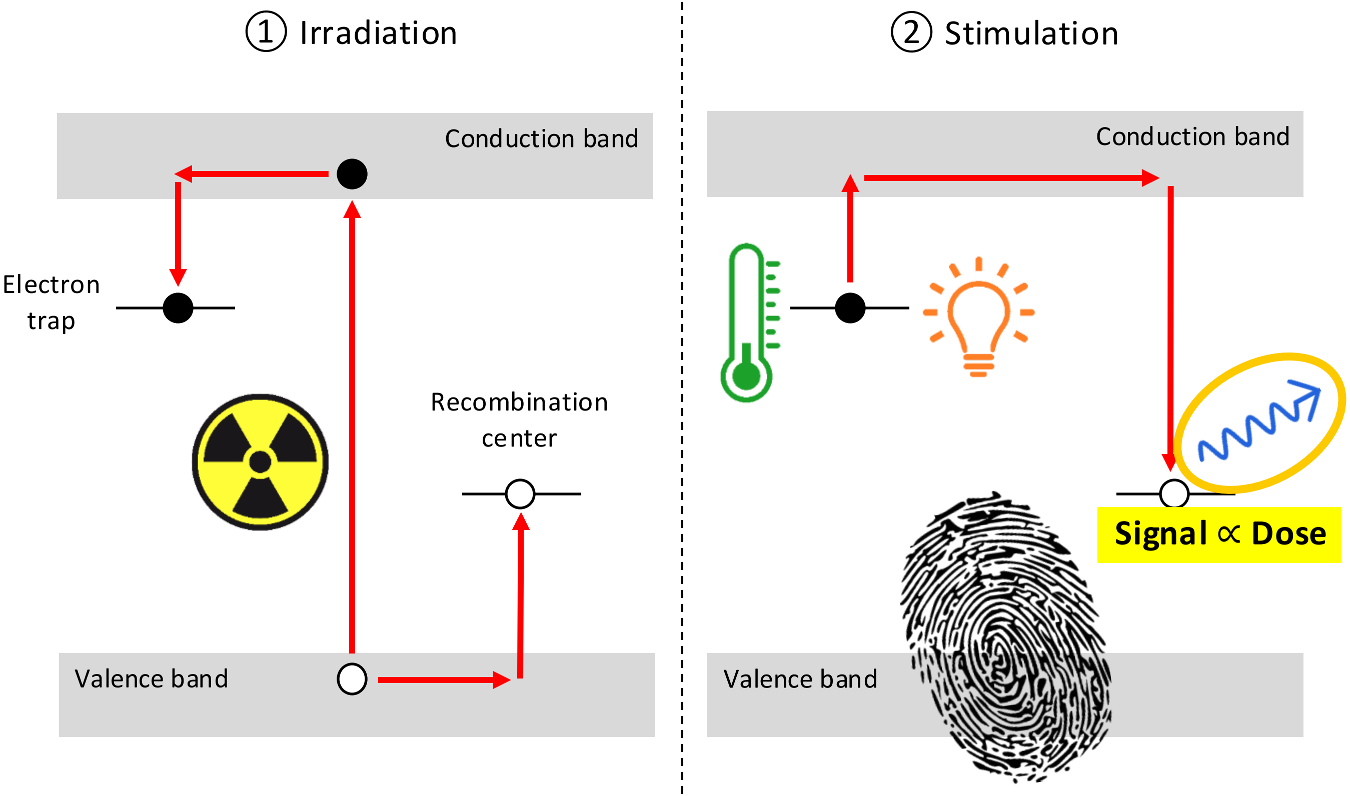
Examples of luminescent detectors

Thermoluminescence (TL) detectors
TLDs



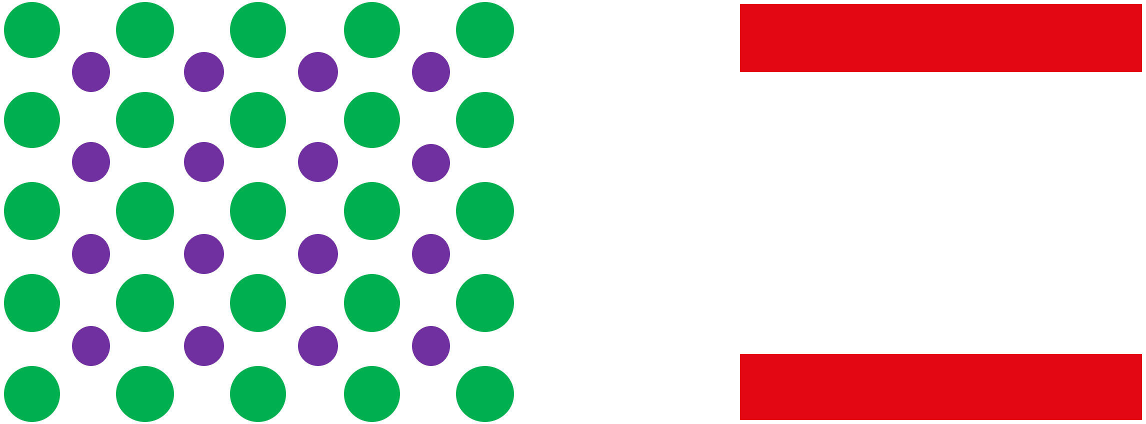
Optically stimulated
luminescence (OSL) detectors
OSLDs

Radiophotoluminescence (RPL)
detectors - RPLDs

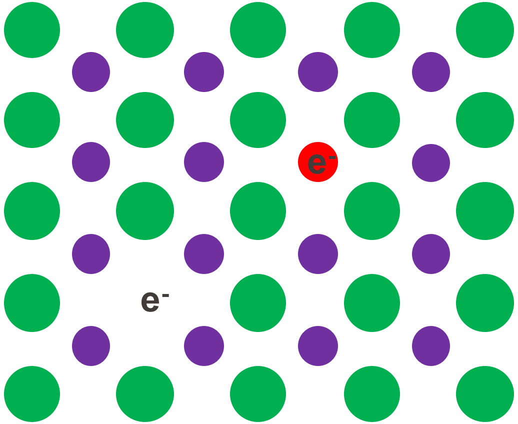

① Irradiation
② Stimulation
Conduction band
Electron trap
Recombination center
Valence band
Conduction band
Valence band

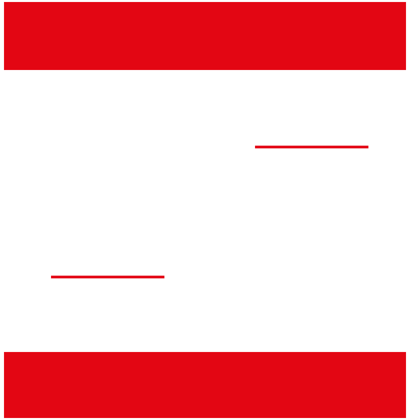
Signal ∝ Dose

A perfect crystal

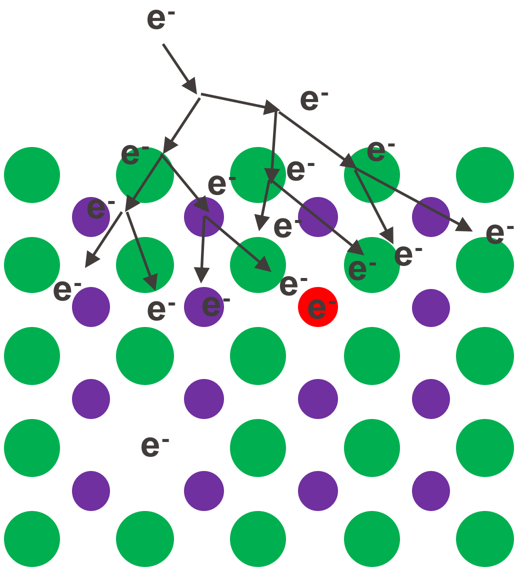


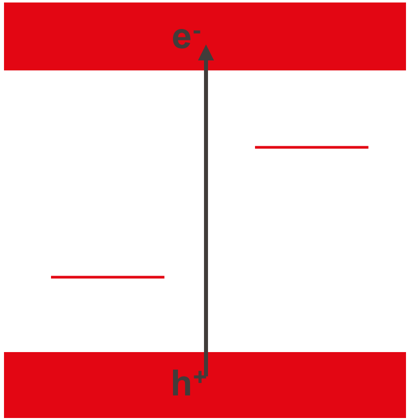
An imperfect perfect crystal



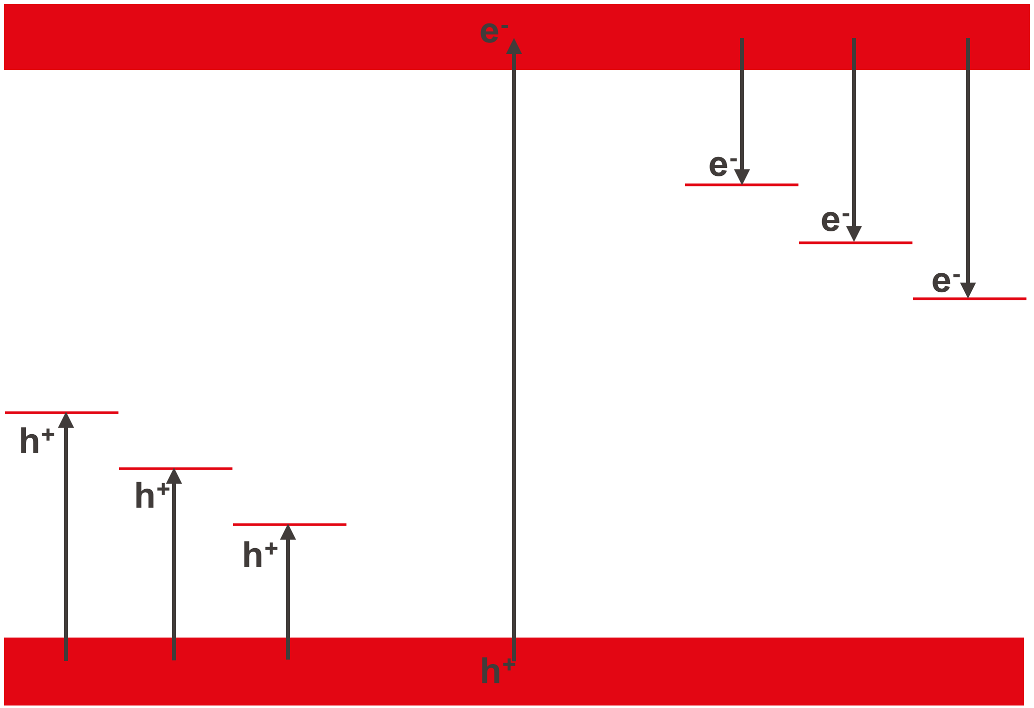


An irradiated imperfect crystal



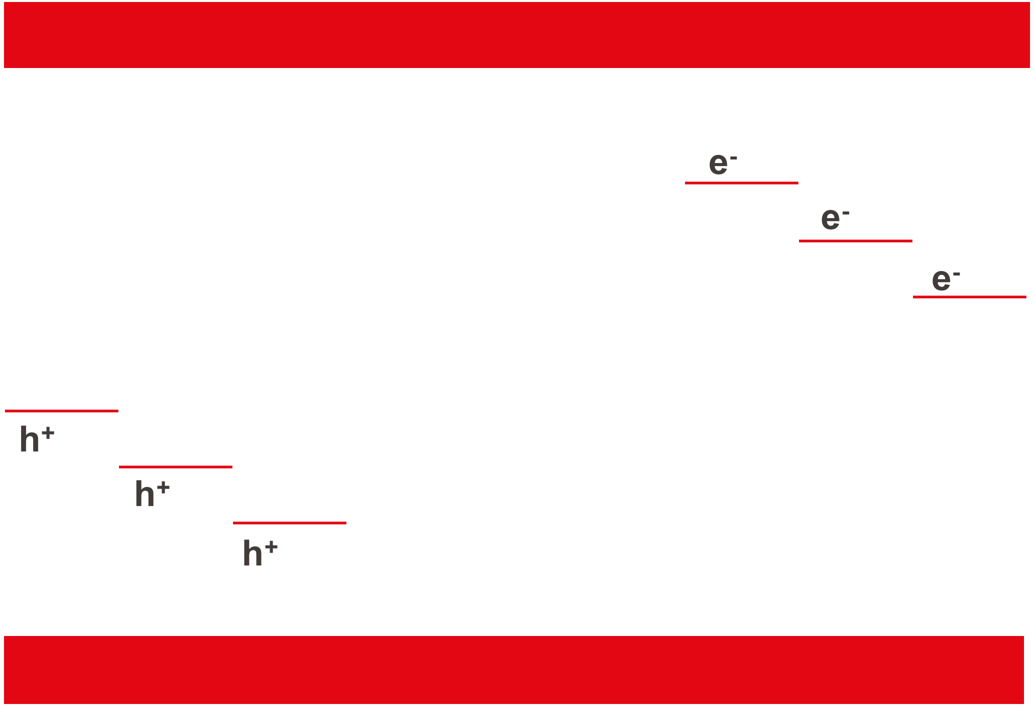


An irradiated imperfect crystal



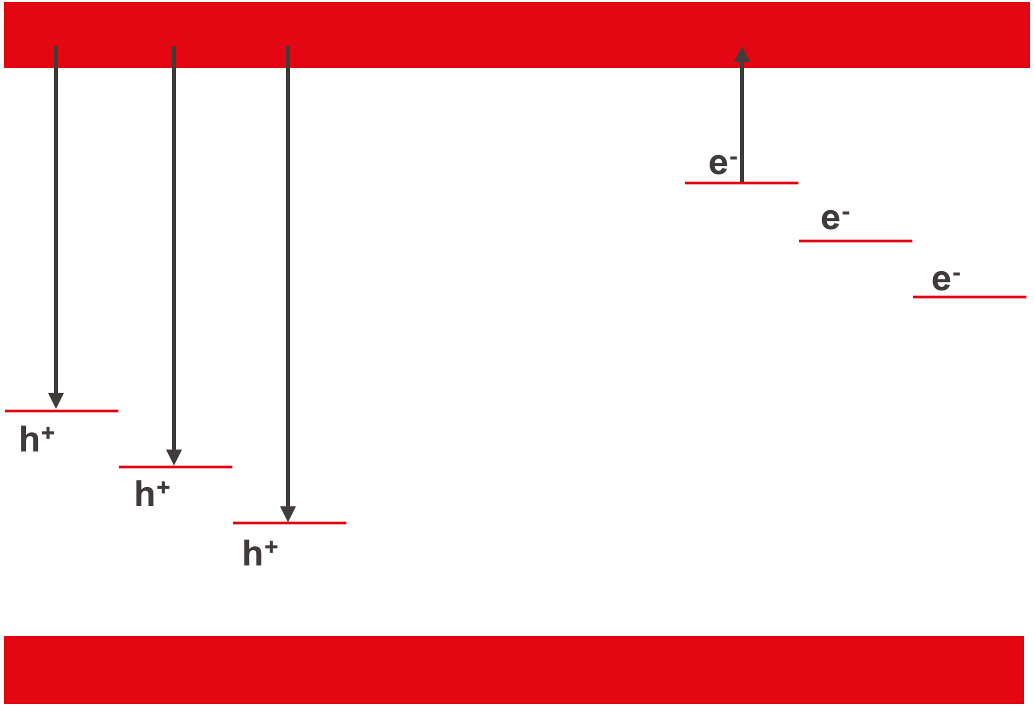
After irradiation: Stable traps

$$p(T) \sim \frac{1}{s} e^{\frac{-E}{kT}}$$

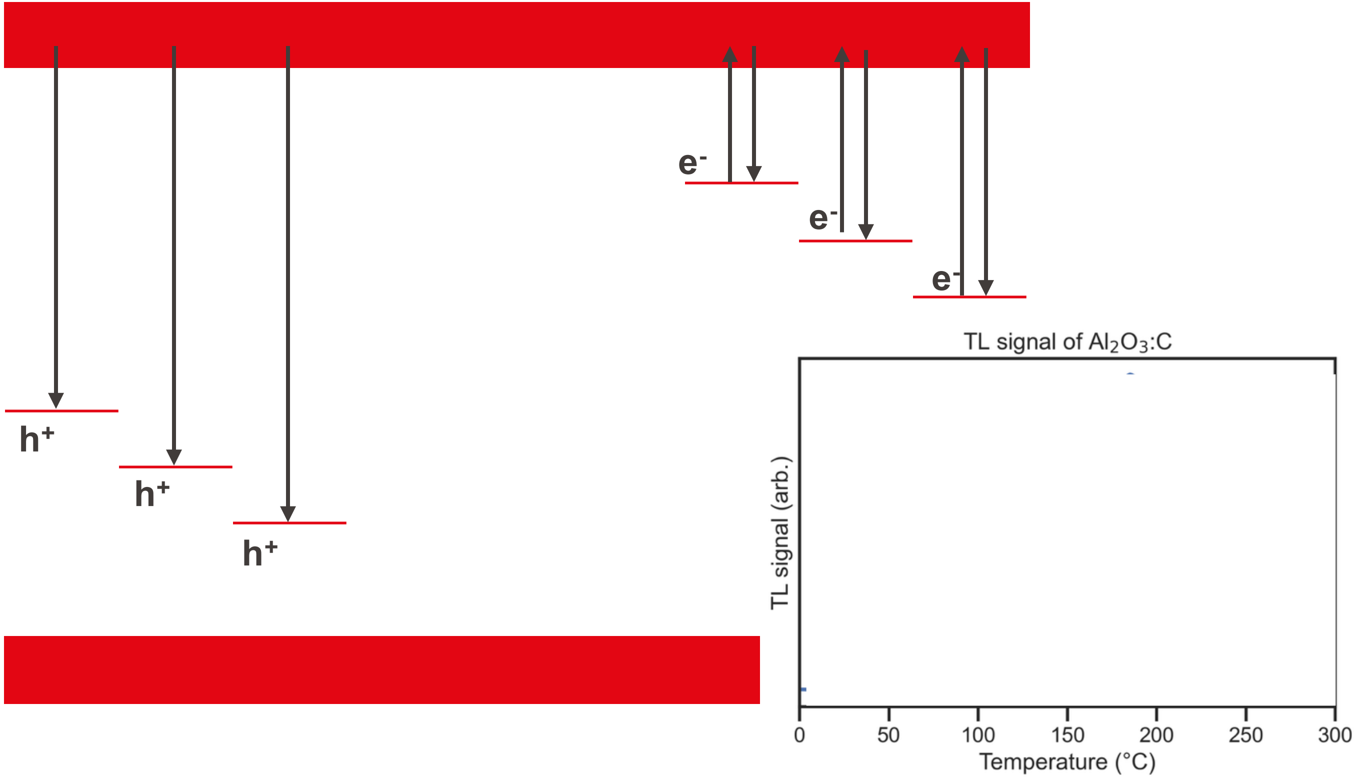


After irradiation:
Shallow traps at room temperature

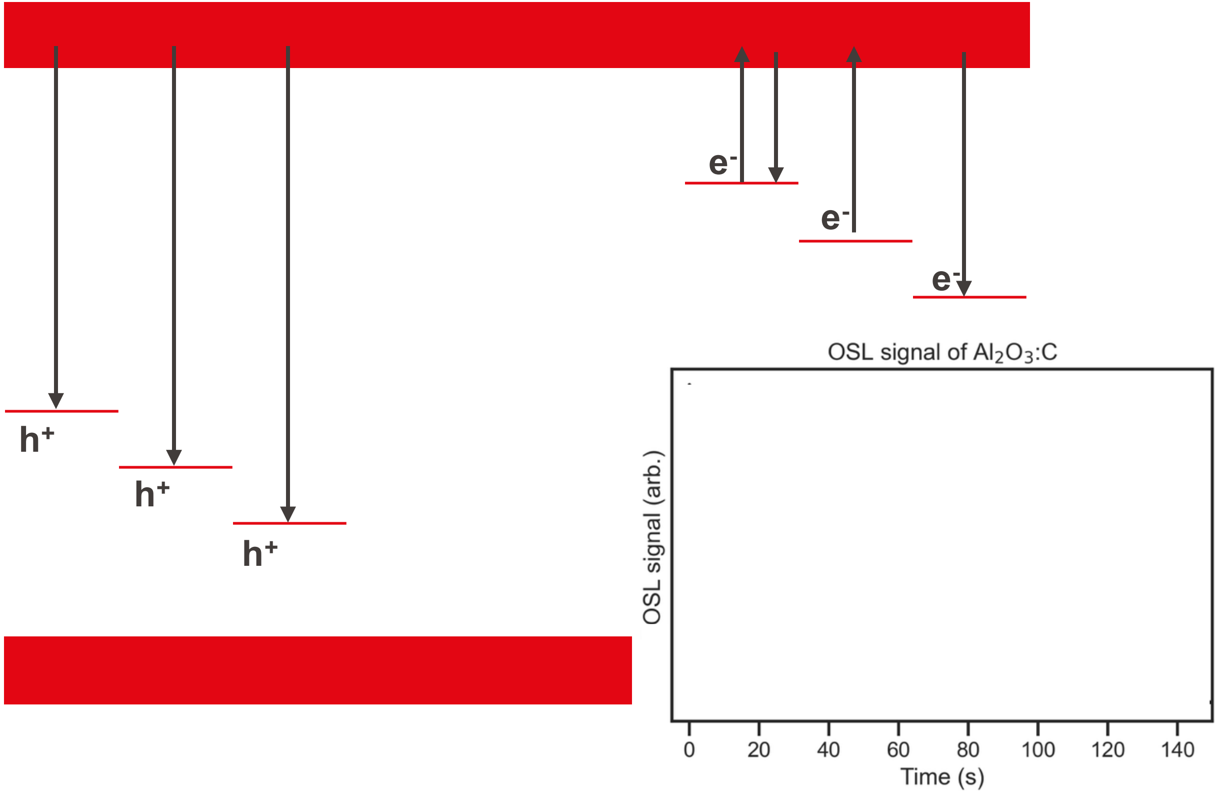
$$p(T) \sim \frac{1}{s} e^{\frac{-E}{kT}}$$



During TL readout



During OSL readout

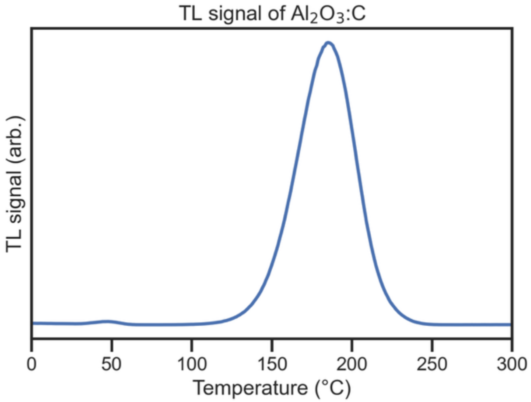


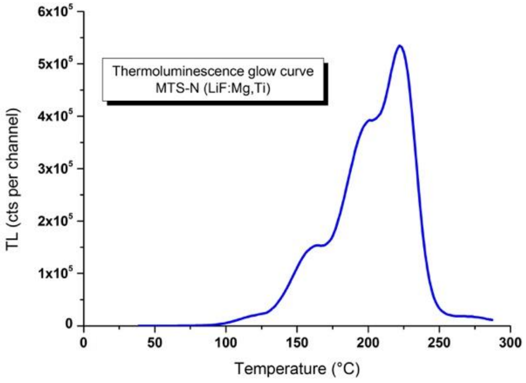
OSL signal of Al_2O_3:C

Material examples

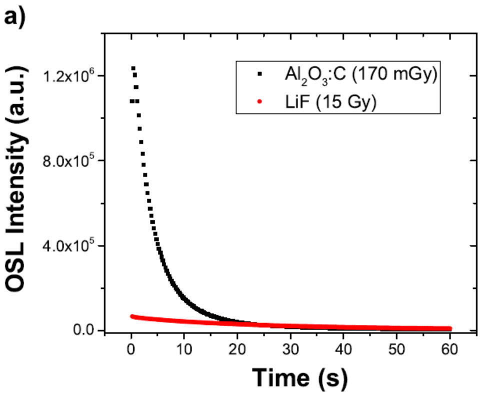
Al_2O_3:C

LiF:Mg,Ti





Sądel, M., Bilski, P., and Swakoń, J. (2014). Relative TL and OSL efficiency to protons of various dosimetric materials. Radiation Protection Dosimetry 161, 112-115.



Influence of the photoionization cross-section on the OSL signal of LiF: A theoretical and experimental approach

Bruna Novais[a], Edward Ferraz[b], Adelmo S. Souza[c], Patrícia L. Antonio[d], Linda V.E. Caldas[d], João Batista[e], Heveson Lima[a,*]

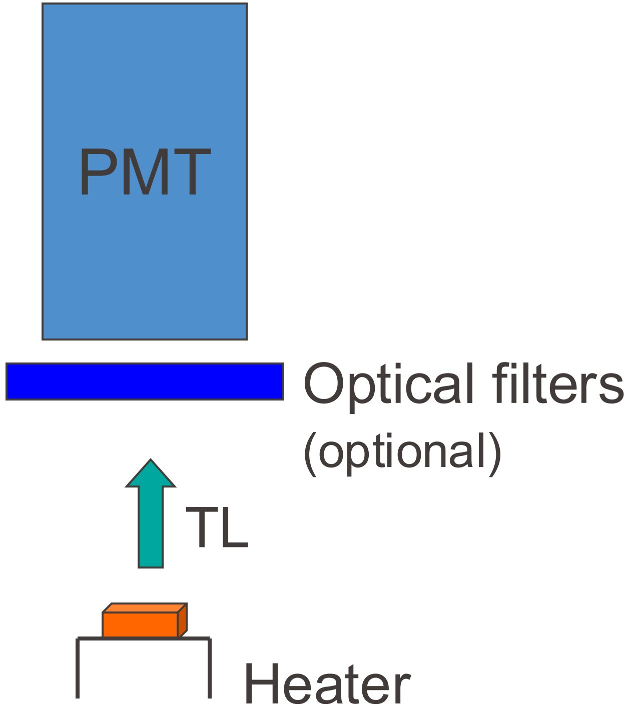
Al_2O_3:C TL vide

Feldspar TL video

A comparison between the techniques

TL	OSL
Thermal contact	Optical readout
Destructive readout	(Semi)destructive readout
Broad detection possible	Need to block stimulation light
Blackbody background	Low background (light leakage)
Only integrated luminescence	Time-resolved measurement possible
Affected by thermal quenching	Not affected by thermal quenching

Basic TL setup



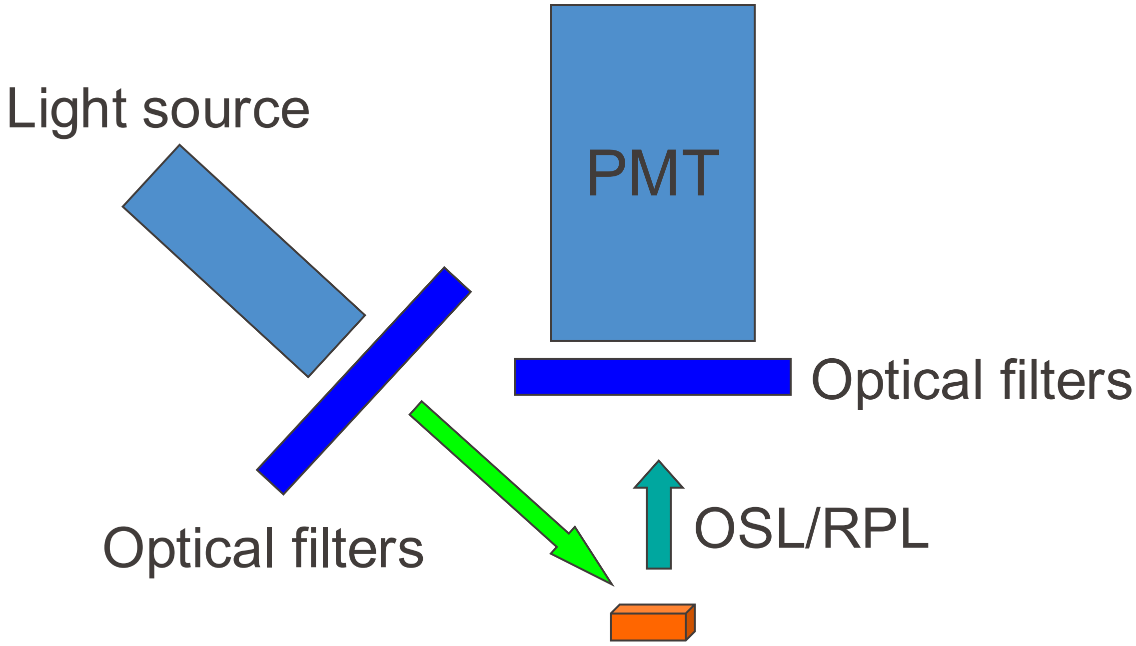
PMT

Optical filters (optional)

TL

Heater

Basic OSL/RPL setup



Light source

PMT

Optical filters

Optical filters

OSL/RPL

Commercial readers

FGD-660 RPL readers
(Chiyoda Technol Co.)

Harshaw TLD readers

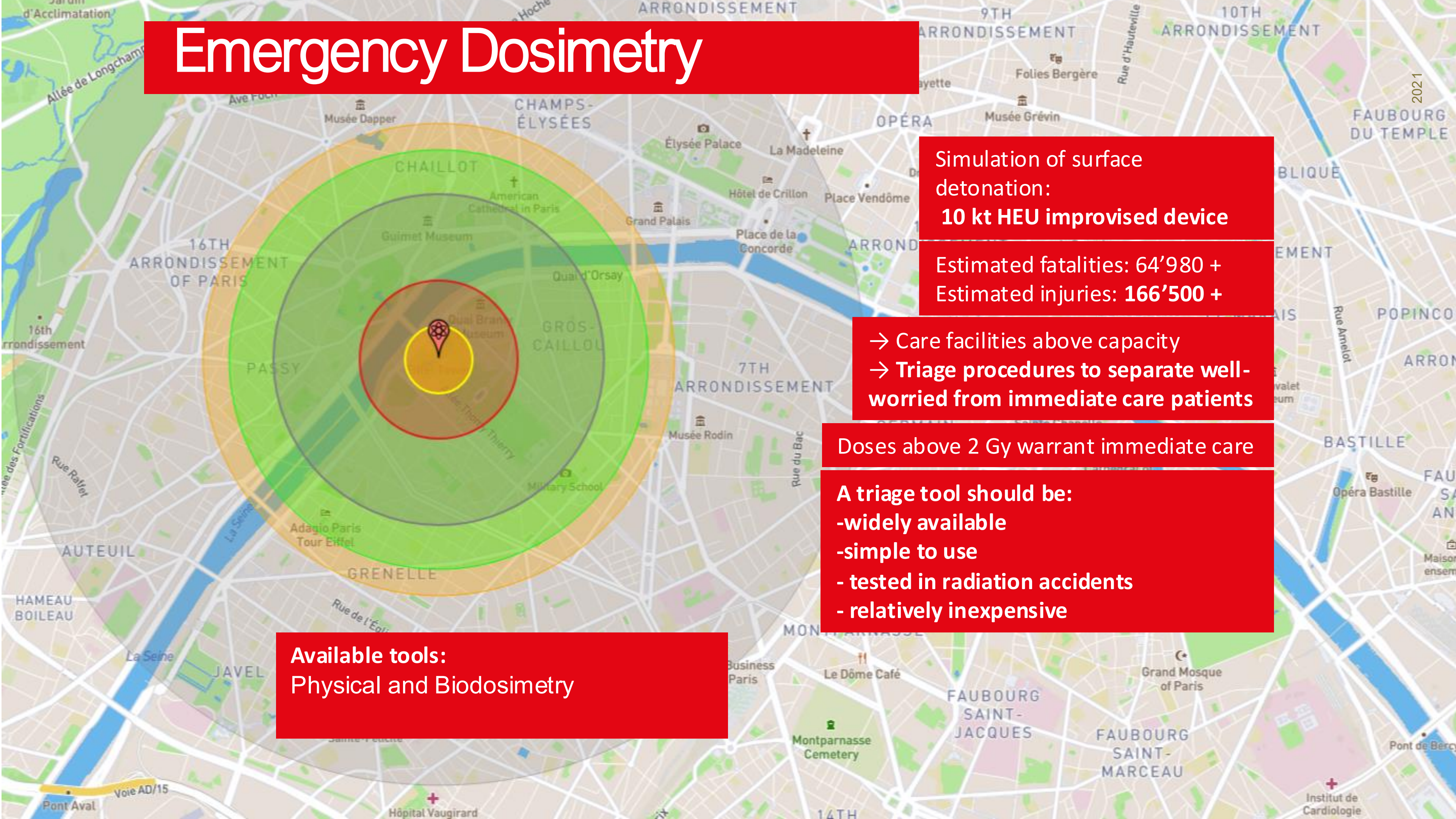
ALNOR TL reader

Procedure

- **Preparation**
  - TL, RPL: Annealing (e.g. 400 °C for 1h)
  - OSL: Annealing or bleaching (e.g. green LEDs for a few hours)
- **Packaging**
  - Individual packaging or dosimeter holders with various filters
  - OSLDs (and some TLDs) must be protected from light
- **Readout**
  - Seconds to minutes per detector, depending on readout protocol
- **Data analysis**
  - Correction for individual sensitivity
  - Calibration (e.g. batch)

Break

Emergency Dosimetry



Simulation of surface detonation:
10 kt HEU improvised device

Estimated fatalities: 64’980 +
Estimated injuries: **166’500 +**

→ Care facilities above capacity
→ **Triage procedures to separate well-worried from immediate care patients**

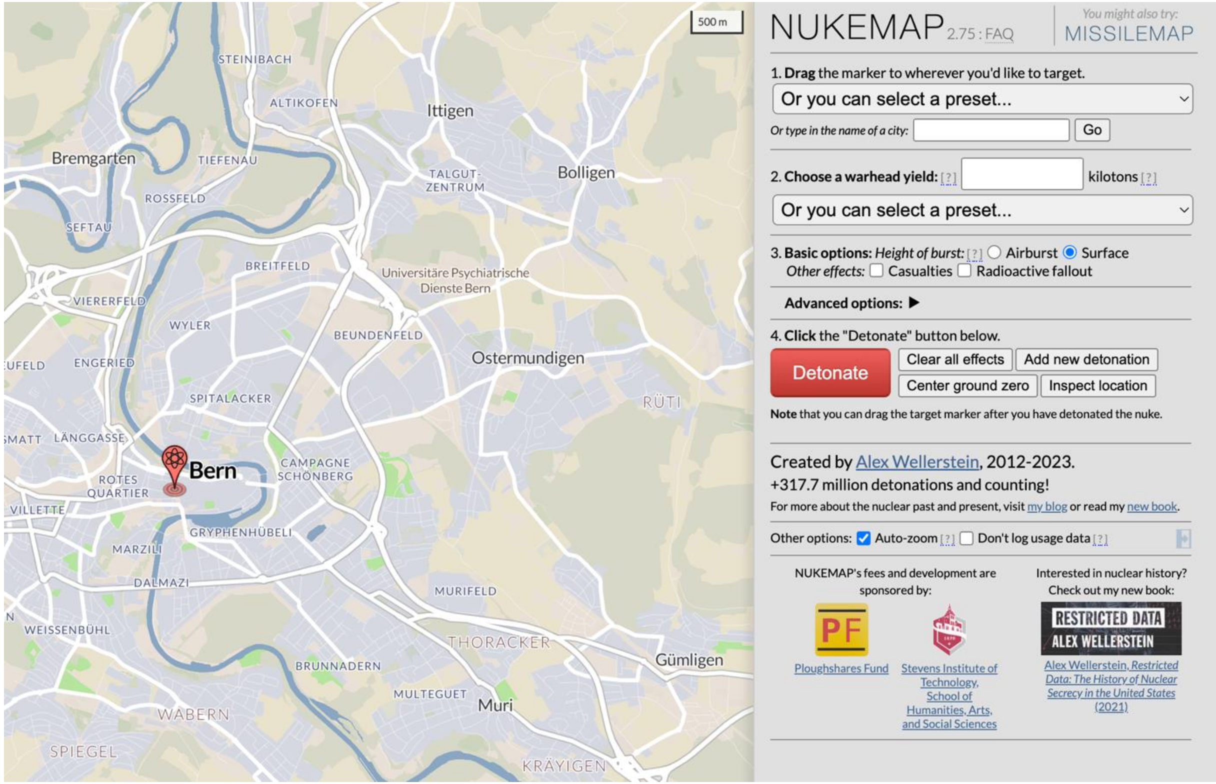
Doses above 2 Gy warrant immediate care

A triage tool should be:
-widely available
-simple to use
- tested in radiation accidents
- relatively inexpensive

Available tools:
Physical and Biodosimetry

NukeMAP by Alex Wellerstein

- https://nuclearsecrecy.com/nukemap/



1. **Drag** the marker to wherever you'd like to target.
Or you can select a preset...
Or type in the name of a city:

2. **Choose a warhead yield:** [?] kilotons [?]
Or you can select a preset...

3. **Basic options:** *Height of burst:* [?] ○ Airburst ● Surface
Other effects: ☐ Casualties ☐ Radioactive fallout

Advanced options: ▶

4. **Click** the "Detonate" button below.

Note that you can drag the target marker after you have detonated the nuke.

Created by Alex Wellerstein, 2012-2023.
+317.7 million detonations and counting!
For more about the nuclear past and present, visit my blog or read my new book.

Other options: ☑ Auto-zoom [?] ☐ Don't log usage data [?]

NUKEMAP's fees and development are sponsored by:
Ploughshares Fund
Stevens Institute of Technology, School of Humanities, Arts, and Social Sciences

Interested in nuclear history? Check out my new book:
Alex Wellerstein, Restricted Data: The History of Nuclear Secrecy in the United States (2021)

Why 2 Gy as limit?

United Nations

Scientific Committee on the Effects of Atomic Radiation

UNSCEAR 1988 Report, Annex D

Annex D: Exposures from the Chernobyl accident

Acute radiation effects in victims of the Chernobyl nuclear power plant accident

Why 2 Gy as limit?

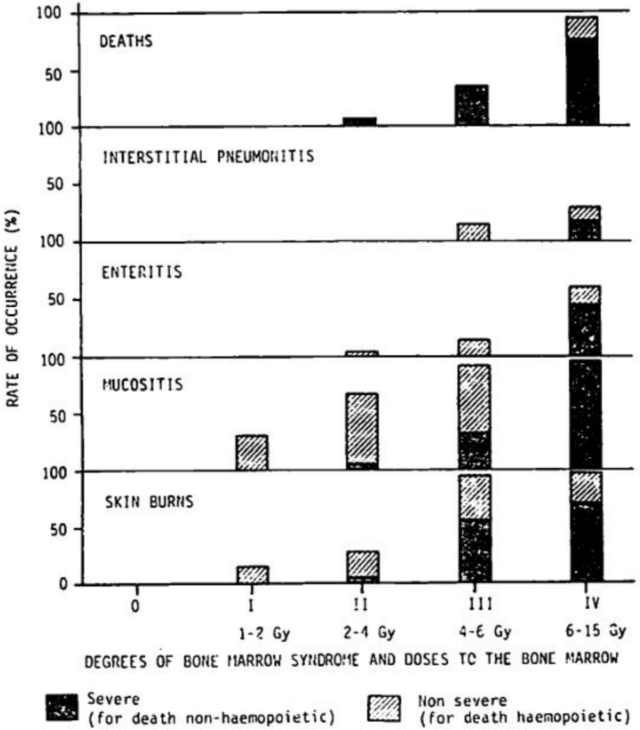


Figure A.VIII. Frequency of deaths and non-bone marrow syndromes for various degrees of bone marrow syndrome in accident victims suffering from acute radiation sickness.

Chernobyl data shows:
Above 2 Gy the chances of death are greatly increased, treatment required to maximize odds of survival

Biological effects of short term radiation

Dose Gy	Effect
< 0.2	No detectable effects
0.2-1.0	Measurable transient blood changes. Temporary decrease in white blood cell count.
1.0-2.0	Acute radiation sickness - nausea, vomiting, longer term decrease in white blood cells.
2.0-3.0	Vomiting, diarrhea, loss of appetite, listlessness, death in some cases.
3.0-6.0	Vomiting, diarrhea, hemorrhaging, deaths occurring in 50% of cases at 3.5 Gy or above without medical treatment.
Above 6.0	Eventual death in almost all cases

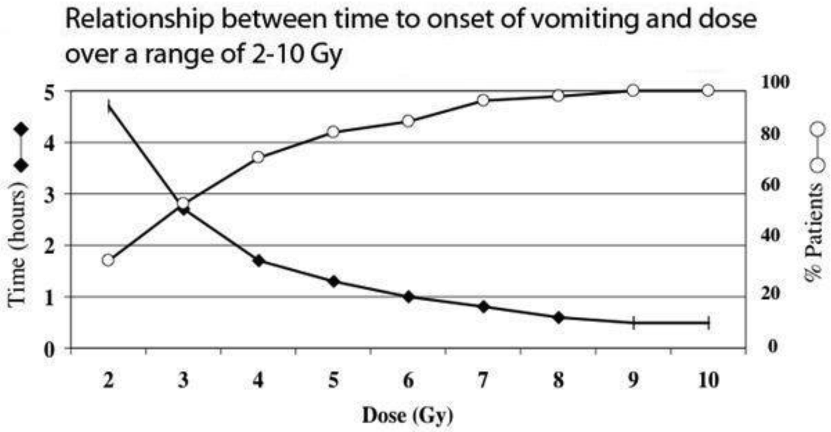
Onset of vomiting

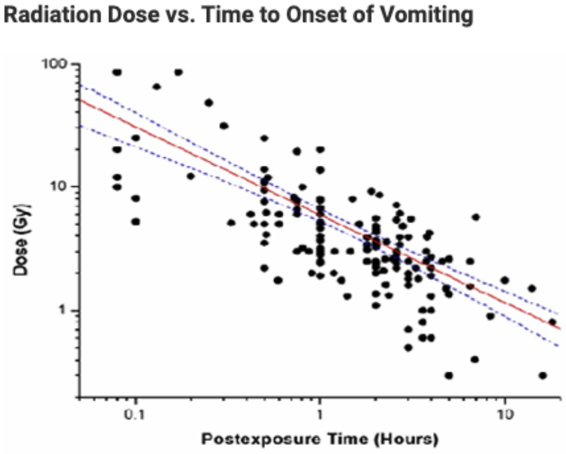
Onset of vomiting is well correlated with dose:
Earlier onset ⟺ Higher Dose

Vomiting also occurs with many clinical disorders as well with mass casualty events involving

- Physical trauma
- Psychological stress
- Biological threats
- Chemical threats

… not very specific signal!


Relationship between time to onset of vomiting and dose over a range of 2-10 Gy


Radiation Dose vs. Time to Onset of Vomiting

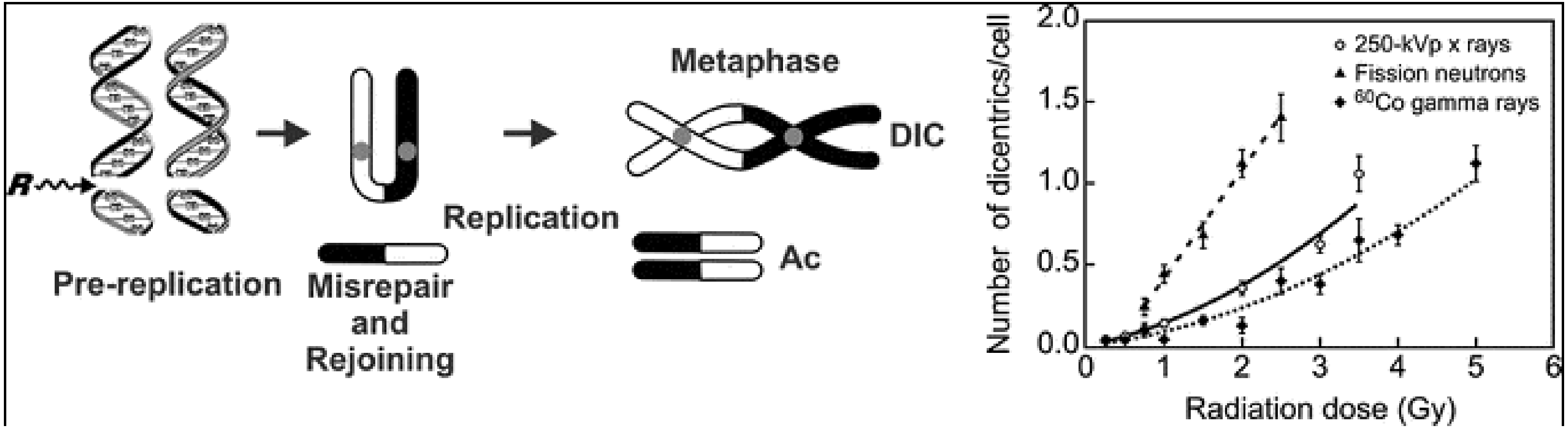
Source:

Symptomatology of Acute Radiation Effects in Humans After Exposure to Doses of 0.5-30 Gy

Anno, George H.; Baum, Siegmund J.; Withers, H. Rodney; Young, Robert W.

Health Physics 56(6):p 821-838, June 1989.

Assay of dicentric chromosomes



Number of observed dicentric chromosomes is a good signal
But:
Few laboratories have sufficient experience to perform this assay..

Biological markers: Blood cell counts

- Radiation can damage or destroy the hematopoietic stem cells in the bone marrow, which are the precursor cells for all blood cells
- Disruption in the normal process of blood cell production: Neutrophils, Lymphocytes, Platelets
- Above: Data from a Chernobyl victim estimated to have received 3 Gy
- Below: Neutrophil/Lymphocyte ratio data from the Y12 accident patient B + data points from Hiroshima & Nagasaki
- N/L ratio good predictor for dose, biggest change after 20d

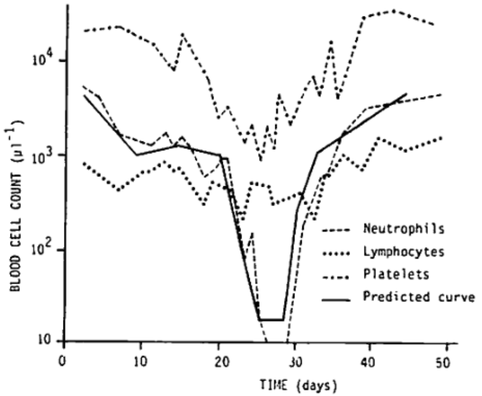


Figure A.IV. Example of the changes in neutrophils, lymphocytes and platelets observed in a patient (case 39) suffering from acute radiation sickness (estimated dose 2.4-3.3 Gy) and the predicted neutrophil curve for a total gamma dose of 3.0 Gy.

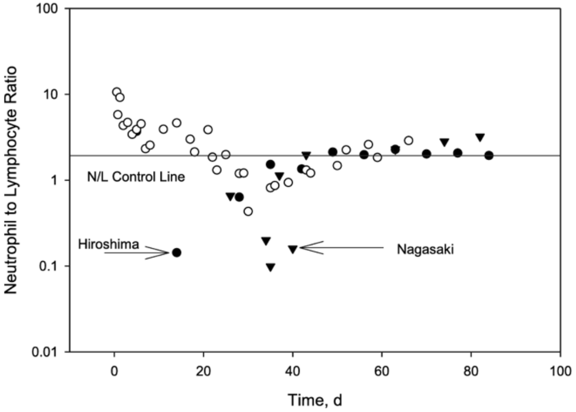
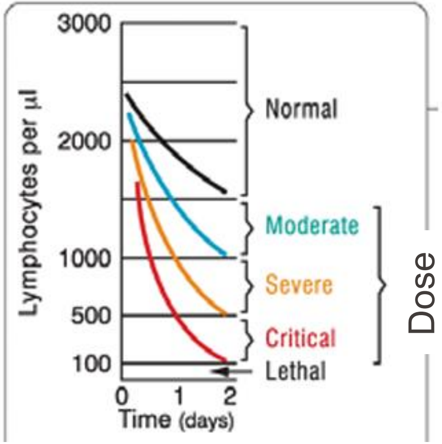


Fig. 1. Time dependence of NLR for patient B in the 1958 Y-12 criticality accident. Late NLR results from Hiroshima and Nagasaki are also shown.

Lymphocyte kinetics after exposure



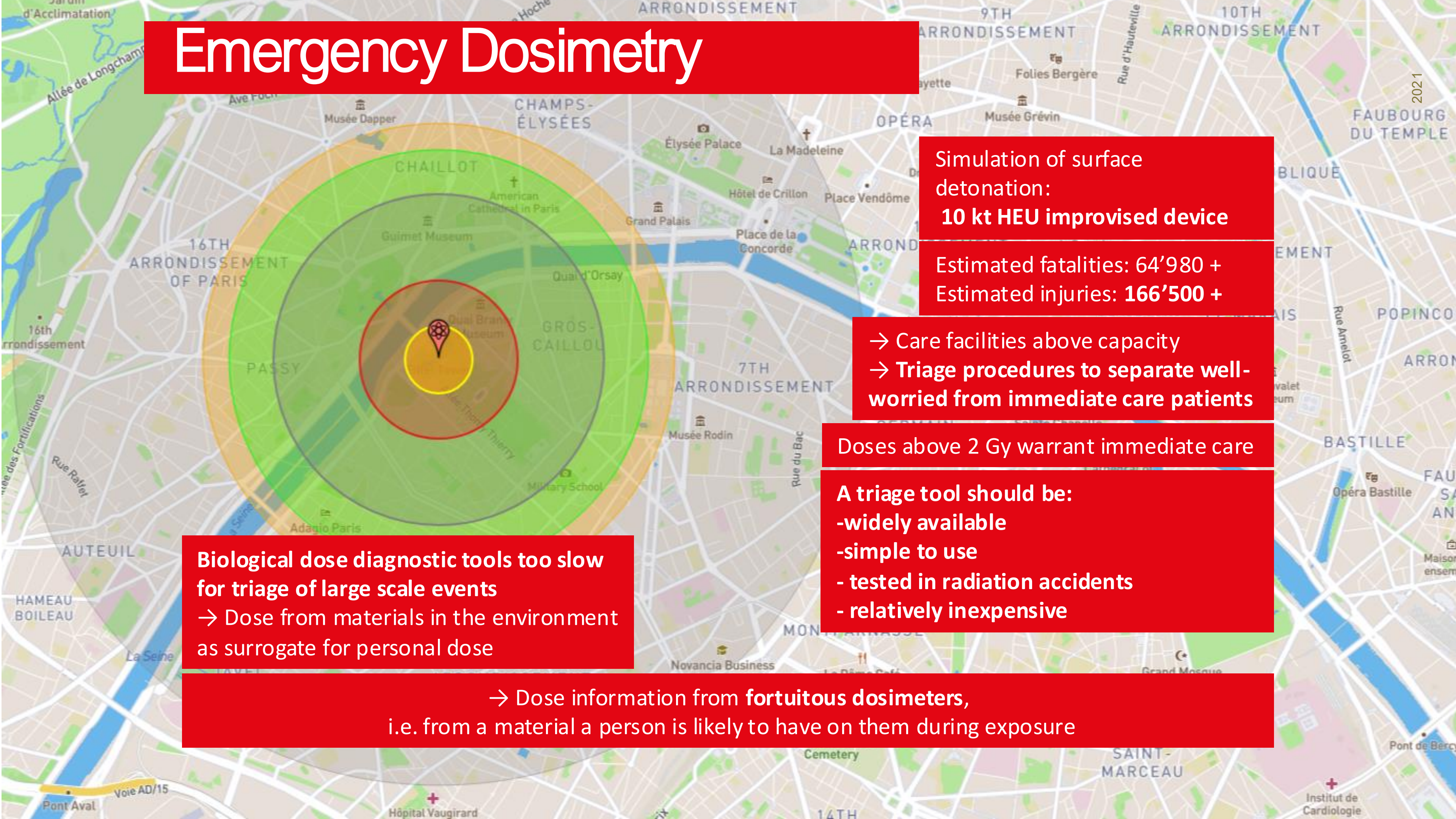
Blood samples taken after exposure can follow the ‘depletion kinetics’ that depends on dose

Gives a rough estimate of dose

Overview on biological methods

Assay	Materials	Period of use since exposure	Partial body exposure	Time (h) from sample receipt to dose estimate	Specificity	Dose Range (Gy)	Automated
DCA	Whole blood, lymphocytes	Days to months	Y	55	IR	0.1-5	Yes
PCC fragments	Whole blood, lymphocytes	Days	Y	2	IR	0.2-20	No
Micronuclei	Whole blood, lymphocytes	Days to months	N	75	IR-BGS	0.2-4	Yes
FISH	Whole blood, lymphocytes	Days to years	N	120	IR-BGS	0.25-4	N
Gamma H2AX	Whole blood, lymphocytes	hours	Y	3	IR/BGS	0.5-10	Y
Gene expression	Whole blood, lymphocytes	Hours to days	Y	4	IR/BGS	0.5-10	N
Small metabolits	Urine, blood, serum, blood plasma	Hours to days	Y	3	IR/BGS	1-10	N
Proteomics	Whole blood, lymphocytes, urine, blood serum, blood plasma	Hours to days	Y	3	IR/BGS	0.5-10	N

Emergency Dosimetry



2021

Simulation of surface detonation:
10 kt HEU improvised device

Estimated fatalities: 64’980 +
Estimated injuries: **166’500 +**

→ Care facilities above capacity
→ **Triage procedures to separate well-worried from immediate care patients**

Doses above 2 Gy warrant immediate care

A triage tool should be:
-widely available
-simple to use
- tested in radiation accidents
- relatively inexpensive

Biological dose diagnostic tools too slow for triage of large scale events
→ Dose from materials in the environment as surrogate for personal dose

→ Dose information from **fortuitous dosimeters**,
i.e. from a material a person is likely to have on them during exposure

Physical dosimetry

- Based on a biological material derived from the individual (bone, teeth, nails) or personal belongings (smartphone, electronics, clothing)
- Available methods:
  - Luminescence techniques (TL, OSL)
  - Electron paramagnetic resonance (EPR) techniques

Fortuitous dosimeters need:

- Ubiquity among population
- Proportionality to dose
- Sensitivity below 2 Gy
- Simplicity and speed of dose information retrieval

Electron paramagnetic resonance (EPR) dosimetry

EPR detects the presence of unpaired electron spins within a substance

With bone, tooth enamel, and finger/toenails, unpaired spins occur in the form of free radicals following the trapping of delocalized electrons induced by exposure to ionizing radiation

E.g. in calcium-based biogenic material carbonate radicals of the type CO_2^- are generated during exposure, which can be seen in EPR

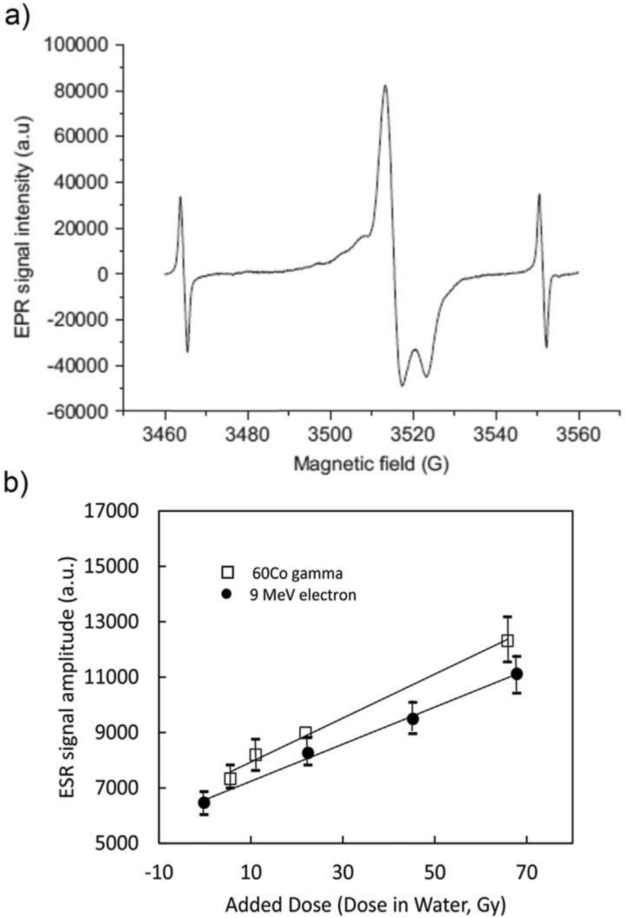
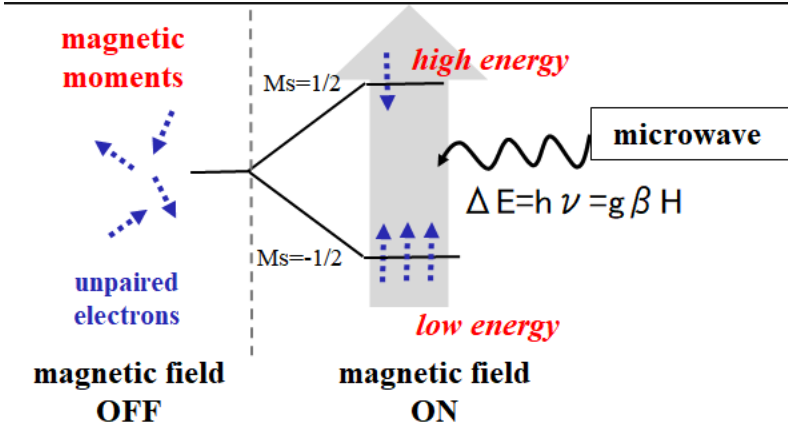
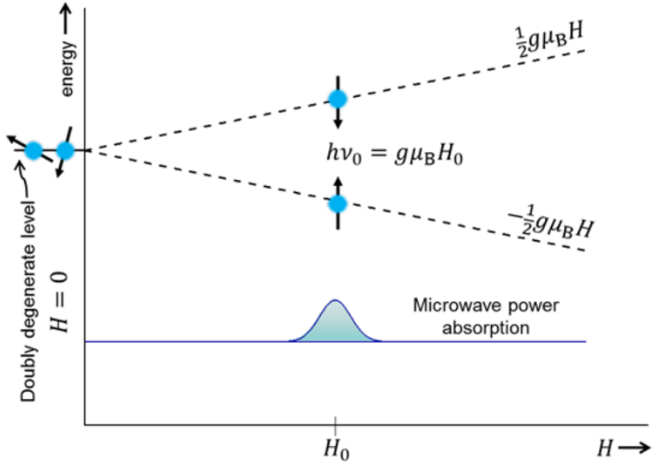


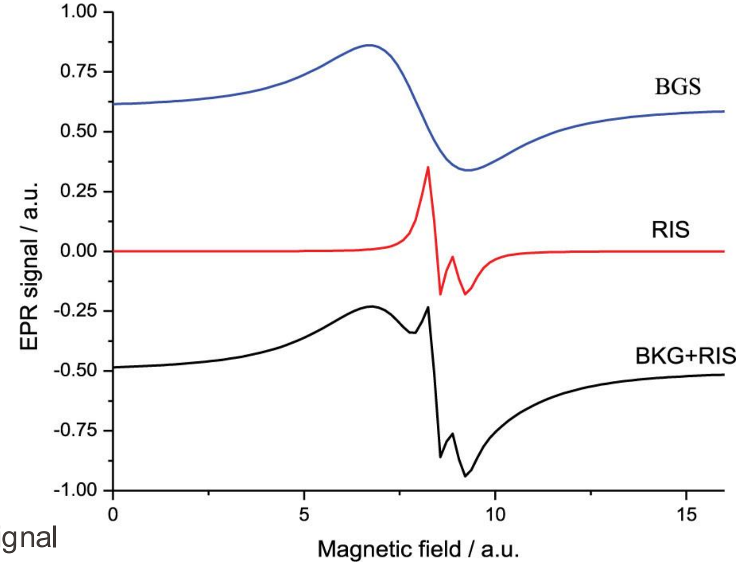
Fig. 4. (a) EPR spectrum from rib bone for a radiotherapy patient. The applied dose was 120 Gy. (Note: 10 G corresponds to 1 mT) (b) RIS dose response. (Reproduced from Trompier et al., 2007a.)

EPR physics





- Unpaired electrons in a magnetic field split into parallel and anti-parallel states.
- Magnetic field scanning with constant microwave energy causes absorption at the 'right' field strength
- Absorption strength correlates with unpaired spin concentration i.e. signal related to absorbed dose.



BGS=Background
RIS=Radiation induced signal

Electron paramagnetic resonance (EPR) dosimetry

Fortuitous dosimeters need:
- Ubiquity among population ✓
- Proportionality to dose ✓
- Sensitivity below 2 Gy ✓
- Simplicity and speed of dose information retrieval ✓ ☺

Works for bone, tooth enamel, and finger/toenails
But: In the case of an emergency, are you willing to give some bone, a tooth or a nail for analysis?

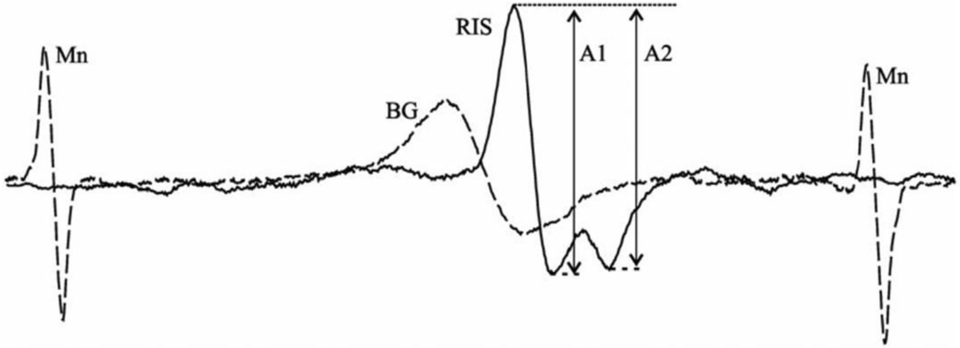
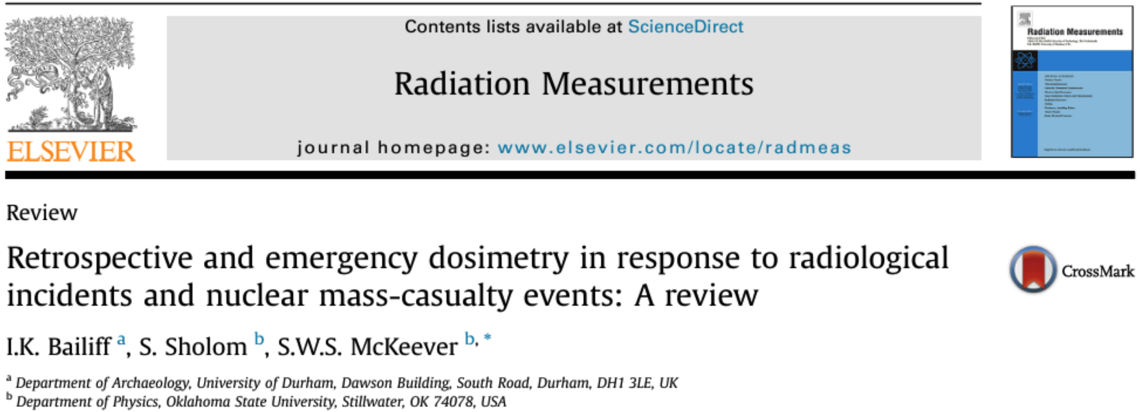


Fig. 3. Radiation-induced (RIS) and non-radiation-induced background (BG) X-band EPR signal from irradiated bone. (Reproduced from Ciesielski et al., 2014.)

Quote



Contents lists available at ScienceDirect

Radiation Measurements

journal homepage: www.elsevier.com/locate/radmeas

Review

Retrospective and emergency dosimetry in response to radiological incidents and nuclear mass-casualty events: A review

I.K. Bailiff [a], S. Sholom [b], S.W.S. McKeever [b,*]

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- In view of the difficulties and uncertainties caused by the mechanical harvesting of finger-and-toenails, the development of an in vivo evaluation technique would be valuable.

In vivo tooth EPR prototype

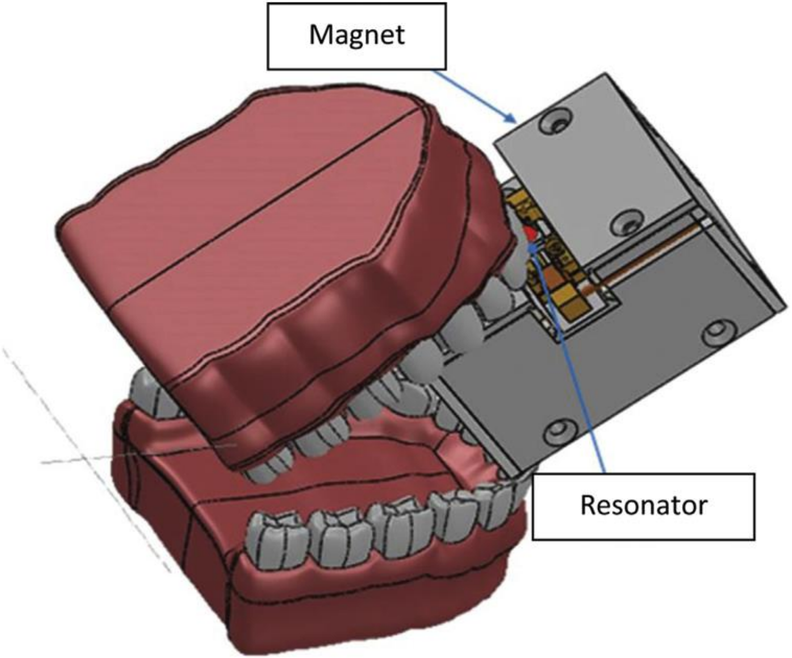


Fig. 10. Schematic of the pulsed EPR probehead for X-band *in-vivo* dosimetry of teeth, showing the permanent magnet and resonator assembly. (Reproduced from Woflson et al., 2015.)

Other EPR sensitive materials

- Sugars
- Some types of clothing
- Smart phones, watches, credit cards

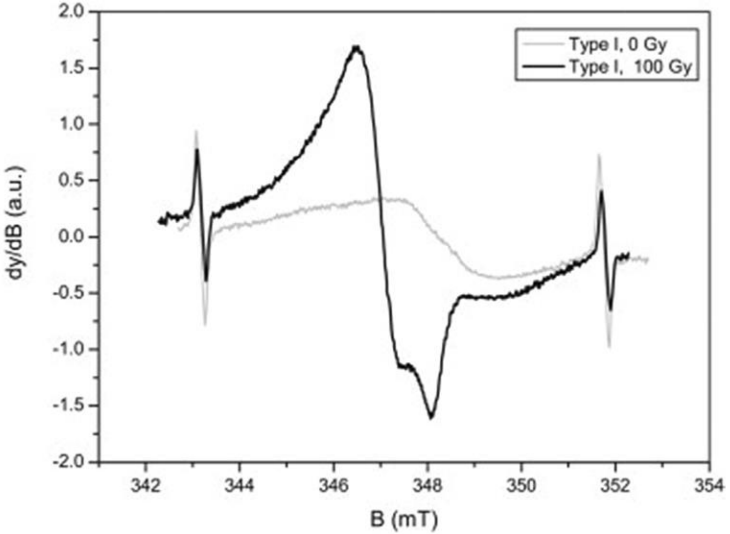


Fig. 18. EPR spectra from "Type I" phone glass. (Reproduced from Trompier et al., 2011).

But: A lot of background signals in these materials, or sensitivity to ambient light

Luminescence techniques

TL and OSL are conventionally used techniques

- High sensitivity
- Ease of use
- High throughput
- Standardized protocols exist

(but obviously people are not always wearing a dedicated dosimeter)

OSL response of tooth enamel

Teeth once more give a good signal.
But similar problem as before…

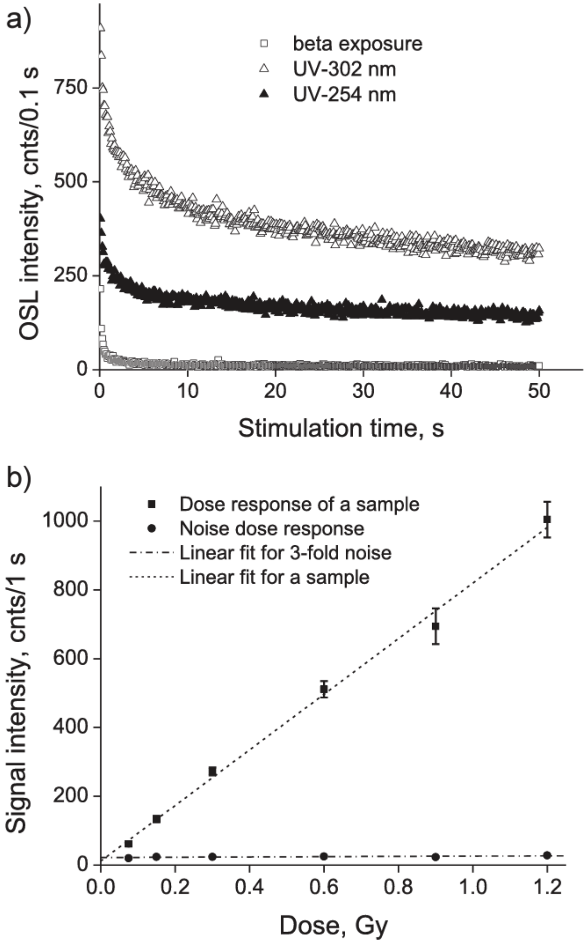


Fig. 20. (a) OSL decay curves from human tooth enamel following irradiations with different sources, as shown. (b) Dose response curve: OSL as a function of beta dose. The MMD for this example is 0.27 Gy. (Reproduced from Sholom et al., 2011a.)

OSL from clothing samples

OSL signal detectable from clothing samples, but only at doses above several Gy

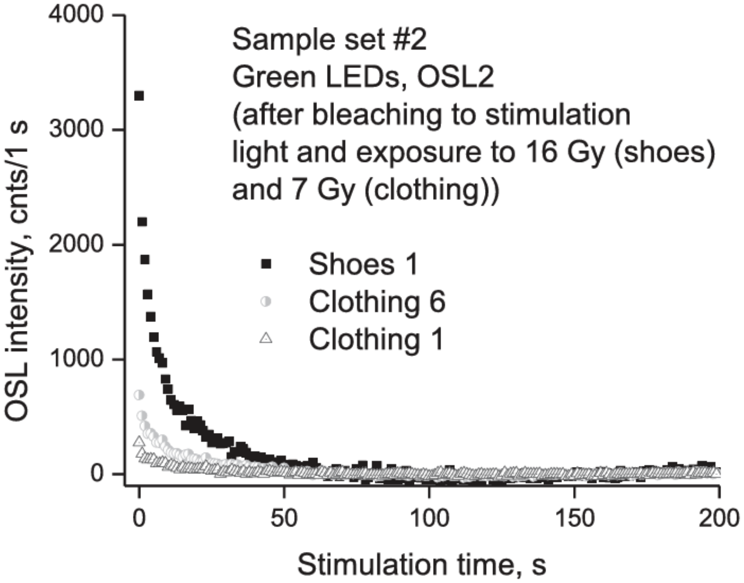
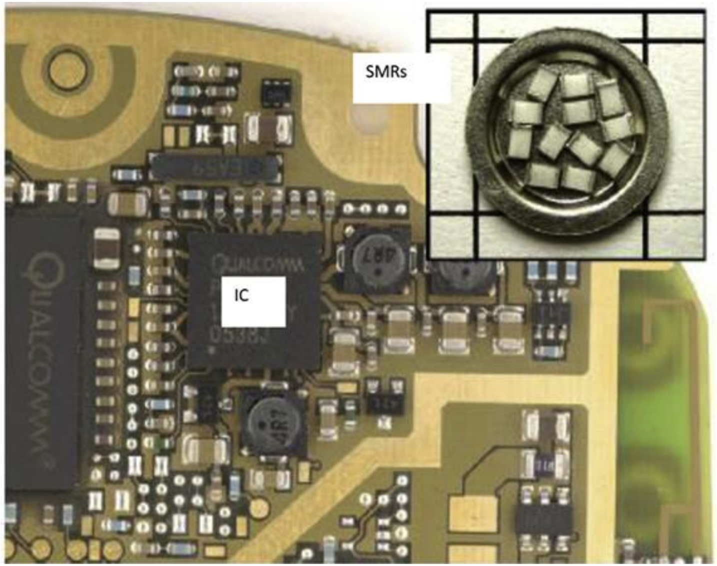


Fig. 26. Green-light (530 nm) stimulated OSL (UV range) from irradiated clothing and shoes. (Reproduced from Sholom and McKeever, 2014a.)

OSL from smartphone components

Surface-mounted resistors (SMRs)



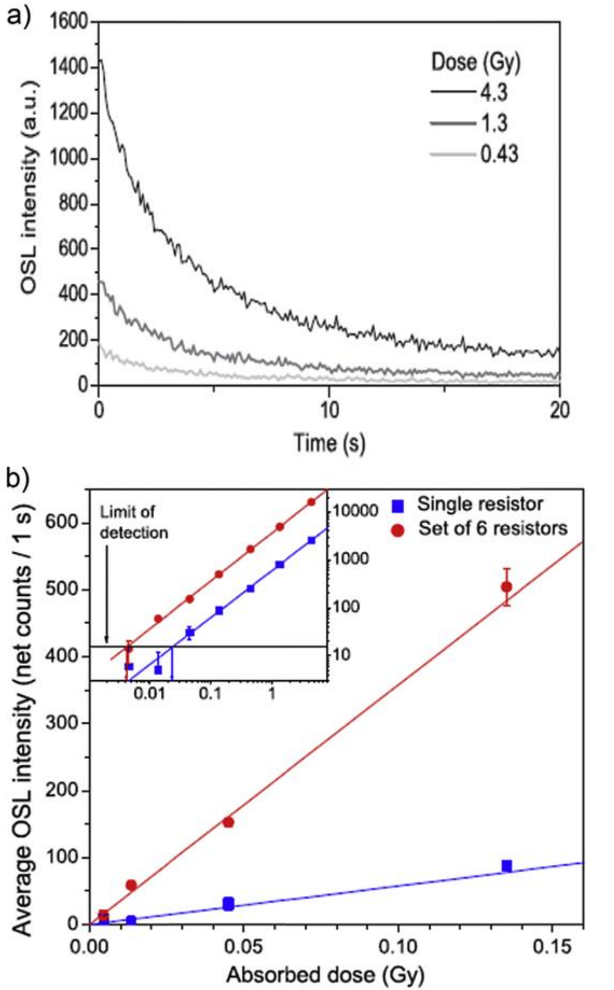
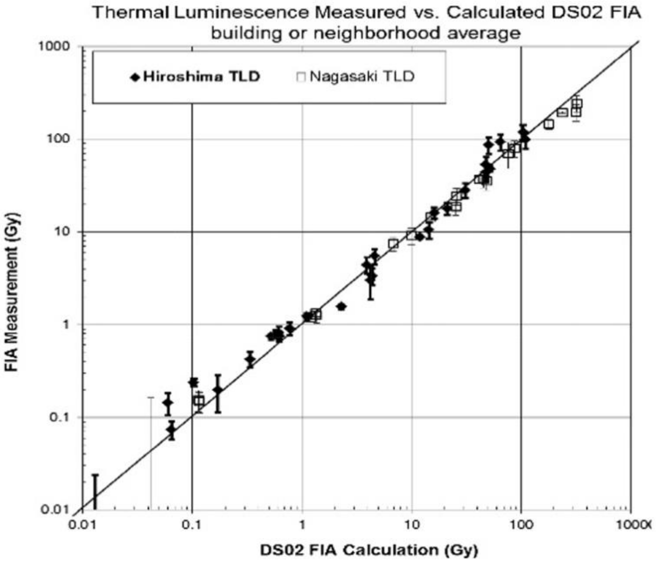


Fig. 32. OSL decay curves (a) and dose response curves (b) for SMRs from mobile phones. (Reproduced from Inrig et al., 2008.)

Building materials

- TL of ceramic tiles of traditional Japanese buildings

(Most were exposed to extreme heat, so very ‘selected’ data)



Other fortuitous dosimeters

Thermoluminescence and phototransferred thermoluminescence dosimetry on mobile phone protective touchscreen glass

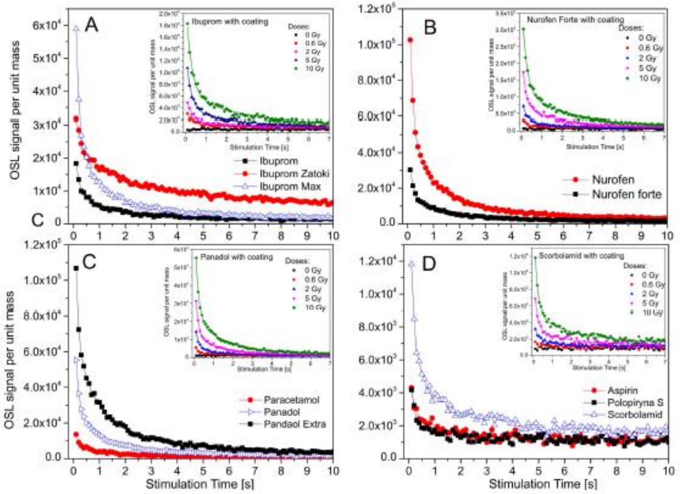
Cite as: J. Appl. Phys. **126**, 074901 (2019); https://doi.org/10.1063/1.5108971
Submitted: 04 May 2019 • Accepted: 24 July 2019 • Published Online: 20 August 2019

J. R. Chandler, S. Sholom, S. W. S. McKeever, et al.

IEEE Sensors Council IEEE SENSORS JOURNAL, VOL. 21, NO. 15, AUGUST 1, 2021 16637

Popular Medicines as Radiation Sensors

Anna Mrozik and Paweł Bilski



Ibuprofen

2021

Dollar Bill OSL

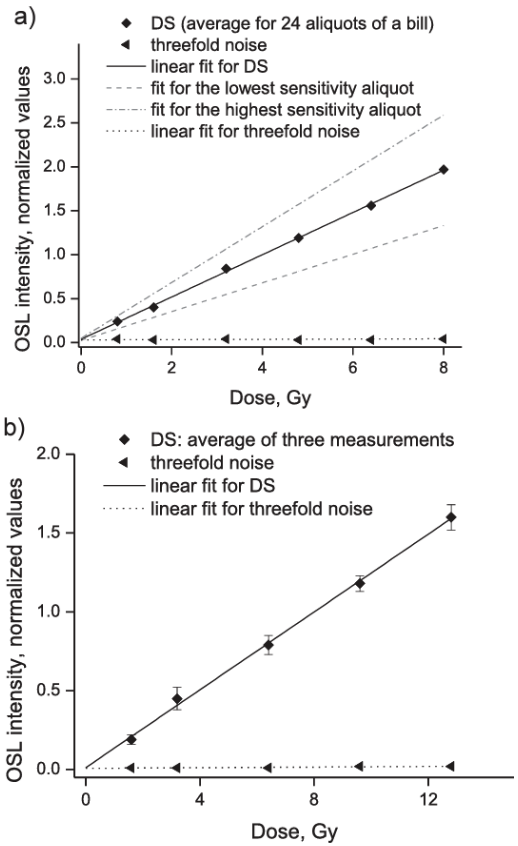
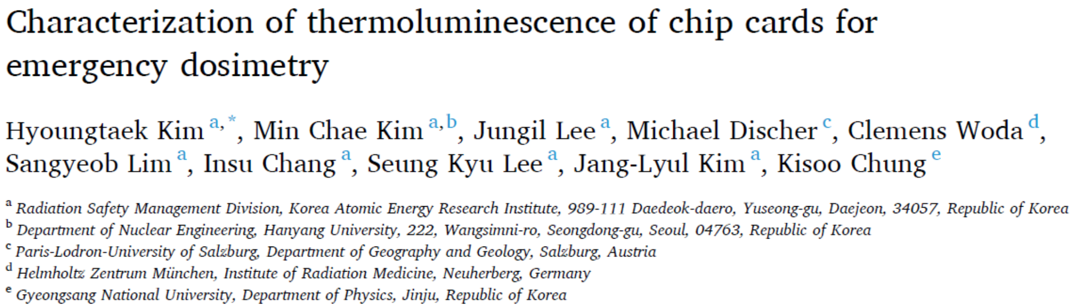


Fig. 28. (a) Dose response for a US $1 bill. The average of all aliquots is plotted with a linear fit (full line). Also, shown are the linear fits but for the highest (dotted line) and lowest (dashed line) sensitivities, illustrating the spread in sensitivities for the samples – all taken from the same $1 bill. Also shown is the linear fit for the 3σ-noise. (b) Dose response for an example plastic card. A linear fit through the data s shown, along with a fit of the 3σ-noise. (Reproduced from Sholom and McKeever, 2014a.)

Continued…



Characterization of thermoluminescence of chip cards for emergency dosimetry

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Thermoluminescence investigations on tobacco dust as an emergency dosimeter

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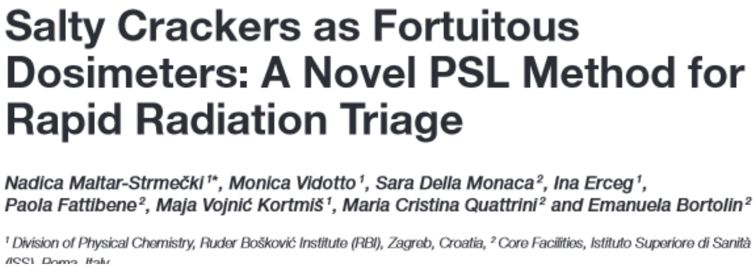

Salty Crackers as Fortuitous Dosimeters: A Novel PSL Method for Rapid Radiation Triage

Nadica Maltar-Strmečki[1*], Monica Vidotto[1], Sara Della Monaca[2], Ina Erceg[1], Paola Fattibene[2], Maja Vojnić Kortmiš[1], Maria Cristina Quattrini[2] and Emanuela Bortolin[2]

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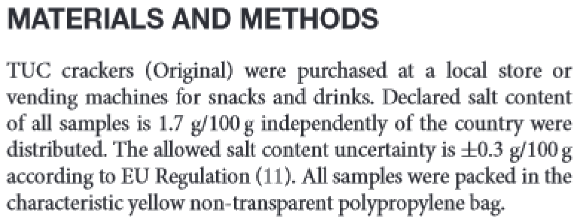

MATERIALS AND METHODS

TUC crackers (Original) were purchased at a local store or vending machines for snacks and drinks. Declared salt content of all samples is 1.7 g/100 g independently of the country were distributed. The allowed salt content uncertainty is ±0.3 g/100 g according to EU Regulation (11). All samples were packed in the characteristic yellow non-transparent polypropylene bag.

Dose Dependence and Fading Effect of the Thermoluminescence Signals in γ-Irradiated Paprika

Virgilio Correcher,* José L Muñiz and José M Gómez-Ros

Insect wings as retrospective/accidental/forensic dosimeters: An optically stimulated luminescence investigation

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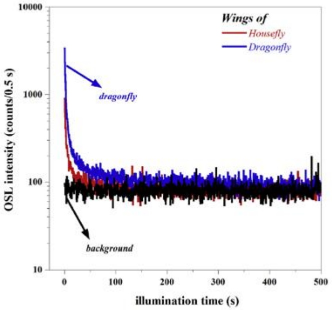

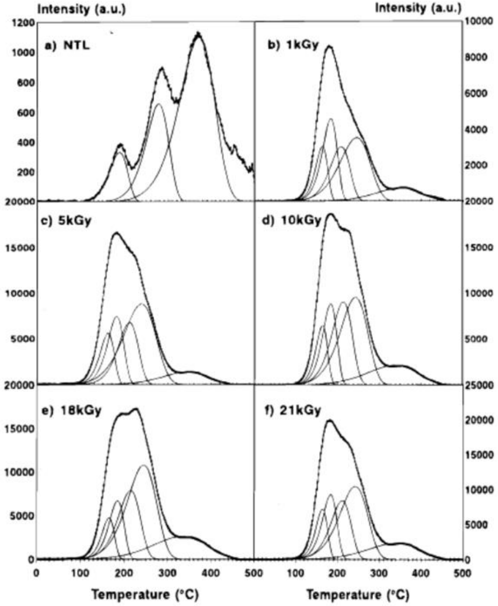

Fig 3. Decomposition of 2D-TL glow curves from inorganic phases of (a) non-irradiated, and (b–f) irradiated paprika. They

Overview on physical methods

Assay	Materials	Period of use since exposure	Identify Partial body exposure	Time (h) from sample receipt to dose estimate	Specificity	Dose Range (Gy)
TL or OSL: surface mounted components	Resistors, inductors	Days to weeks	No	1-2	G,X,b	0.1-10
TL or OSL: ICs	Epoxy encapsulation	Days to weeks	No	1-2	G,X,b	0.01-10
TL or PTTL phone glass	Protective glass, display glass	Days to weeks	No	1-4	G,X,b, UV, BgS	0.3-20
OSL: other electronic components	Chip cards	Days to weeks	No	1-2	G, X, BGS	0.01-10
OSL clothing	Fabrics, shoes (e.g. polymers such as in cotton, PVC, polyester)	Days to weeks	No	1	G, X, b, bgs	0.1-10
TL or OSL: other	Plastic cards, dust, money	Days to weeks	No	1	G, X, b, bgs	0.1-10
OSL dental materials	Tooth enamel, repair ceramics	Days to weeks	No	1	G,X,b, UV, BgS	0.01-10
EPR teeth	Enamel	Days to years	possible	1	G,X,b, UV, BgS	0.01-10
EPR bone	Hydroxyapatite	Days to years	Possible	Several	G, X, BGS	1-10
EPR nails	Finger or toes	Days	Possible	2-4	G,X,b, UV, BgS	0.1-10
EPR phone glass	Protective glass, display glass	Days to years	No	1	G,X,b, UV, BgS	1-few
EPR, other	Plastic components of clothing	Days to years	No	1	G,X,b, UV, BgS	1-few

Summary

- Emergency triage in radiological mass casualty events requires dose information (>2Gy YES/NO): Quickly, Easily, Reliably
- Biodosimetry tools
  - give good signals
  - classical tools such as blood cell counts quick and reliable, signal in days
  - modern tools (gamma-H2AX), signal in hours
  - …. but ‘fancy tools’ require ‘fancy’ labs
- Physical (fortuitous) dosimetry based on TL, OSL or EPR can give good signals within minutes
  - EPR signals from bone, teeth, nails are good & are quickly measurable (but sample ‘retrieval’ can be tricky)
  - TL and OSL signals from clothing, smart phones usable, but standard protocols are yet to emerge (willing to yield your phone in a nuclear event?)

Literature

- Hempelman, Louis Henry; Lushbaugh, Clarence C.; Voelz, George L. (October 19, 1979). *What Has Happened to the Survivors of the Early Los Alamos Nuclear Accidents?*
- **Reassessment of the Atomic Bomb Radiation Dosimetry for Hiroshima and Nagasaki – Dosimetry System 2002 (DS02) https://www.rerf.or.jp/en/library/list-e/scids/ds02-en/**
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- **https://www.iaea.org/sites/default/files/21/12/12_accident-_reformat.pdf IAEA guide on Accident Dosimetry**