

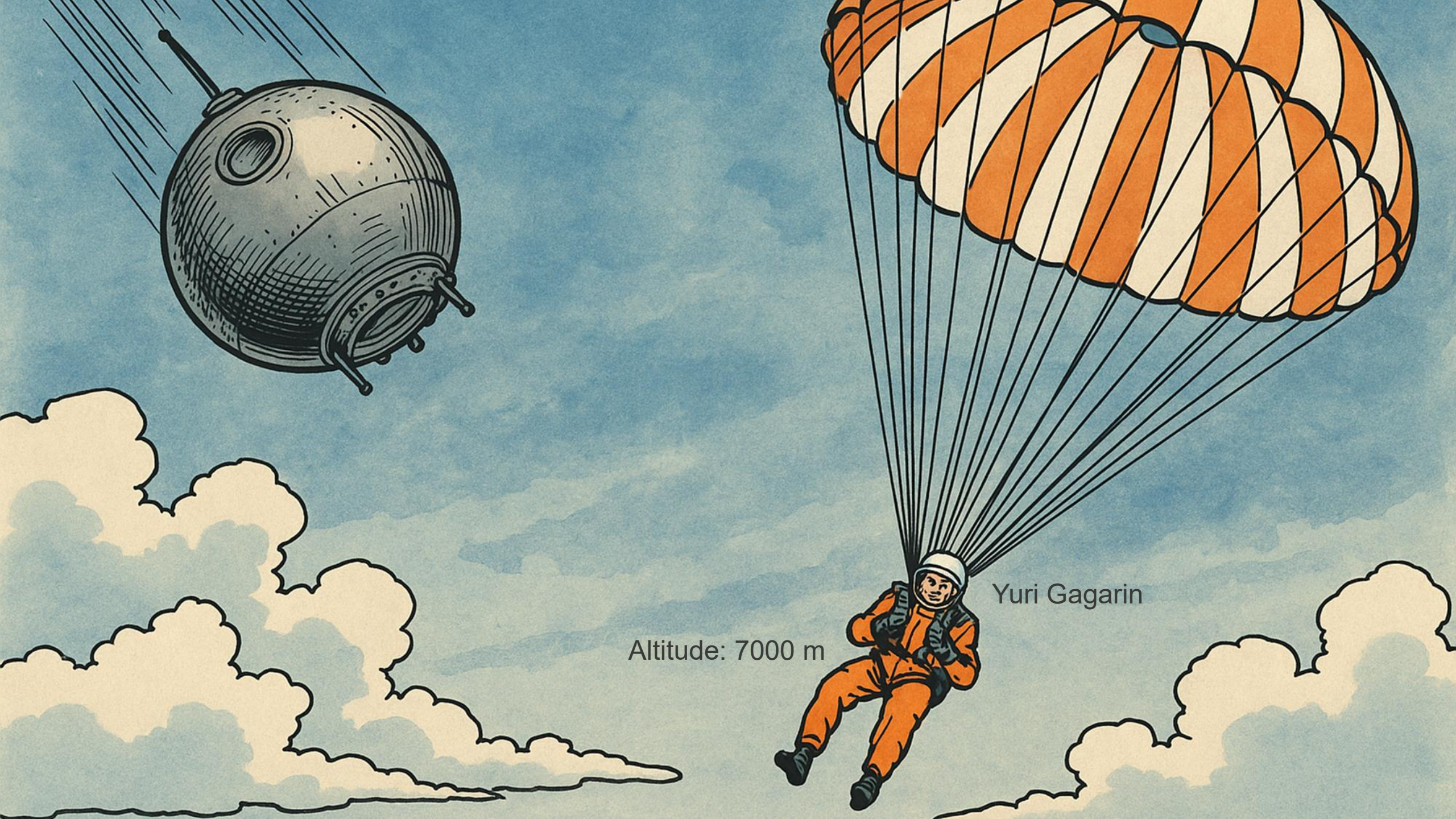




Advantages of ^{60}Co in brain radiosurgery

Riccardo Bevilacqua, PhD





Altitude: 7000 m

Yuri Gagarin

9.5 km

Opening braking parachute

8.5 km

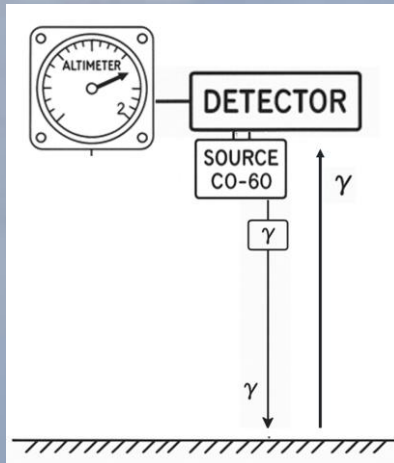
Opening main parachute

5.5 km

Separation heat shield

0.8 m

Firing of soft-landing engines



Soyuz





⁶⁰Co sterilization

16

Just in the United States, over **16 billion** single-use medical devices are sterilized annually with Cobalt 60

%

30 to 40% of all single-use medical devices globally are sterilized with Cobalt 60

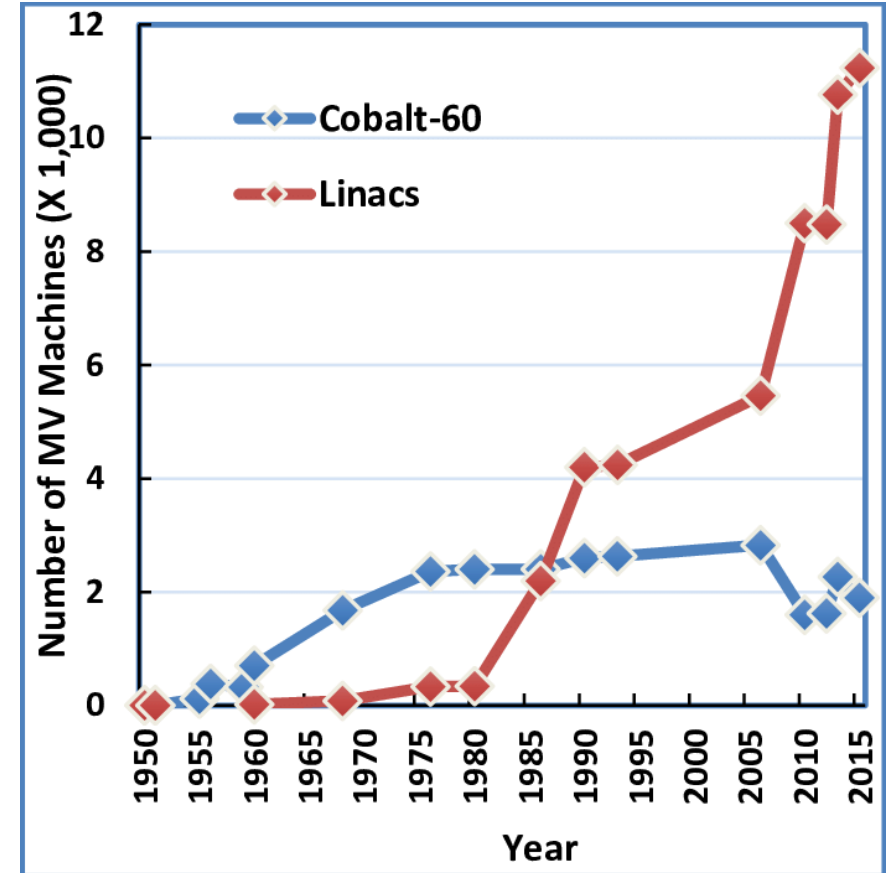
200

According to the IAEA, there are around **200 large irradiator facilities** in operation worldwide, for a total of **500 MCi**

Cobalt 60 teletherapy



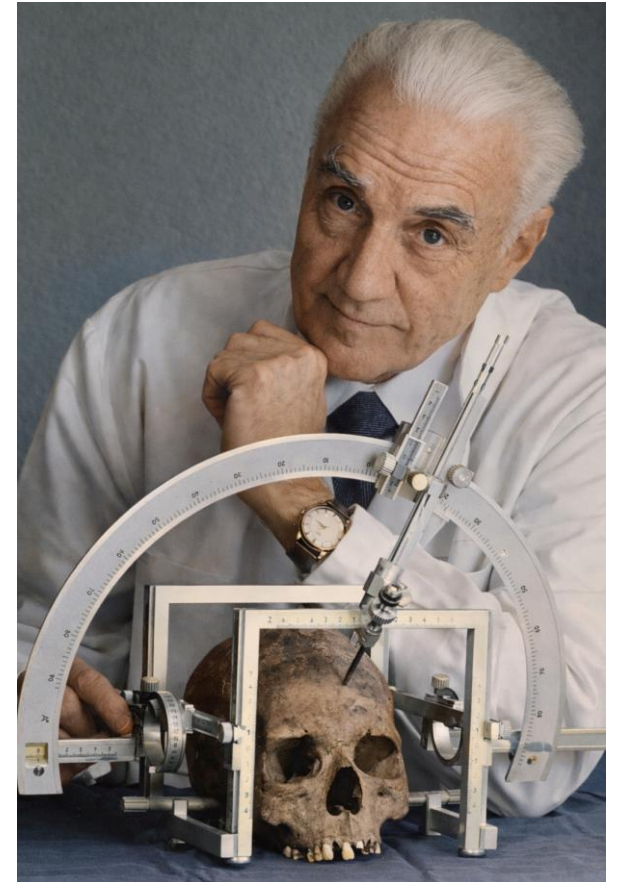
Atomic Energy of Canada Ltd., Therapy machine, cobalt, 1956, Artifact no. 1966.0043, Ingenium – Canada's Museums of Science and Innovation, <http://collection.ingenium.ca/en/id/1966.0043.001/>



Van Dyk, Jacob & Battista, Jerry & Almond, P. (2020). A Retrospective of Cobalt-60 radiation therapy : "The Atom Bomb that Saves Lives". 2020.

Stereotactic Radiosurgery (SRS)

- **Stereotactic radiosurgery** is a radiation therapy technique in which a high dose of ionizing radiation is delivered to a precisely defined target with sub-millimetric spatial accuracy
- **Stereotactic** refers to the use of a three-dimensional coordinate system, based on imaging, that allows accurate localization of a target in space and reproducible positioning relative to the radiation source.
- **Radiosurgery** denotes that the radiobiological effect is equivalent to a surgical intervention, achieved by a highly concentrated radiation dose, without a surgical incision.



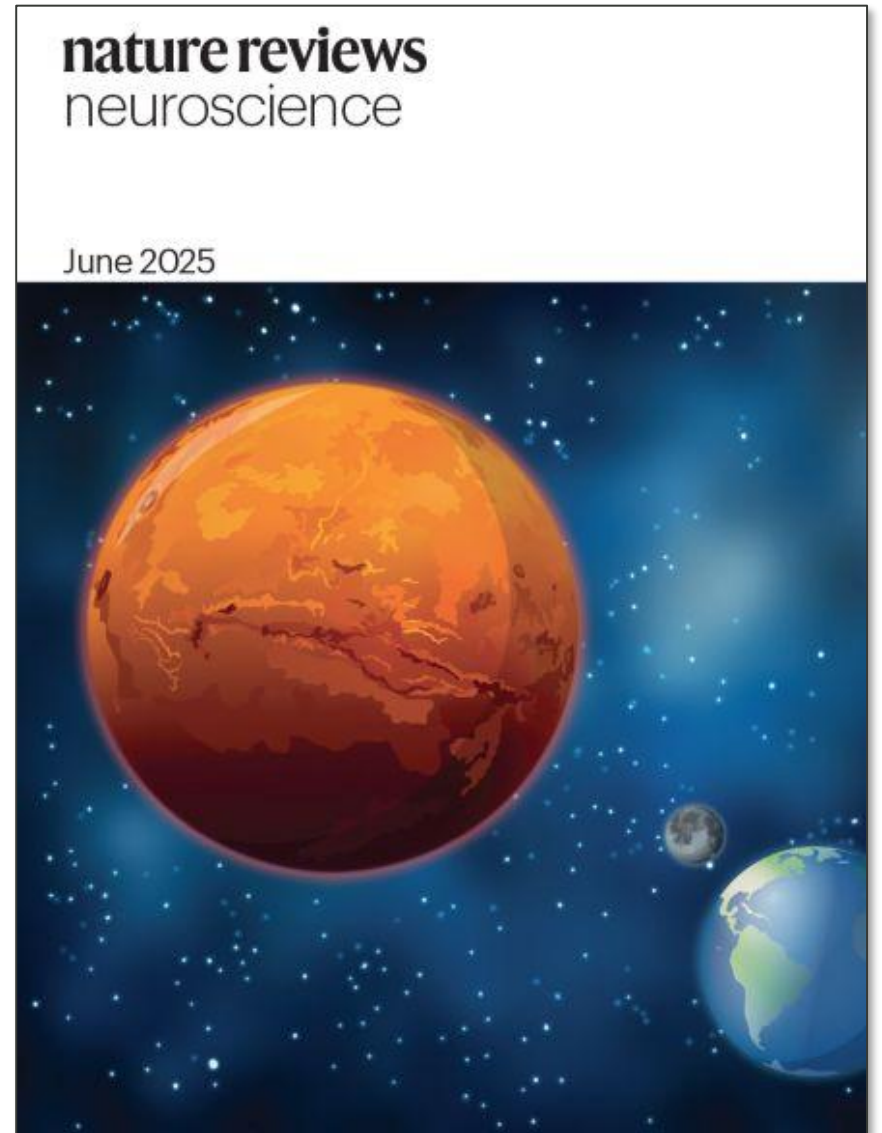
Stereotactic radiosurgery was proposed and developed by the Swedish neurosurgeon Lars Leksell, who introduced the term “radiosurgery” in a 1951 paper.

Radiation delivery approaches in SRS

- **Linear accelerators (LINACs)**
Photon-based systems generating high-energy X-rays, delivered via rotating gantries and dynamically shaped beams.
- **Charged particle systems (protons)**
Proton beams with finite range in tissue, delivered using scanning or passive beam delivery techniques.
- **Three-dimensionally distributed arrays of Cobalt-60 sources**
Multiple compact gamma-ray sources arranged around a common isocenter, delivering radiation through a large number of fixed beam trajectories.

Effects at low doses

- **Brains in space: impact of microgravity and cosmic radiation on the Central Nervous System during space exploration** (Wuyts et al. Nature Reviews Neuroscience volume 26, pages354–371, June 2025)
- Describes how microgravity and cosmic radiation affects cognitive functions in astronauts.
- Key message for us: cosmic radiation, **high energy protons**, secondary neutrons and secondary gamma radiation, have a measurable impact on cognitive function, **even at low dose**
- Hence, the boundaries of dose delivery in the brain are critical



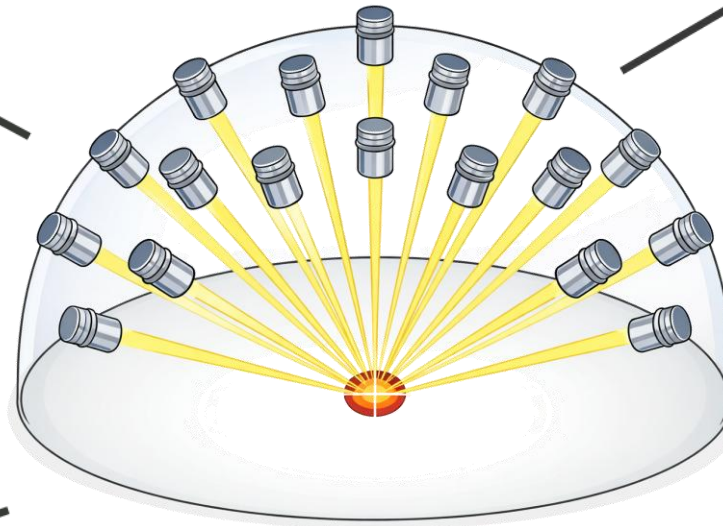
3D distributed arrays of Co-60 sources

1. Steep dose gradient and sharp penumbra

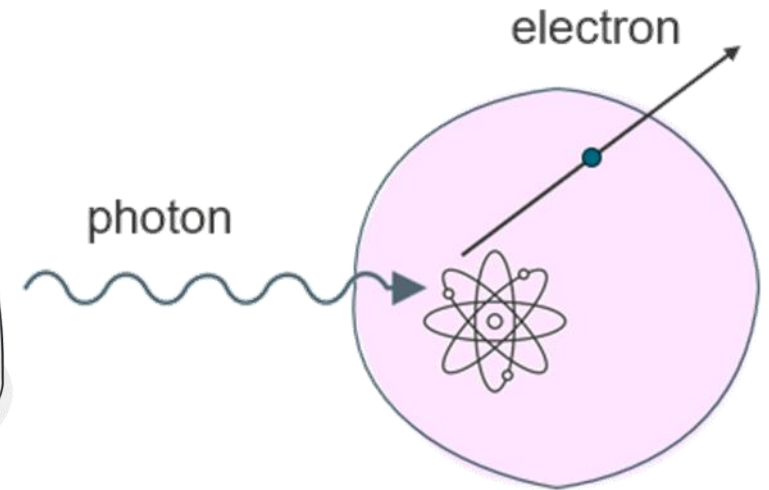
Dimension of the sources
distance from the isocentre,
precise collimation

2. Cumulative dose fall-off

Combined effect of multiple independent
beams on a 3-dimensional pattern:
the 3D Archimedes' heat ray effect



4. Lateral Electron Equilibrium and Kerma

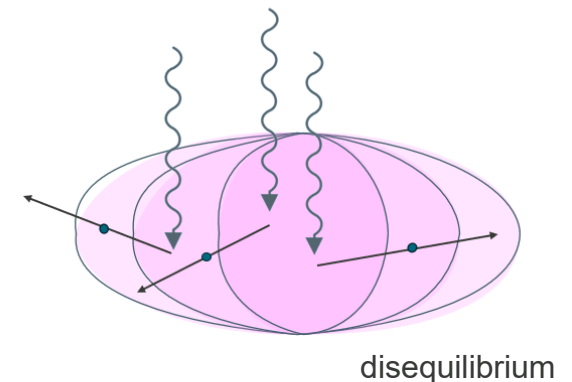
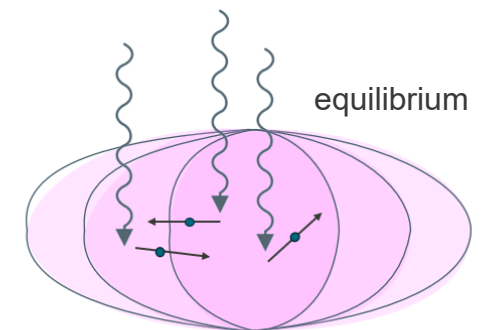
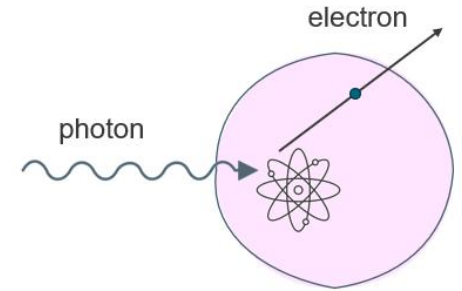


3. Dosimetric penumbra

High-definition energy,
two well defined single energy lines
1.17 MeV and 1.33 MeV

Lateral Electron Equilibrium

- When photons interact with tissue, they generate **electrons**.
- Electrons travel for a certain distance in the tissue (**range**), depositing energy, hence **delivering the dose** to the intended target.
- Now, you see, there is a mismatch between the irradiated volume and where dose is delivered. This is most relevant for small targets.
- Optimal dose delivery: **electron equilibrium**
 - A condition where the **number of electrons generated and absorbed** within the volume are balanced
 - Ensuring the dose is truly delivered **where intended**.
- **Electron disequilibrium** occurs when:
 - the **irradiated volume is too small** for the photon energy delivered
 - Resulting in electrons delivering the dose outside the intended target.

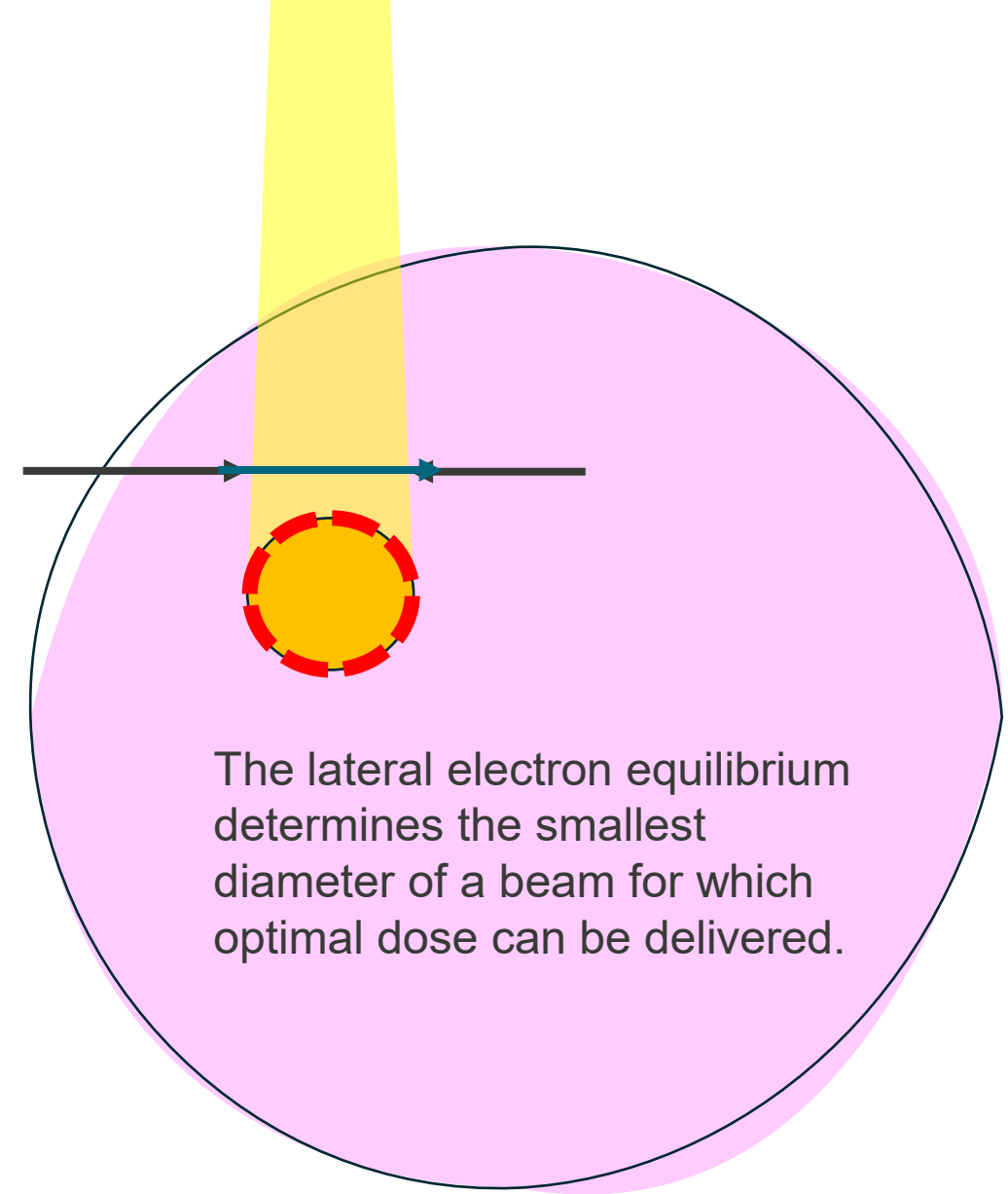


Lateral Electron Equilibrium

- The dimension in which such equilibrium is reached depends on the photon energy.
- The lateral electron equilibrium (LEE) shows the minimum size of the treatable volume for which equilibrium is reached. **The smaller the LEE, the smaller volume can be treated in equilibrium.**

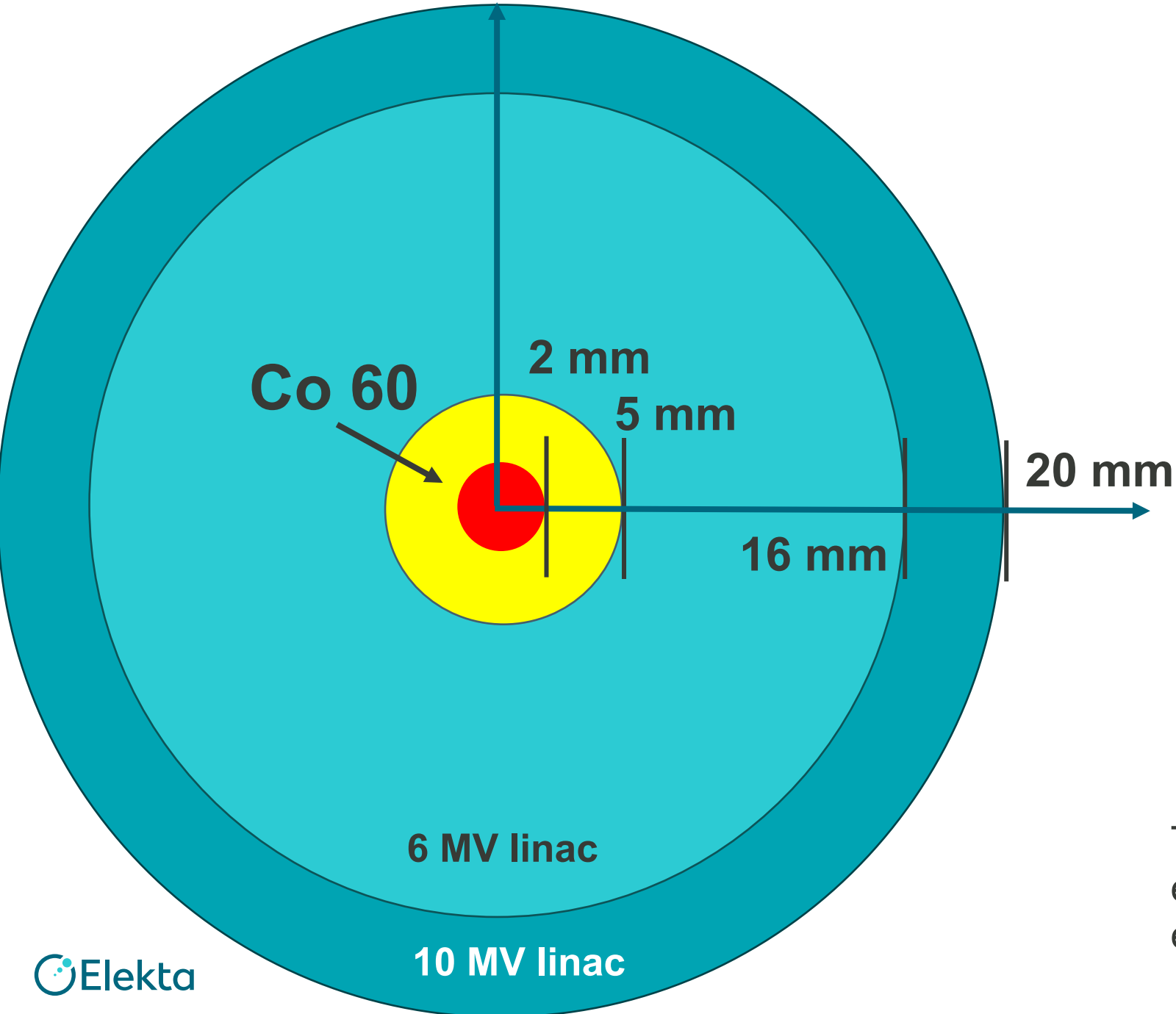
Beam	r _{LEE} (g/cm ²)
⁶⁰ Co	0.6
6 MV	1.3
10 MV	1.7
15 MV	1.9
24 MV	2.1

Note: the LEE is given as a surface density (g/cm²), as the actual dimension depends on the density of the tissue irradiated (expressed in g/cm³).



Kerma

	Kerma 90% radius	Kerma 100% radius
Cobalt 60	2 mm	5 mm
6 MV	6 mm	16 mm
10 MV	10 mm	20 mm



The kerma is the ratio between energy released in a volume and the energy absorbed in the same volume.

3D distributed arrays of Co-60 sources

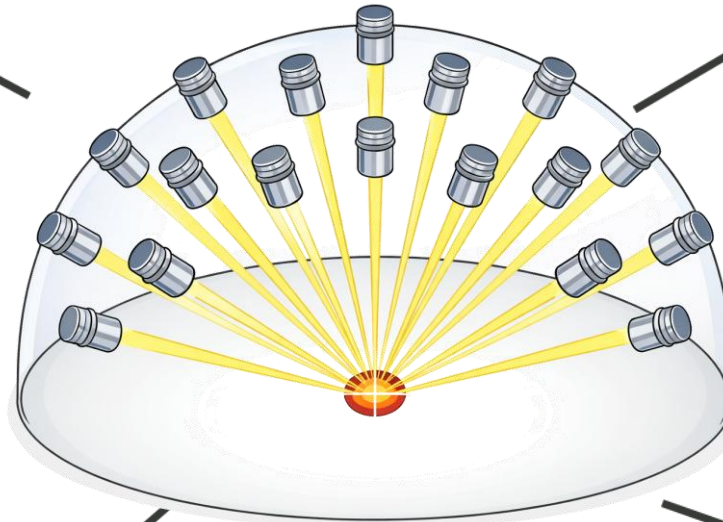
1. Steep dose gradient and sharp penumbra

2. Cumulative dose fall-off

3. Dosimetric penumbra

4. Lateral Electron Equilibrium and Kerma

5. Extracranial dose

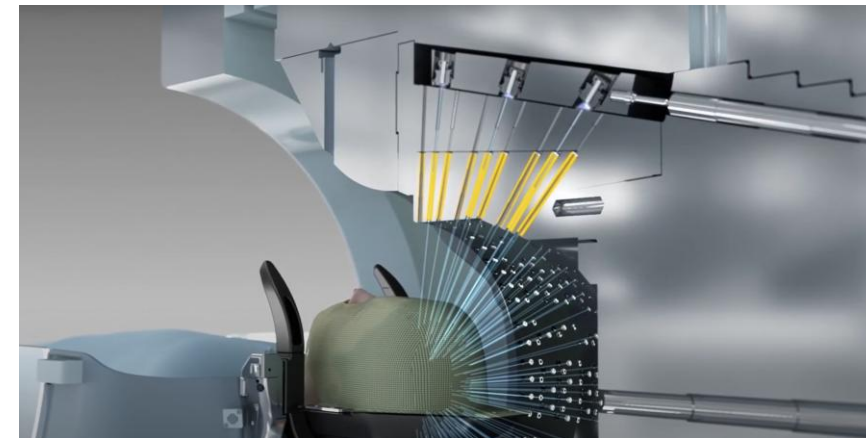
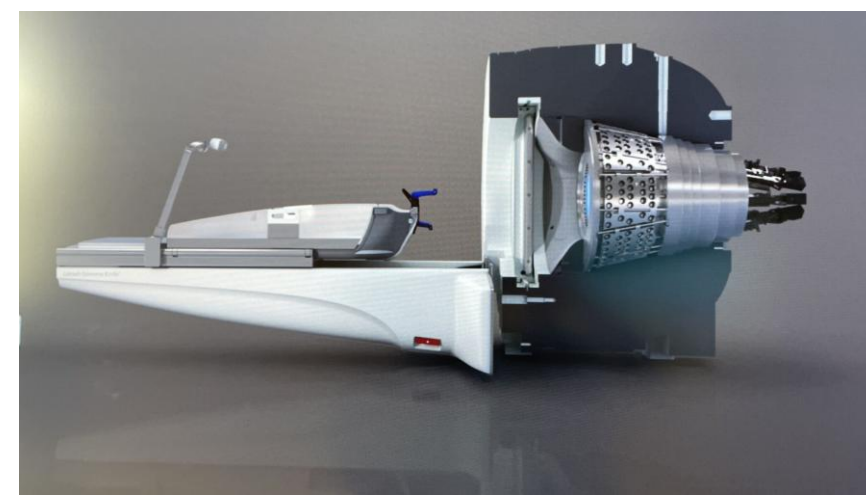


Specific for brain SRS →

Lowest extracranial dose than any other SRS system. Low scattering, shielding design.

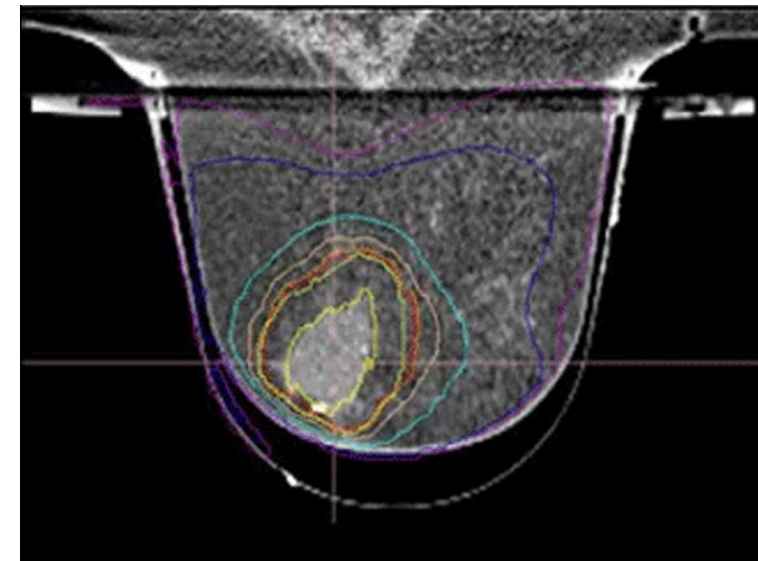
Leksell Gamma Knife®

- **Dedicated system for intracranial stereotactic radiosurgery**, designed for single-session, high-precision treatments.
- **Radiation delivery based on a fixed three-dimensional array of 192 sealed Cobalt-60 sources**, all focused on a common isocenter.
- **Static geometry**: dose shaping is achieved by source arrangement and collimation rather than beam steering or dynamic modulation.
- **Mechanical and geometrical accuracy** determined by the fixed source–collimator–isocenter relationship.



^{60}Co -based SRS beyond the brain

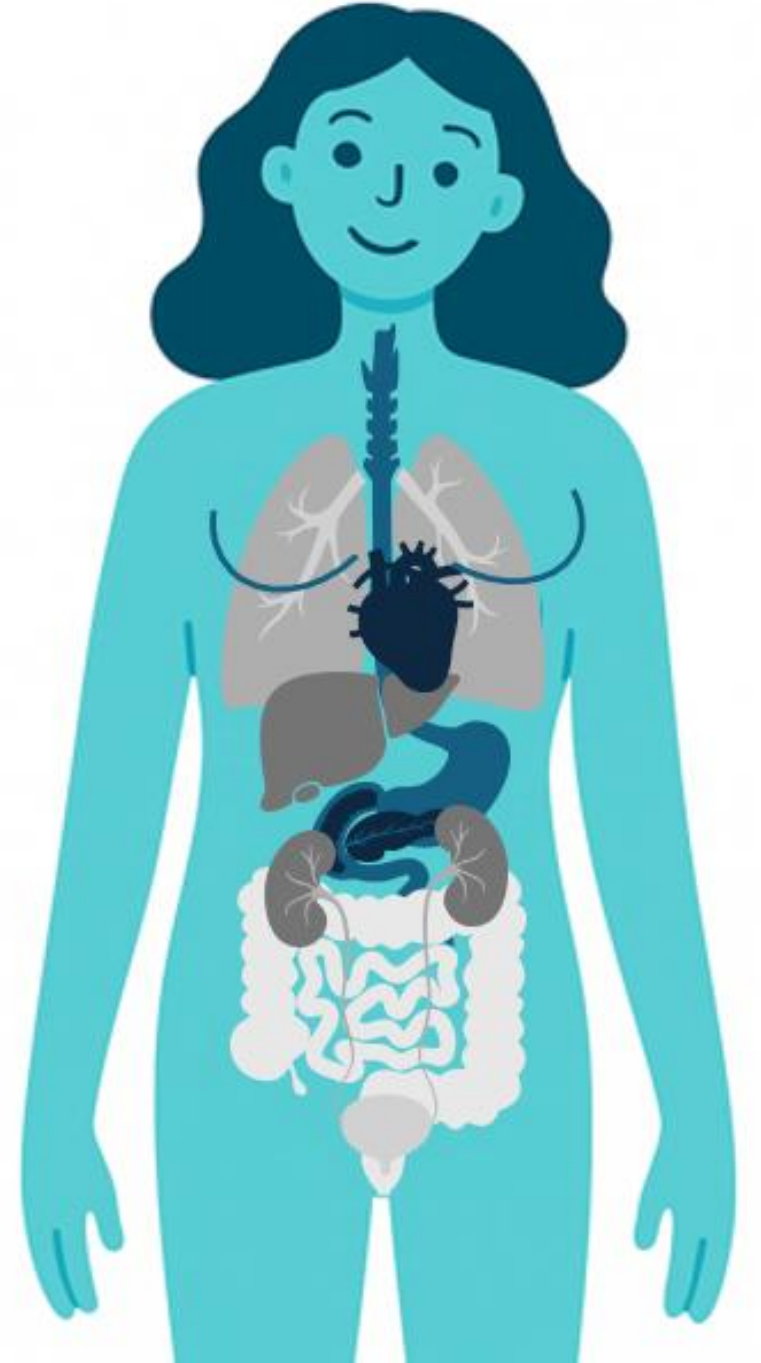
- Cobalt-60-based stereotactic systems are not limited to intracranial radiosurgery. The same delivery principle, multiple compact Co-60 sources arranged around a common isocenter, has also been applied to extracranial targets.
- One example is a dedicated **breast stereotactic radiotherapy system** (GammaPod™), which exploits multiple compact Cobalt-60 sources to achieve:
 - Uniform and conformal dose distribution
 - Steep dose fall-off at the target boundary



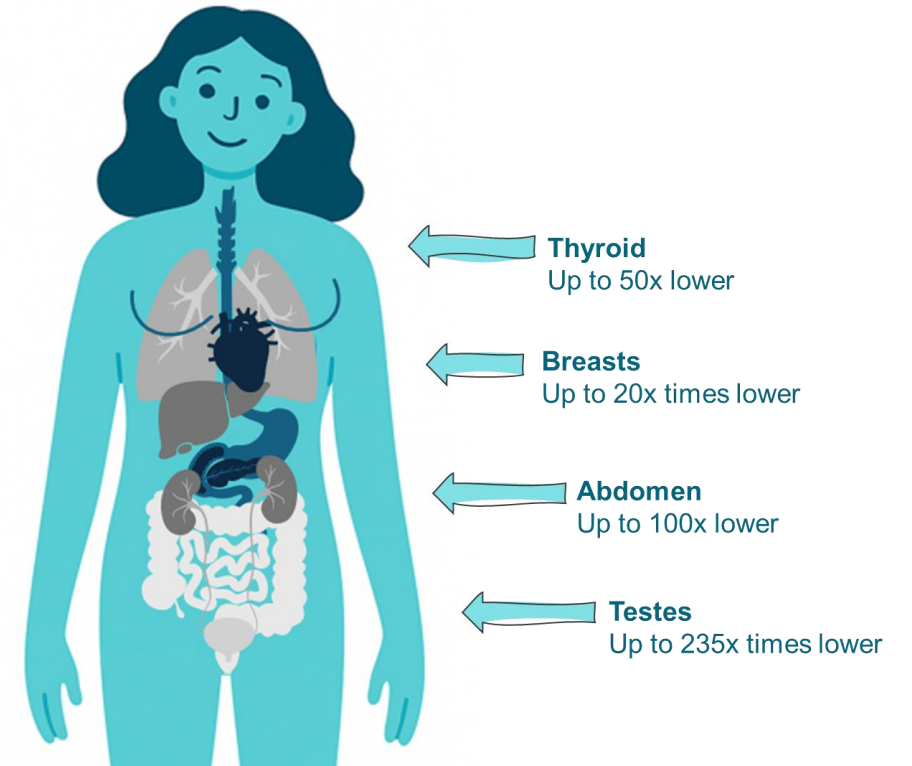
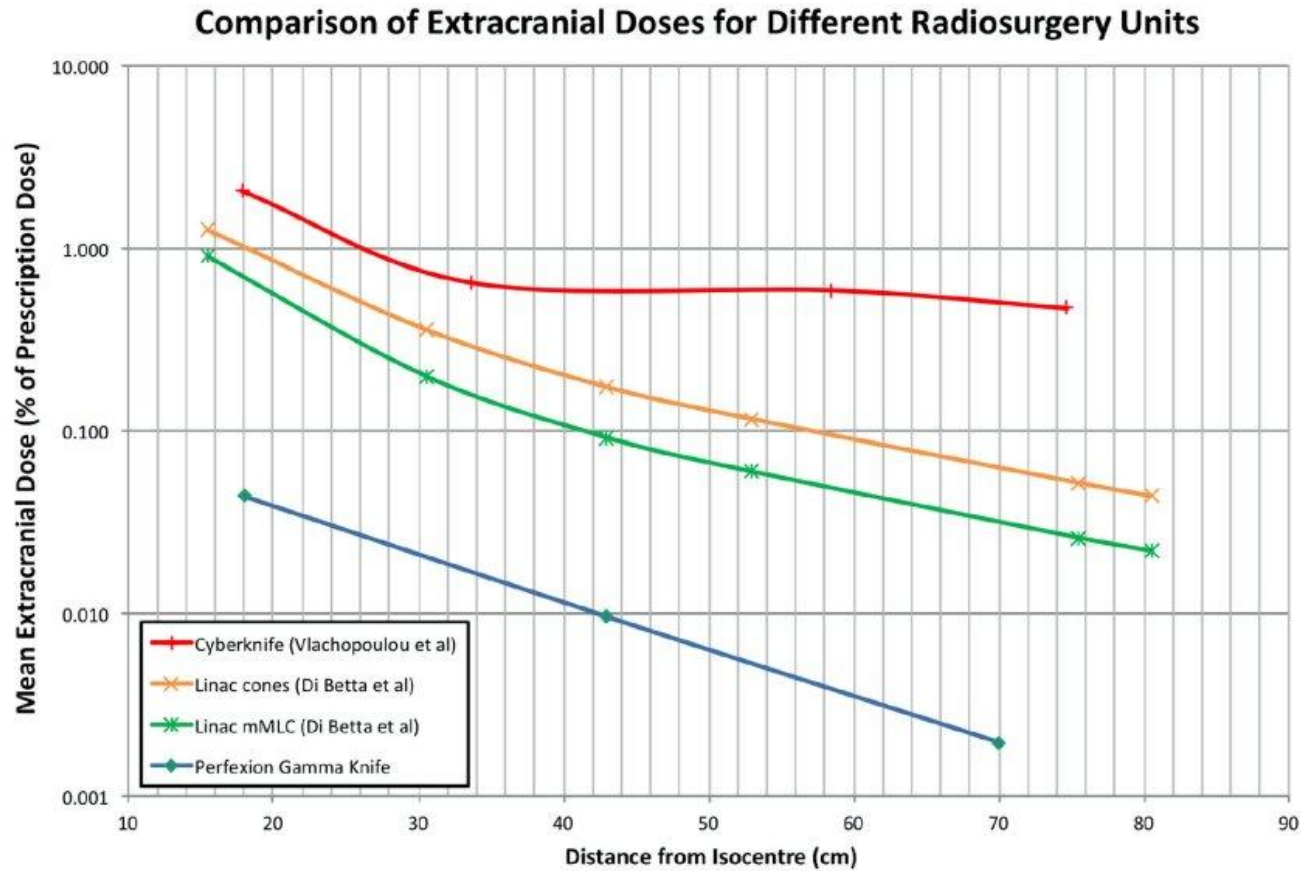
Images: www.gammapod.eu and GammaPod™ brochure by Tema Sinergie SpA
Manufacturer Xcision Medical Systems, LLC
Supplier Europe: TEMA SINERGIE S.p.A.

Extracranial dose

- Extracranial dose during SRS treatment varies largely depending on the SRS system used, **comparable to 1 to 100+ abdomen-pelvis CT-scans**
- Ian Paddick and colleagues discussed it extensively in their 2020 study on “Extracranial dose and the risk of radiation-induced malignancy after intracranial stereotactic radiosurgery.”
- The Gamma Knife design and use of Cobalt 60 as source of radiation **greatly reduces extracranial dose** compared to any other SRS system.



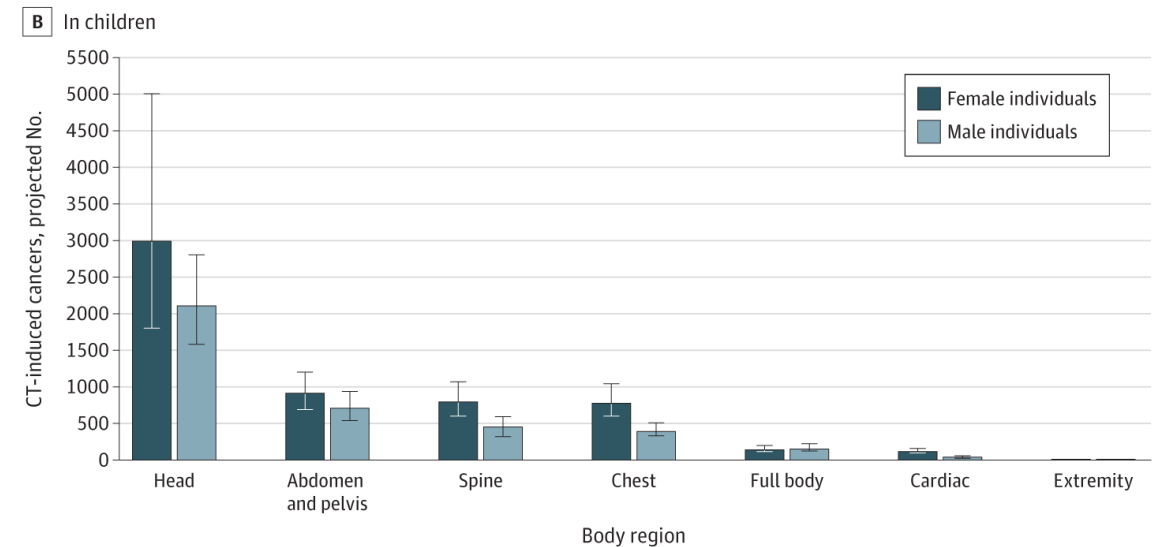
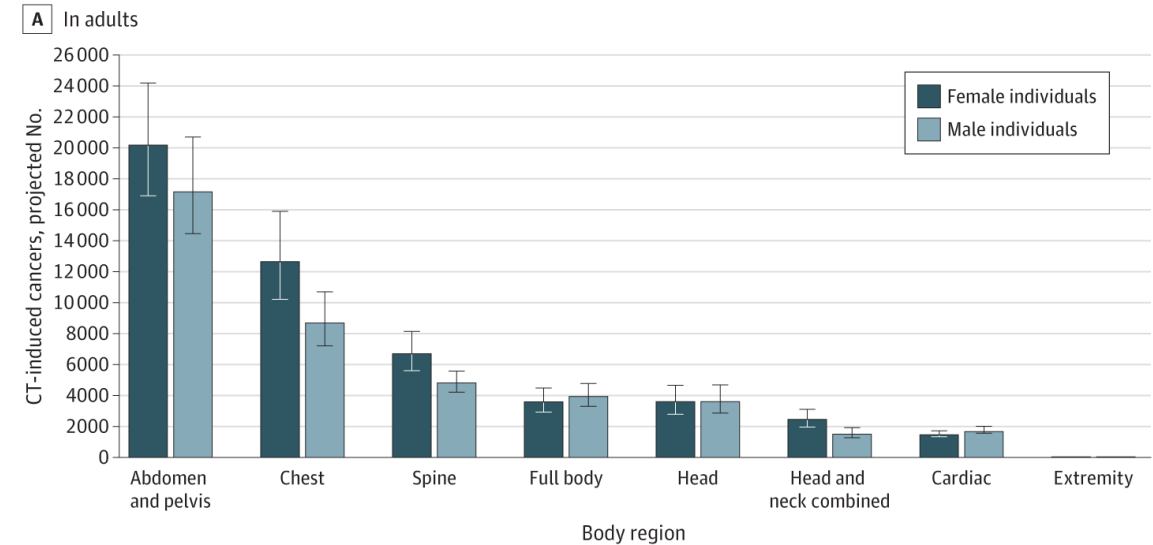
Extracranial dose



Ian Paddick, A. Cameron & A. Dimitriadis Acta Neurochirurgica volume 163, pages 971–979 (2021)

Extracranial dose

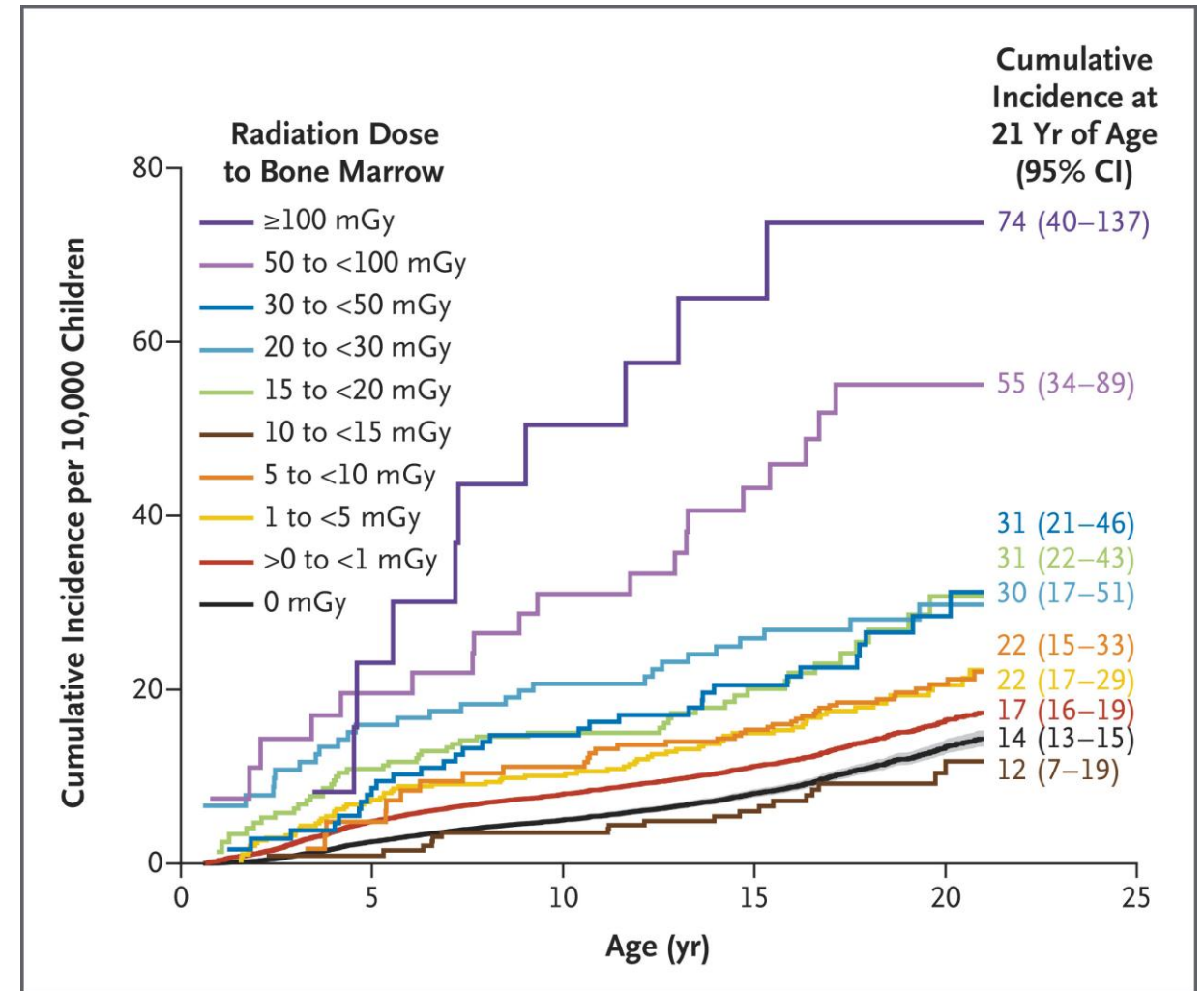
- “**Projected Lifetime Cancer Risks From Current Computed Tomography Imaging**”, Rebecca Smith-Bindman et al. (University of California), published in April 2025
- Multicenter sample of CT examinations from the University of California San Francisco International CT Dose Registry. Cancer risk was calculated based on dose models.
- The organ-specific radiation doses were analysed by patient age, sex, and type of scan and scaled to the US population, for year 2023.
- **Approximately 5% of future annual cancer diagnoses** (in the US) were projected to result from CT utilization in 2023 only.



JAMA Intern Med Published Online: April 14, 2025;
185;(6):710-719. doi:10.1001/jamainternmed.2025.0505

Extracranial dose

- “Medical Imaging and Pediatric and Adolescent Hematologic Cancer Risk” published in September 2025 on the New England Journal of Medicine
- Followed a retrospective cohort of 3.7 million children born 1996 - 2016 in the USA and Canada.
- They looked at the associations between hematologic cancers and cumulative radiation exposure (vs. no exposure).
- **Medical imaging in childhood was associated with 10.1% of hematologic cancers at age 21.** Cumulative incidence will probably increase with longer follow-up.



The New England Journal of Medicine 2025;393:1269-1278 DOI: 10.1056/NEJMoa2502098 VOL. 393 NO. 13

Summary

- The main application of Cobalt-60 technology is sterilization.
- External beam radiotherapy with linear accelerators has largely replaced Co-60 teletherapy units.
- However, in stereotactic radiosurgery, particularly for brain applications, the **physics properties of Cobalt-60** provide characteristics that are not matched by accelerator-based systems.



Hope for everyone
dealing with cancer.