Semester 1 2022/2023
Sistem Pengawasan Nuklir (RN6086)
FMIPA ITB

Sistem Pengawasan Nuklir (RN6086)

Sinergitas konsep 3S dan konsep dasar depence in depth dalam konsep safety (keselamatan)

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Sistem Pengawasan Nuklir

1. tekait tema pengawasan, juga tema keselamatan atau safety dan juga keamanan atau security fasilitas nuklir

2. Sinergitas konsep 3S safety, secuarity dan safeguard proses dan implementasinya,

3. konsep dasar depence in depth dari safety dan safeguard,

4. analisa desain basis dari konsep safety dan safeguard by design

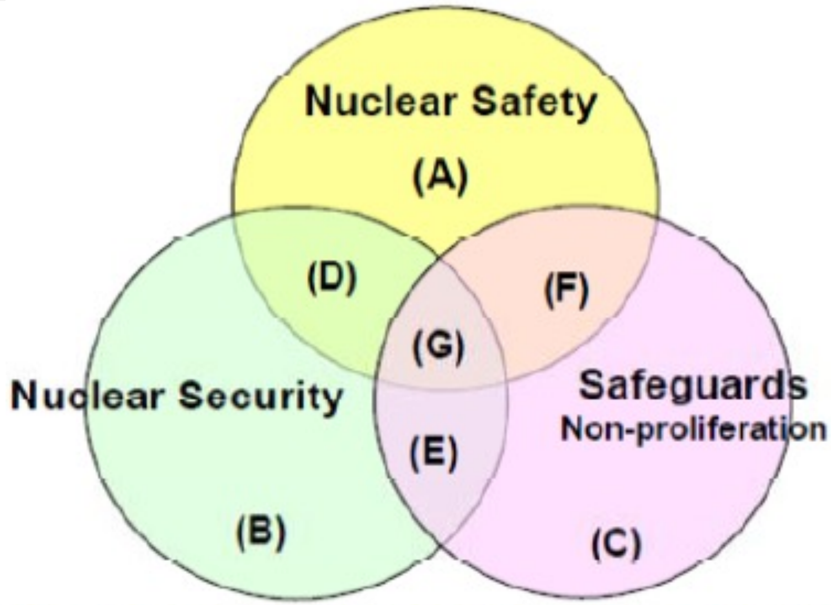
5. material nuklir terkait daur ulang bahan bakar, kuantitas materil nuklir terkait data

6. pelaporan khusunya material nuklir terkait uranium dan plutonium

7. konsep non proliferasi nuklir, pengetahuan mengenai protected plutonium proliferation

8. Konsep material attractiveness,

Sinergisasi Konsep 3 S



(A) Emergency core cooling system for nuclear power plant, (B) Barrier at the facility entrance, (C) Authenticated apparatus

(D) Double-entry doors to keep negative pressure and prevent radioactive release

(E) Management of nuclear material using containment and surveillance and remote monitoring camera

(F) Management of nuclear material for criticality and accounting control

(G) Possible monitoring camera for multipurpose use, such as joint use of equipment

Figure 1 - A Venn diagram depiction of potential synergies among the 3Ss, with examples. (Courtesy of the IAEA, via blanket permission, from Suzuki et al., 2010)

Nuclear Security Science & Policy Institute
A Division of the Texas Engineering Experiment Station

SAFETY, SAFEGUARDS AND SECURITY IN INDIAN CIVIL NUCLEAR FACILITIES

Sinergisasi Konsep 3 S

B. Keselamatan, Keamanan dan *Safeguards*

16. Apakah itu keselamatan nuklir?

Keselamatan nuklir merupakan suatu tindakan untuk pencapaian kondisi operasi yang tepat suatu reaktor nuklir sesuai desain, untuk pencegahan terjadinya kecelakaan atau mitigasi konsekuensi kecelakaan, untuk melindungi pekerja, masyarakat dan lingkungan dari bahaya radiasi yang tidak semestinya, dan termasuk untuk proteksi radiologi.

17. Apakah itu keamanan nuklir?

Keamanan nuklir merupakan tindakan pencegahan, deteksi. dan respons terhadap pencurian, sabotase, akses dan transfer ilegal atau tindakan berbahaya lainnya terhadap bahan nuklir dan zat radioaktif yang berhubungan dengan reaktor nuklir fasilitas terkait.

18. Apakah itu *safeguards* nuklir?

Safeguards nuklir merupakan sarana yang diterapkan untuk verifikasi kepatuhan suatu negara untuk menerima kesepakatan *safeguards* IAEA terhadap semua bahan nuklir dalam semua kegiatan nuklir untuk tujuan damai dan untuk verifikasi bahwa bahan nuklir tersebut tidak dialihkan ke senjata nuklir atau alat peledak nuklir lainnya.

Safeguards didesain terutama untuk dua tujuan yaitu: 1) untuk mendeteksi kegiatan proliferasi yang melibatkan pengalihan bahan dari siklus bahan bakar nuklir sipil, dan 2) untuk memberikan peringatan dari setiap kejadian tersebut kepada forum internasional secara tepat.

Sinergisasi Konsep 3 S

B. Keselamatan, Keamanan dan *Safeguards*

19. Apakah tujuan umum keselamatan, keamanan dan *safeguards*?

Tujuan umum dari keselamatan nuklir, keamanan nuklir dan *safeguards* adalah untuk melindungi manusia dan lingkungan dari efek radiasi pengion yang ditimbulkan oleh fasilitas dan kegiatan pemanfaatan nuklir. Tujuan keselamatan nuklir diarahkan lebih ke arah mengendalikan risiko yang melekat dalam mengoperasikan peralatan nuklir dan fasilitas atau transportasi bahan radioaktif. Tujuan keamanan nuklir ditargetkan untuk memberikan perlindungan terhadap tindakan berbahaya yang dapat menyebabkan lepasan radiologi atau efek menghancurkan yang dihasilkan dari penggunaan zat radioaktif atau bahan nuklir. Sedangkan tujuan dari *safeguards* adalah untuk memastikan bahwa penggunaan bahan nuklir untuk tujuan damai tidak membuat senjata atau bahan peledak nuklir.

Sinergisasi Konsep 3 S

B. Keselamatan, Keamanan dan *Safeguards*

20. Apakah persyaratan keselamatan nuklir?

Persyaratan keselamatan nuklir reaktor nuklir dan fasilitas nuklir lainnya harus memenuhi dua persyaratan keselamatan utama yaitu:

a. Persyaratan keselamatan nuklir untuk fasilitas tersebut selamat untuk dioperasikan dengan probabilitas kecelakaan sangat kecil; dan

b. Persyaratan keselamatan radiasi bahwa paparan radiasi dalam operasi normal berada di bawah batas yang ditetapkan untuk personil, anggota masyarakat dan lingkungan.

21. Apakah yang harus dilakukan untuk mencapai keselamatan reaktor nuklir?

Pemohon izin terkait reaktor nuklir harus melakukan upaya keselamatan dan memenuhi ketentuan yang diberikan oleh badan pengawas (di Indonesia, badan pengawas tenaga nuklir/BAPETEN). Selain itu desain reaktor nuklir harus menerapkan pertahanan berlapis.

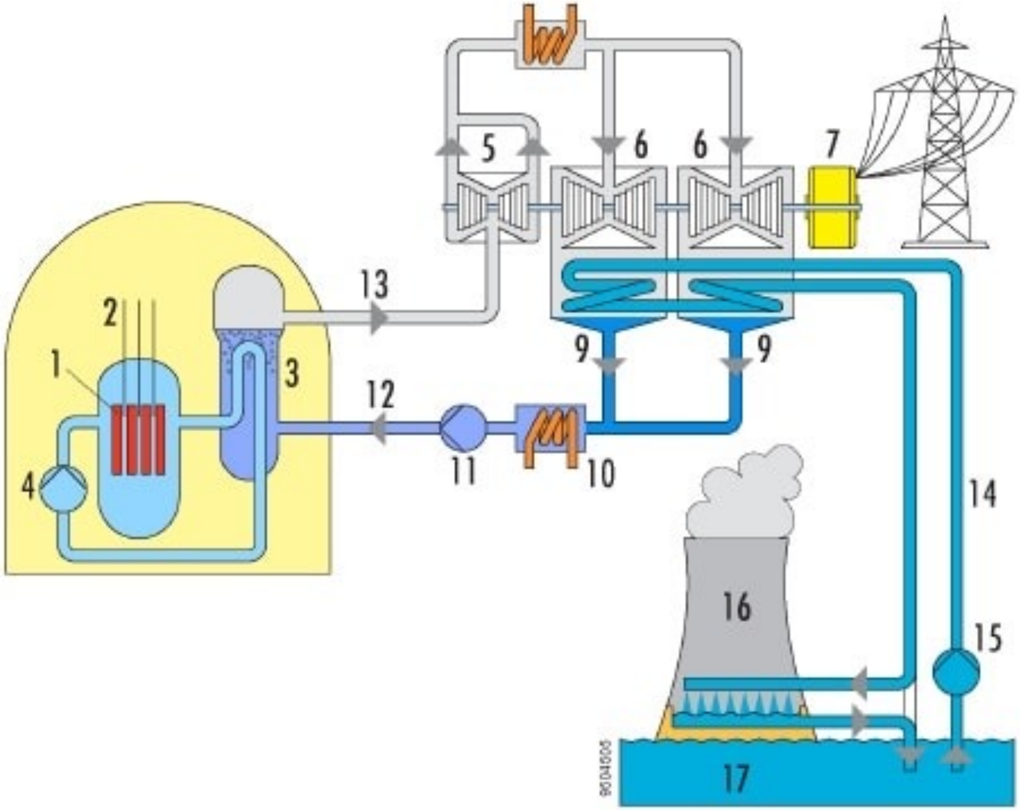
Sinergisasi Konsep 3 S

D. Pengawasan Reaktor Nuklir

33. Apakah dasar hukum/peraturan pengawasan nuklir?

a. Pembukaan Undang-Undang Dasar 1945.
b. Undang-Undang (UU) No.8 Tahun 1978 tentang Pengesahan Perjanjian Mengenai Pencegahan Penyebaran Senjata Nuklir.
c. UU No. 9 Tahun 1997 tentang Pengesahan *Treaty on the Souteast Asia Nuclear Weapon Free Zone*.
d. UU No. 10 Tahun 1997 tentang Ketenaganukliran.
e. UU No. 1 Tahun 2012 tentang Pengesahan Traktat Pelarangan Menyeluruh Uji Coba Nuklir.
f. UU No. 10 Tahun 2014 tentang Pengesahan *Inter-national Convention for Suppresion of Acts of Nuclear Terorism*.
g. Keputusan Presiden (Keppres) No.81 Tahun 1993 tentang Pengesahan *Convention on Early Notification of Nuclear Accident*.
h. Keppres No. 82 Tahun 1993 tentang Pengesahan *Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency*.
i. Keppres No.106 Tahun 2001 tentang Pengesahan *Convention On Nuclear Safety*.
j. Perpres No 46 Tahun 2006 tentang Pengesahan *Convention on Physical Protection of Nuclear Material*.
k. Perpres No.84 Tahun 2010 tentang Pengesahan *joint convention on the safety of fuel Management and The safety of Spent Fuel Management*.
l. Perpres No.74 Tahun 2012 tentang Pertanggungja-waban Kerugian Nuklir.

Nuclear Energy Production

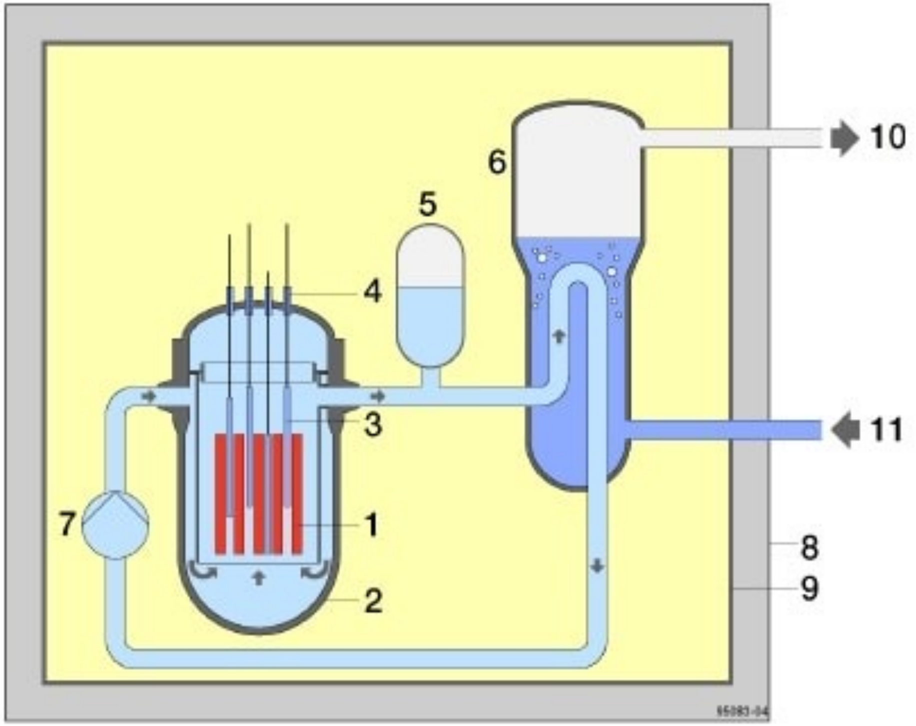


1 Reactor core
2 Control rods
3 Steam generator
4 Recirculation pump
5 HP-part of turbine
6 LP-part of turbine
7 Generator
8 Reheater
9 Condensor
10 Preheater
11 Feedwater pump
12 Feedwater line
13 Main steam line
14 Cooling water
15 Cooling water pump
16 Cooling tower
17 River

GRS

Protection Goals (Nuclear Safety Goals)

- **Reactivity control**
- **Fuel cooling**
- **Confinement of radioactive materials**
- Limitation of radiation exposure

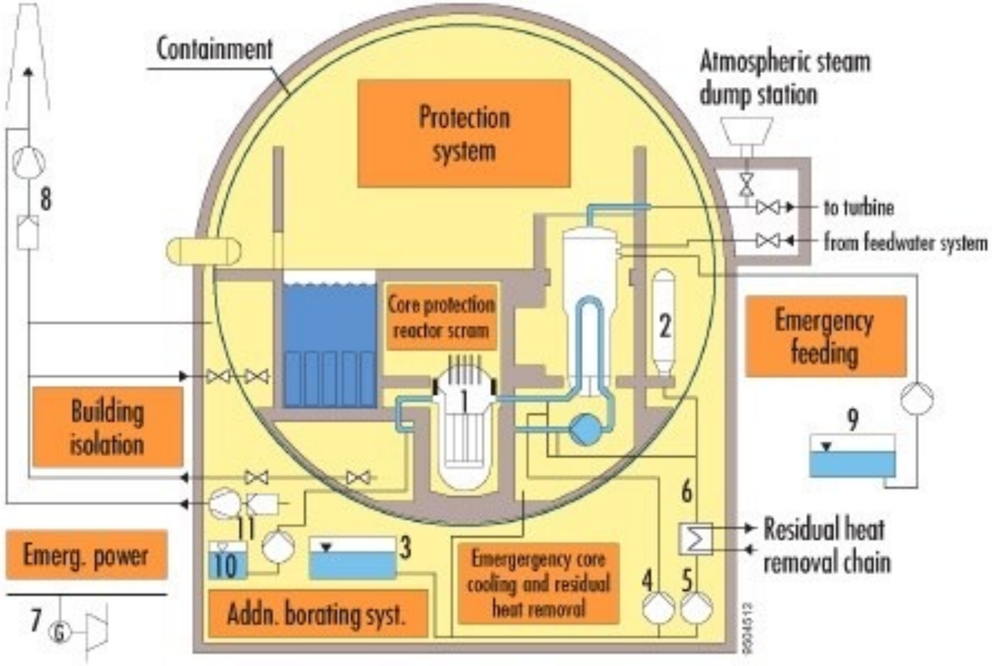


1 Fuel elements
2 Reactor pressure vessel
3 Control rods
4 Control rod drives
5 Pressuriser
6 Steam generator
7 Coolant pump
8 Concrete structure
9 Steel liner
10 Steam
11 Water

G. Thuma, Basic Safety Concepts in Nuclear Engineering 02.06.2010 5

Safety Concepts

- Defence in depth
- Multiple barriers
- Fail Safe Design
- Single failure concept
- Redundancy
  - Physical Separation
- Diversity
- …



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Defence in Depth

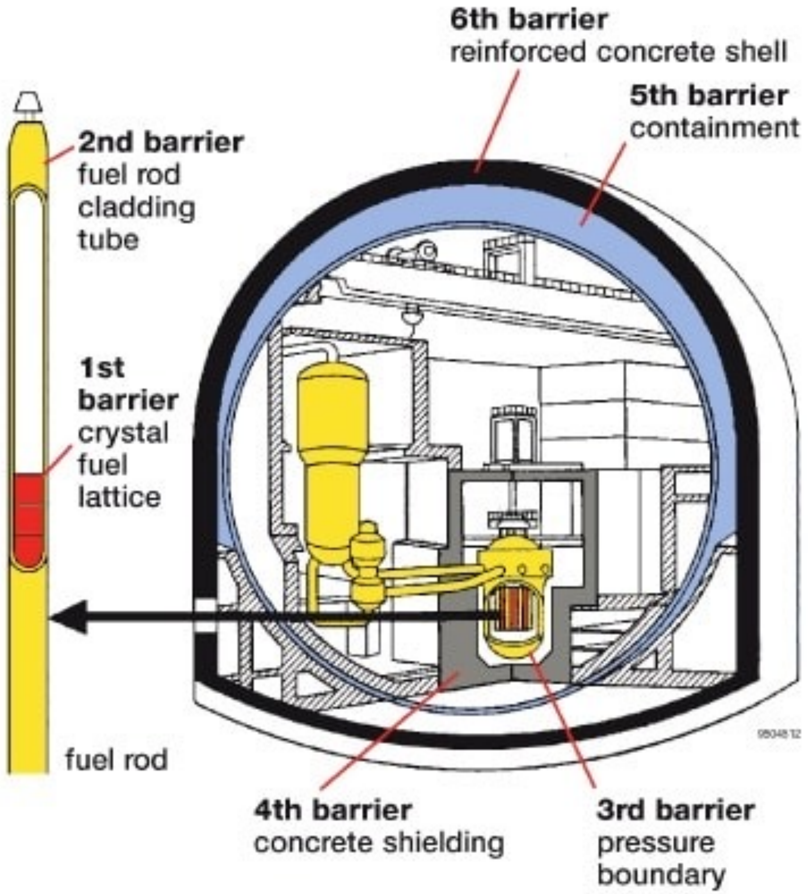
The concept of defence in depth, as applied to all safety activities, whether organizational, behavioural or design related, ensures that they are subject to overlapping provisions, so that if a failure were to occur, it would be detected and compensated for or corrected by appropriate measures […] Application of the concept of **defence in depth** throughout design and operation **provides a graded protection against** a wide variety of **transients, anticipated operational occurrences and accidents**, including those resulting from equipment failure or human action within the plant, **and events that originate outside the plant.**

[IAEA Safety Requirements, NS-R-1, Safety of Nuclear Power Plants: Design]

Multiple Barriers

There are barriers for various purposes:

- Containment of radioactive materials
- Radiation protection
- Fire protection
- Limitation of effects of component failures
  - Missiles
  - Flooding
- Physical protection (security)
- …



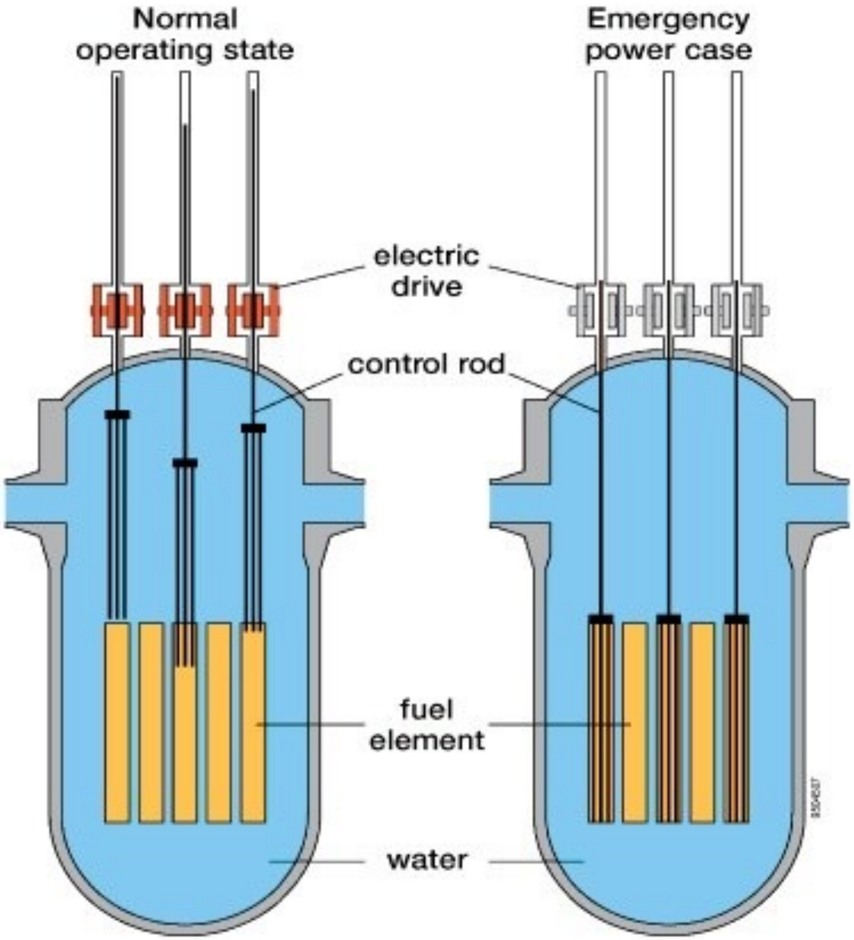
Fail Safe Design

Definition:

- Design ensuring that in the event of a failure the system behaves in a way that will cause no harm

Example:

- To shutdown the reactor the control rods have to be inserted into the reactor core
  - Normally the control rods are held and moved by electric drives
  - In the event of a power failure, the control rods fall into the core under gravity



Single Failure Concept

Aim:

- Safety function available (100 %)

Assumption:

- Failure of a safety installation due to a random single failure with the most unfavourable effect
- Unavailability of a safety installation due to maintenance measures with the most unfavourable effect

Solutions:

- 3 sub-systems á 100 %
- 4 sub-systems á 50 %

Advantage of the 4 x 50 % solution:

- In some situations 50 % are enough to accomplish the task

Redundancy

Definition:

- Duplication of critical structures, sub-systems, or components

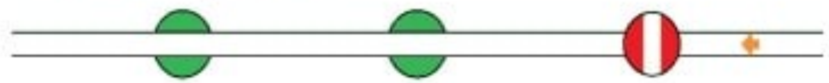
Aim:

- Backup for random failures, maintenance,…

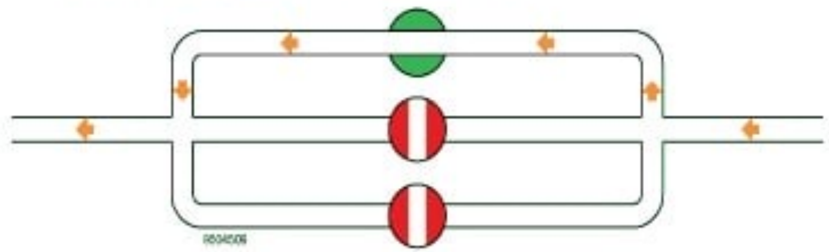
Design:

- Realization depends on the safety function that has to be performed

Redundancy in the closing function:
Valves arranged in series



Redundancy in the opening function:
Parellel arrangement of the valves



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Diversity

Definition:

- Different technical implementations of a given safety function

Aim:

- Prevention of common cause failures

Caveat:

- Not everything that looks like a different implementation is a different implementation

GRS

What else?

- Design basis accidents
  - 30 minutes criterion
    - No operator action required during the first 30 minutes of an accident
- Internal and external hazards
- Appropriate instructions
  - Operating and maintenance instruction (normal operation and operational occurrences)
  - For incidents and accidents:
    - Event sequence based workflow instruction (operational occurrences and design basis accidents)
    - Protection goal oriented instructions (other accidents)
  - Internal accident management measures (severe accidents)
  - Off-site emergency response measures (severe accidents)
- Evaluation of the operating experience
- Systematic safety assessments (on a regular basis, e.g. every 10 years)
  - Deterministic safety assessments + probabilistic safety assessments

Internal and External Hazards

Internal hazards

- Fire
- Explosion
- Flooding
- Missiles
  (e.g. from high energy components)
- Heavy load drop
  (e.g. from structural failures
  or crane failures)

External Hazards

Natural Hazards
- Earthquake
- Flooding
- Storm
- Lightning
- Other meteorological hazards

Man-made Hazards
- Explosion (off-site)
- Fire (off-site)
- Aviation accidents

Typical exceedance probabilities for the design basis events: 10^{-4} - 10^{-5} per year

Safety Aspects of Nuclear Reactor

Under Guidance of

Prof J.B.Doshi

Submitted by

Rajan.D.Lanjekar

Roll no : 07310R09

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Outline :

- Objectives of Nuclear Reactor Safety
- Principles of Nuclear Reactor Safety.
- Inherently Safe Nuclear Reactors
- Principles of Radiation dose limits.
- Radiation Hazards
- Classification of Nuclear Reactor Accidents
- Conclusion

Objectives of Nuclear Reactor Safety:

- The basic objective of Nuclear Reactor Safety is the safety of operating personnel and general public and minimum impact on the environment.
- Protection against consequences of nuclear excursion.

The SAHARA Principle :

- **S**afety
- **A**s
- **H**igh
- **A**s
- **R**easonable
- **A**chievable

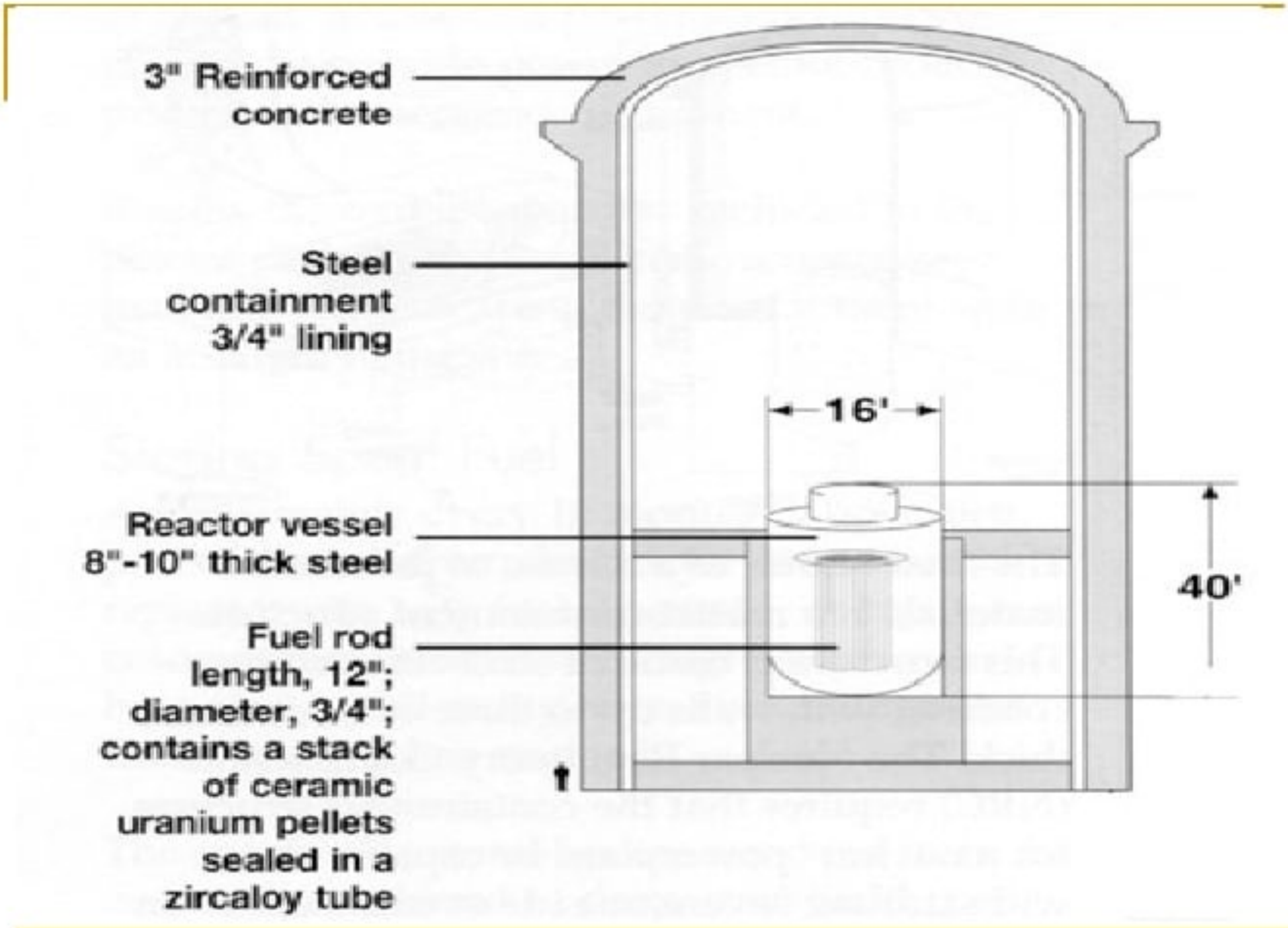
Three levels of Nuclear Reactor Safety:

- **First level**: It addresses the prevention of accidents by virtue of design, construction and surveillance of the plant.
- **Second level** : It provides safety systems to protect operators and the public and to prevent or minimize damage, if accident occurs despite of prevention in first level.
- **Third level** : It supplements the first two by adding margin of safety in the event of extremely unlikely or unforeseen events.

Multiple barrier concept :

- Fuel pellet.
- Fuel cladding.
- Closed loop heat transfer system.
- Reactor vessel.
- Containment.

Konsep Keselamatan (Safety)



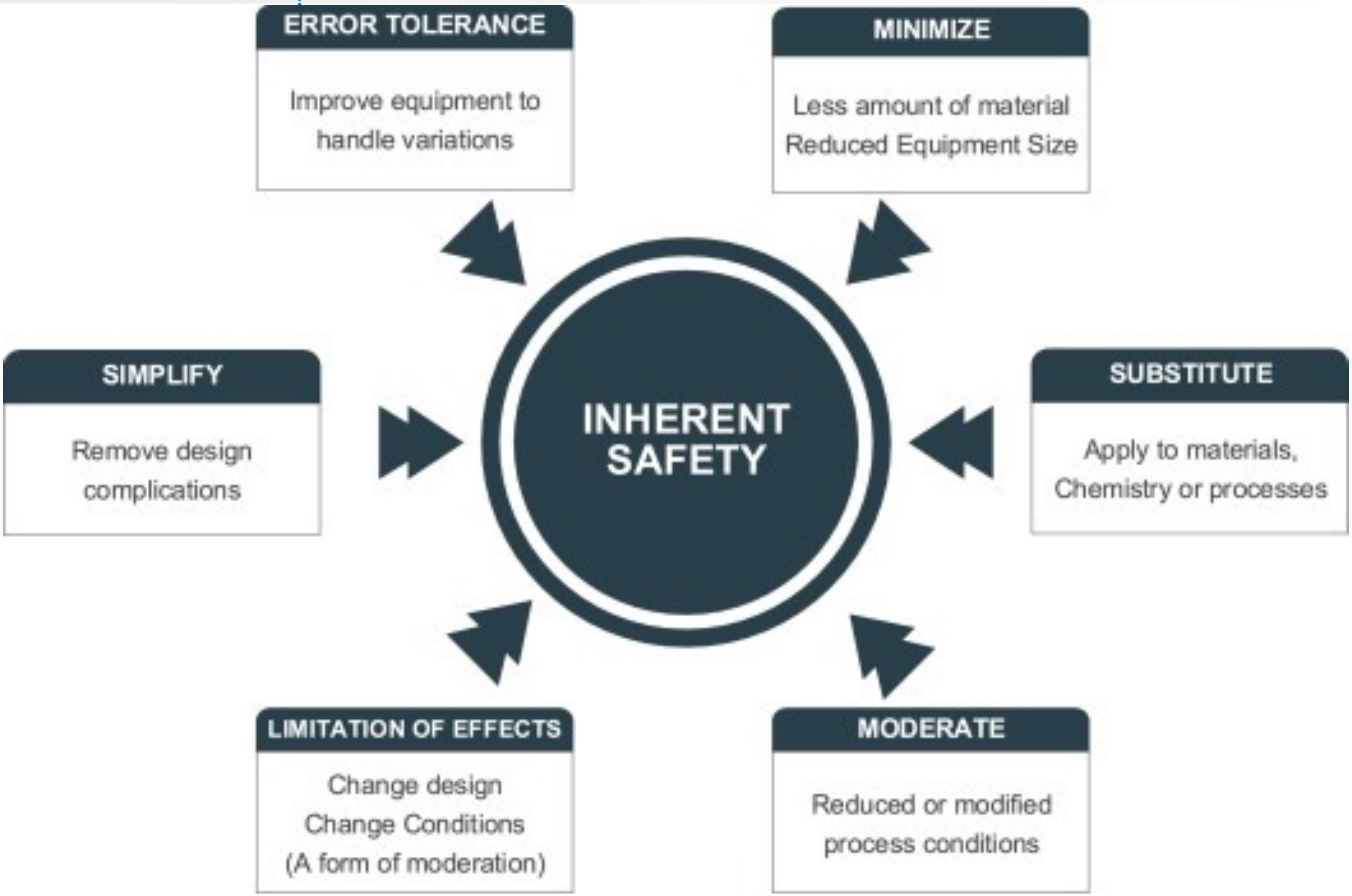
Inherent safety features :

- **Inherent or full passive safety design** depends only on physical phenomena such as convection, gravity or resistance to high temperatures, not on functioning of engineered components.
- **Negative temperature coefficient.**
- **Negative void coefficient.**

Source : R.D. Lanjekar and J.B Doshi, Safety Aspect of Nuclear Reactor

https://www.linkedin.com/pulse/inherent-safety-design-sameh-makhlof-msc

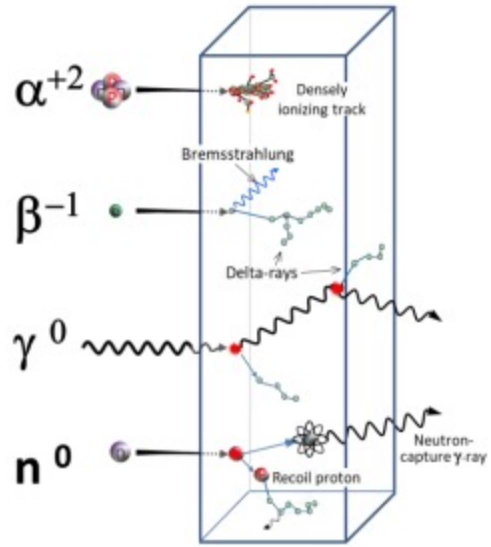
Konsep Keselamatan (Safety)



Source : https://www.sciencedirect.com/science/article/abs/pii/S0957582018308425

Principles for radiation dose limit :

- **Justification**
- **Optimization**
- **Dose limit**



EHSS Office of Environment, Health, Safety and Security Information Brief

Alpha emitters:
radium, radon, uranium, thorium

Pure beta emitters:
strontium-90, carbon-14, tritium, and sulfur-35

Gamma emitters:
iodine-131, cesium-137, cobalt-60, radium-226, and technetium-99m

Neutron emitters:
californium-252, nuclear fission, nuclear fusion, spallation

Radiation Quantities

System of Units	Absorbed Dose ☆	Equivalent Dose ☆	Effective Dose	Radio-Activity
SI	gray (Gy)	sievert (Sv)	sievert (Sv)	bequerel (Bq)
Traditional	rad	rem	rem	Curie (Ci)
"The size of the SI and conventional units differs, and in some cases **the conversions are not arithmetically convenient...**" (NAS Workshop, held in 2016; http://www.nap.edu/24645)		**(...equals absorbed dose multiplied by the Radiation Weighting Factor)**	**(...equals equivalent dose multiplied by the Tissue Weighting Factor)**	☆(Quantities used on Dose Ranges Chart)

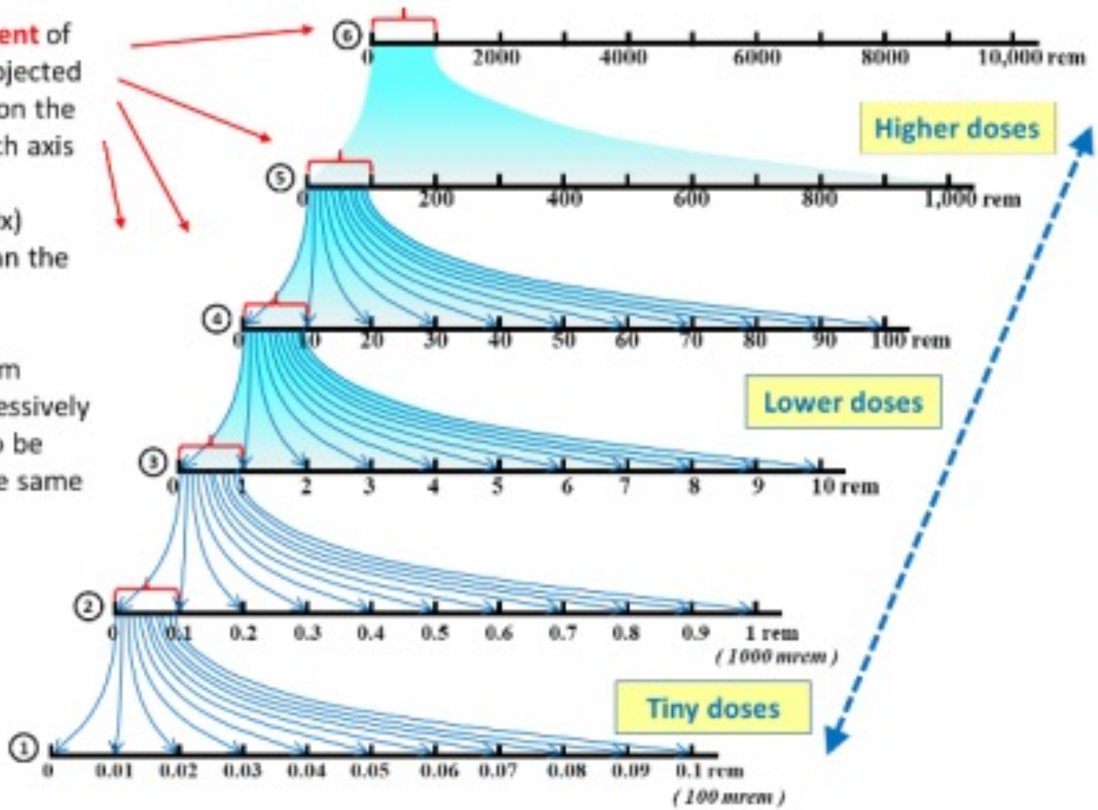
Source : R.D. Lanjekar and J.B Doshi, Safety Aspect of Nuclear Reactor

Principles for radiation dose limit :

- Justification
- Optimization
- Dose limit

The first segment of each axis is projected out to display on the axis below. Each axis is an order of magnitude (10x) lower dose than the axis above.

This allows from higher to successively lower doses to be graphed on the same page.



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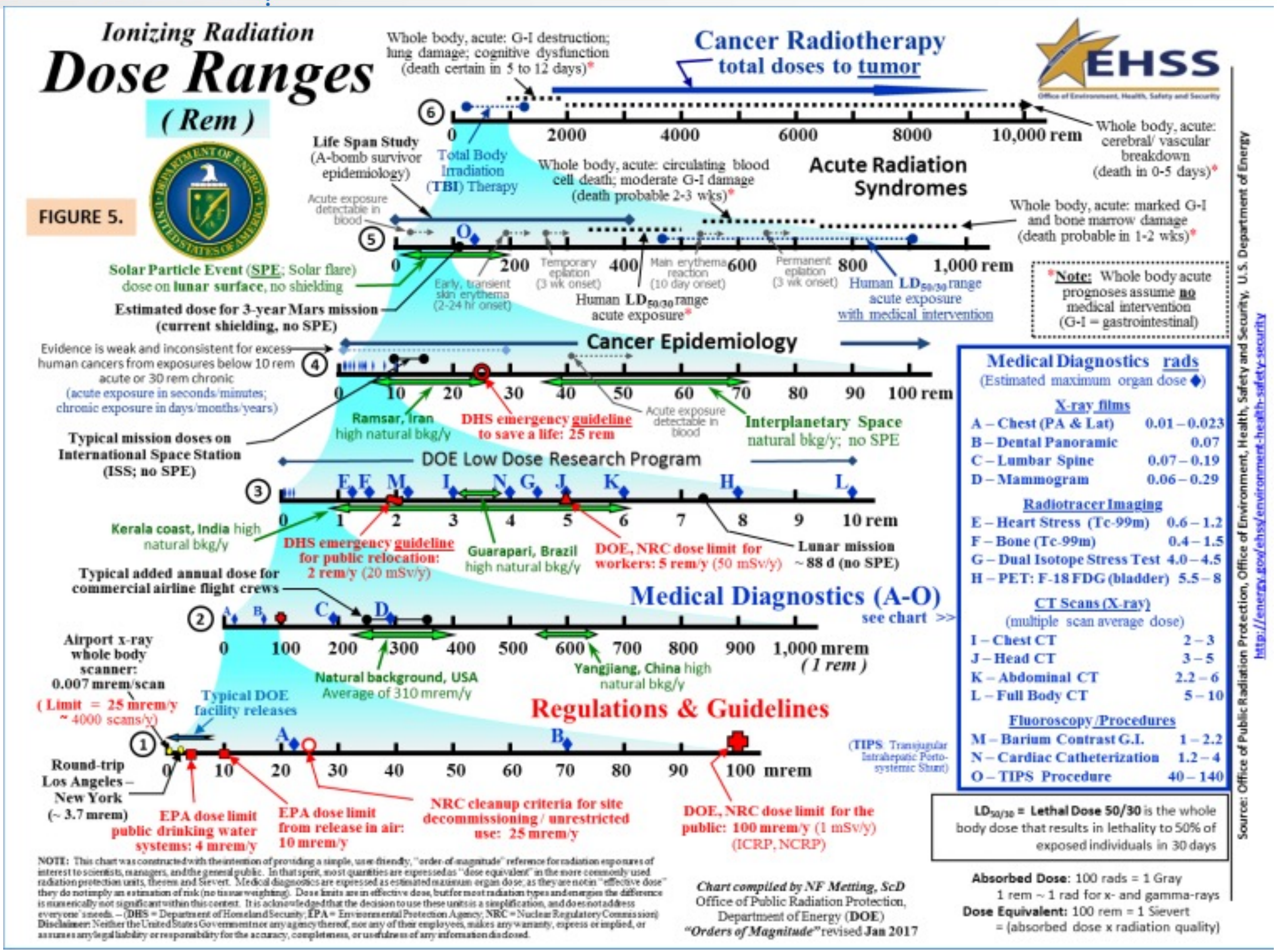
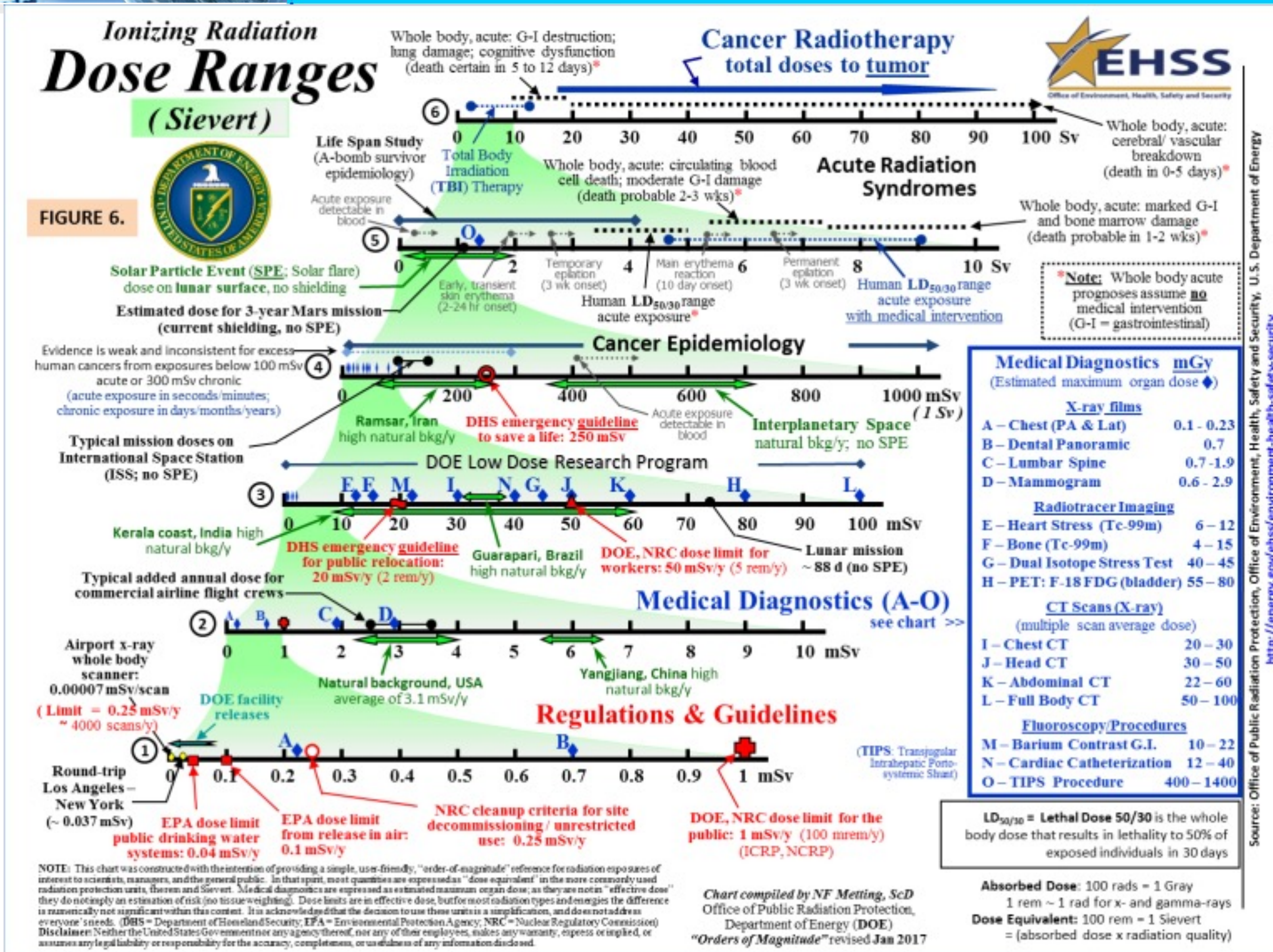
Office of Environment, Health, Safety and Security
Information Brief

Source : R.D. Lanjekar and J.B Doshi, Safety Aspect of Nuclear Reactor

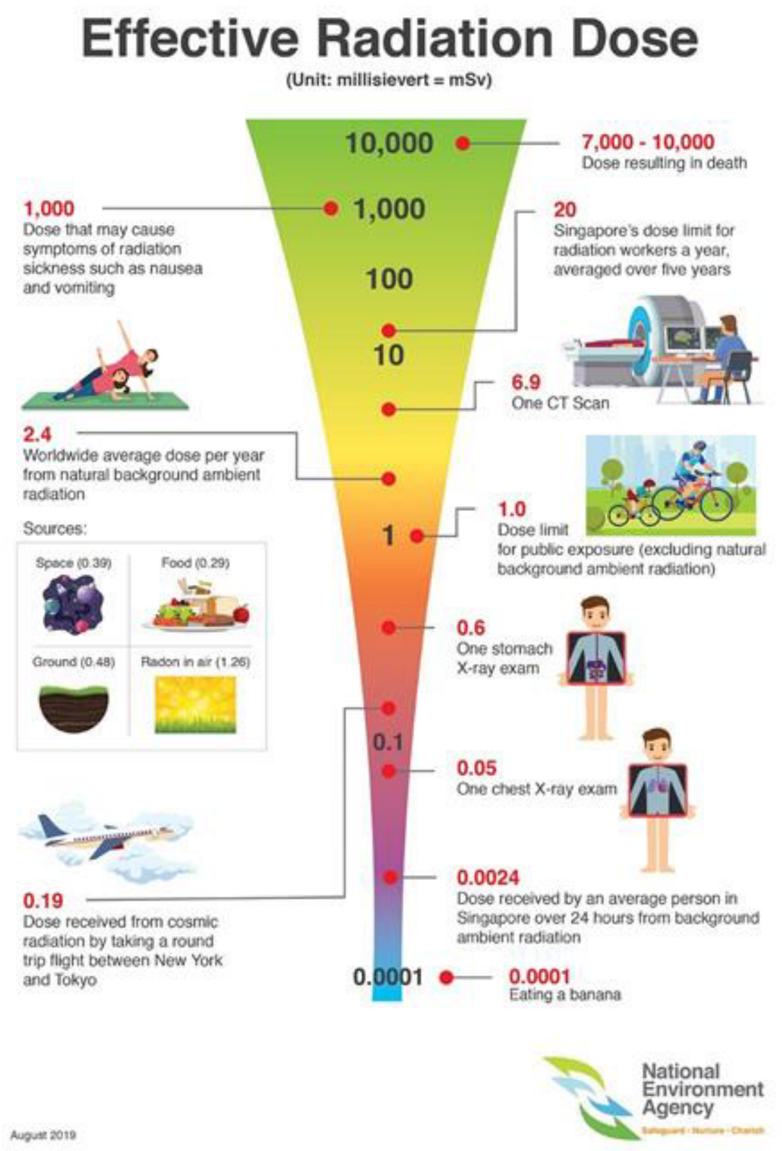
Konsep Keselamatan (Safety)



Konsep Keselamatan (Safety)

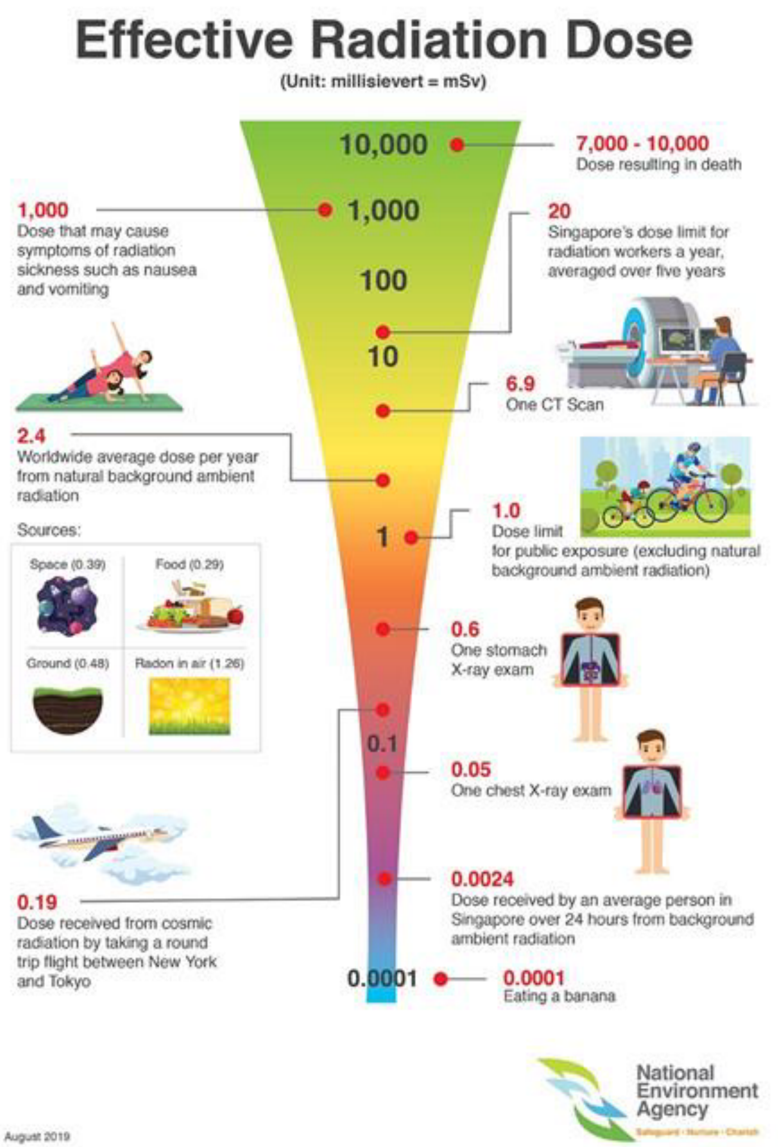


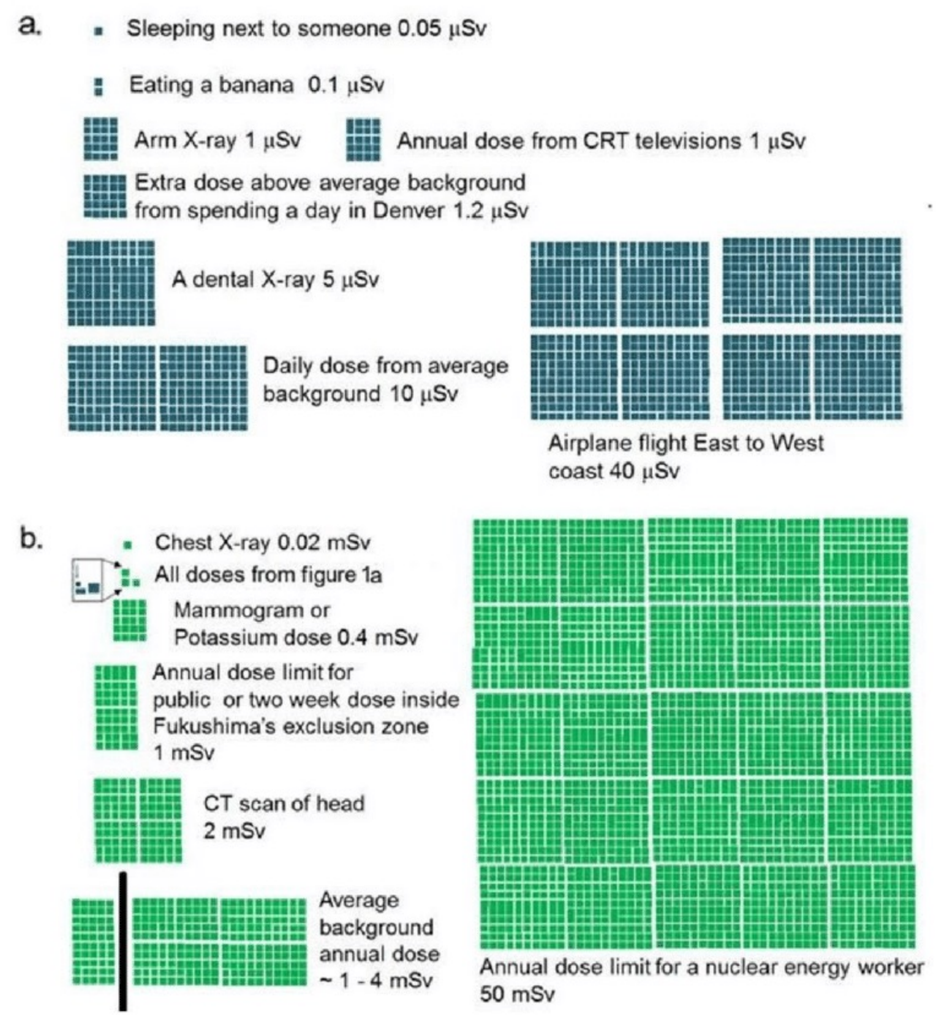
Konsep Keselamatan (Safety)



https://www.nea.gov.sg/our-services/radiation-safety/understanding-radiation/health-effects-of-ionising-radiation-on-people

Konsep Keselamatan (Safety)

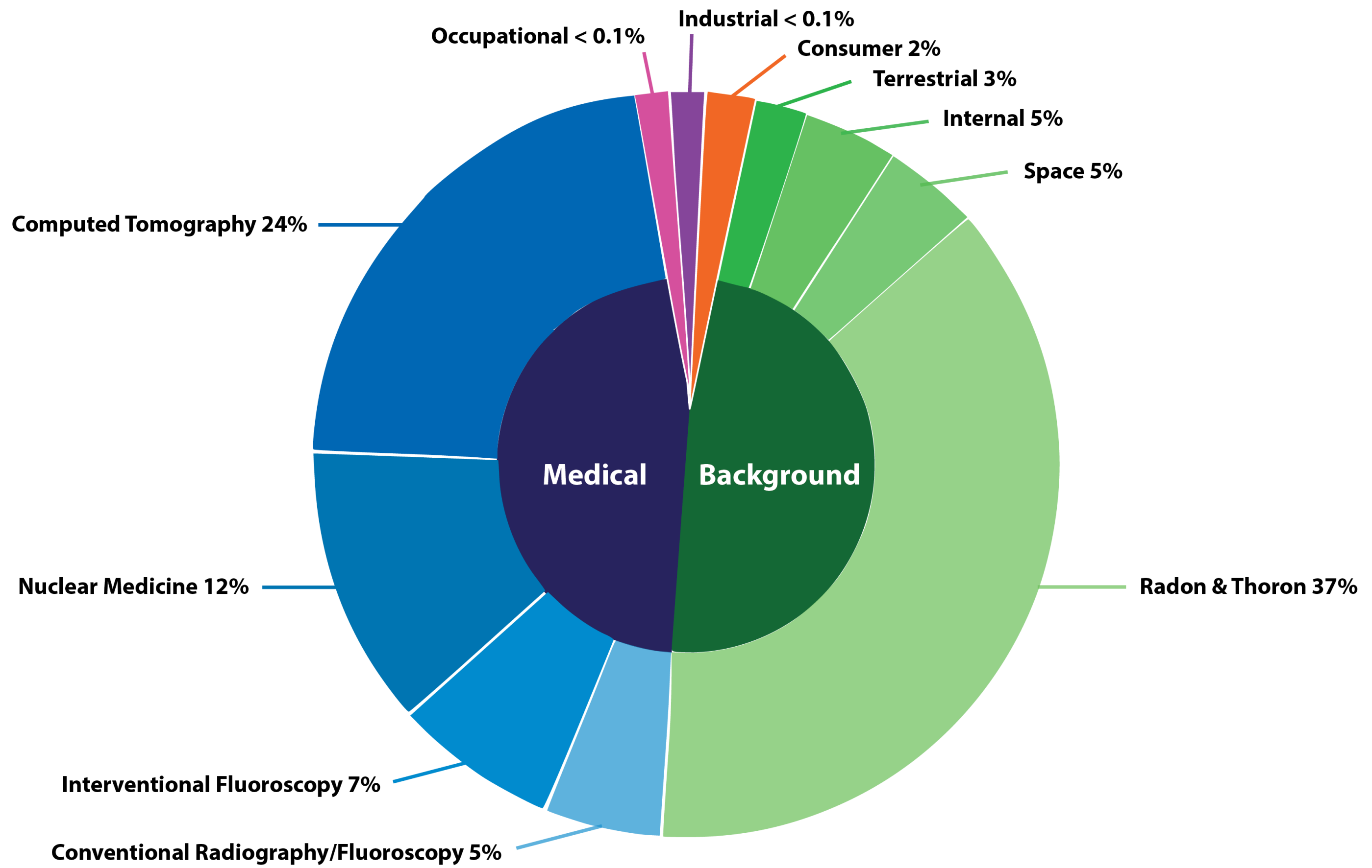




https://www.researchgate.net/publication/320360030_Assessing_Health_Implications_of_the_Potential_Radiation_Exposure_in_the_Community_During_Pregnancy_A_Case_Study/figures?lo=1

https://www.nea.gov.sg/our-services/radiation-safety/understanding-radiation/health-effects-of-ionising-radiation-on-people

Sources of Radiation Exposure



Average Annual Radiation Dose

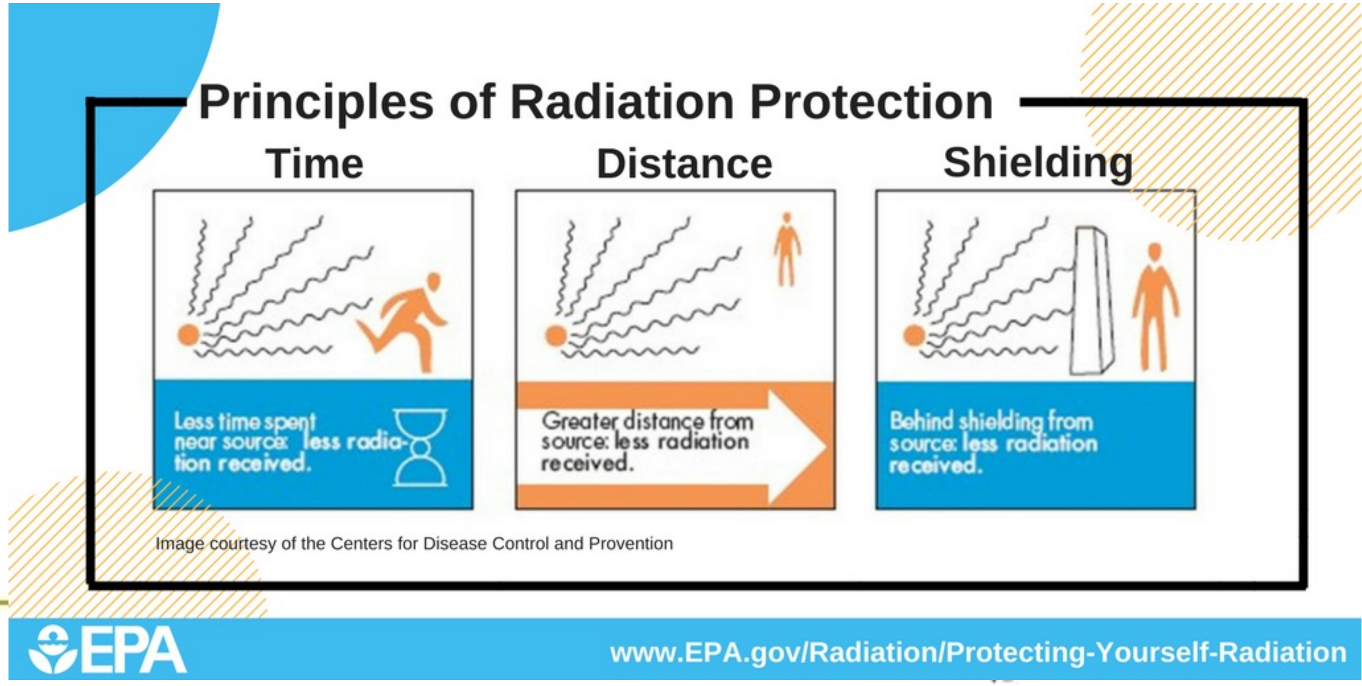
Sources	Radon & Thoron	Computed Tomography	Nuclear Medicine	Interventional Fluoroscopy	Space	Conventional Radiography/ Fluoroscopy	Internal	Terrestrial	Consumer	Occupational	Industrial
Units mrem (United States) mSv (International)	228 mrem 2.28 mSv	147 mrem 1.47 mSv	77 mrem 0.77 mSv	43 mrem 0.43 mSv	33 mrem 0.33 mSv	33 mrem 0.33mSv	29 mrem 0.29 mSv	21 mrem 0.21 mSv	13 mrem 0.13 mSv	0.5 mrem 0.005 mSv	0.3 mrem 0.003 mSv

https://www.epa.gov/radiation/radiation-sources-and-doses

(Source: National Council on Radiation Protection & Measurements, Report No. 160)

The ALARA Principle :

- **A**s
- **L**ow
- **A**s
- **R**easonably
- **A**chievable



Source : R.D. Lanjekar and J.B Doshi, Safety Aspect of Nuclear Reactor

The ALARA Principle :

- **A**s
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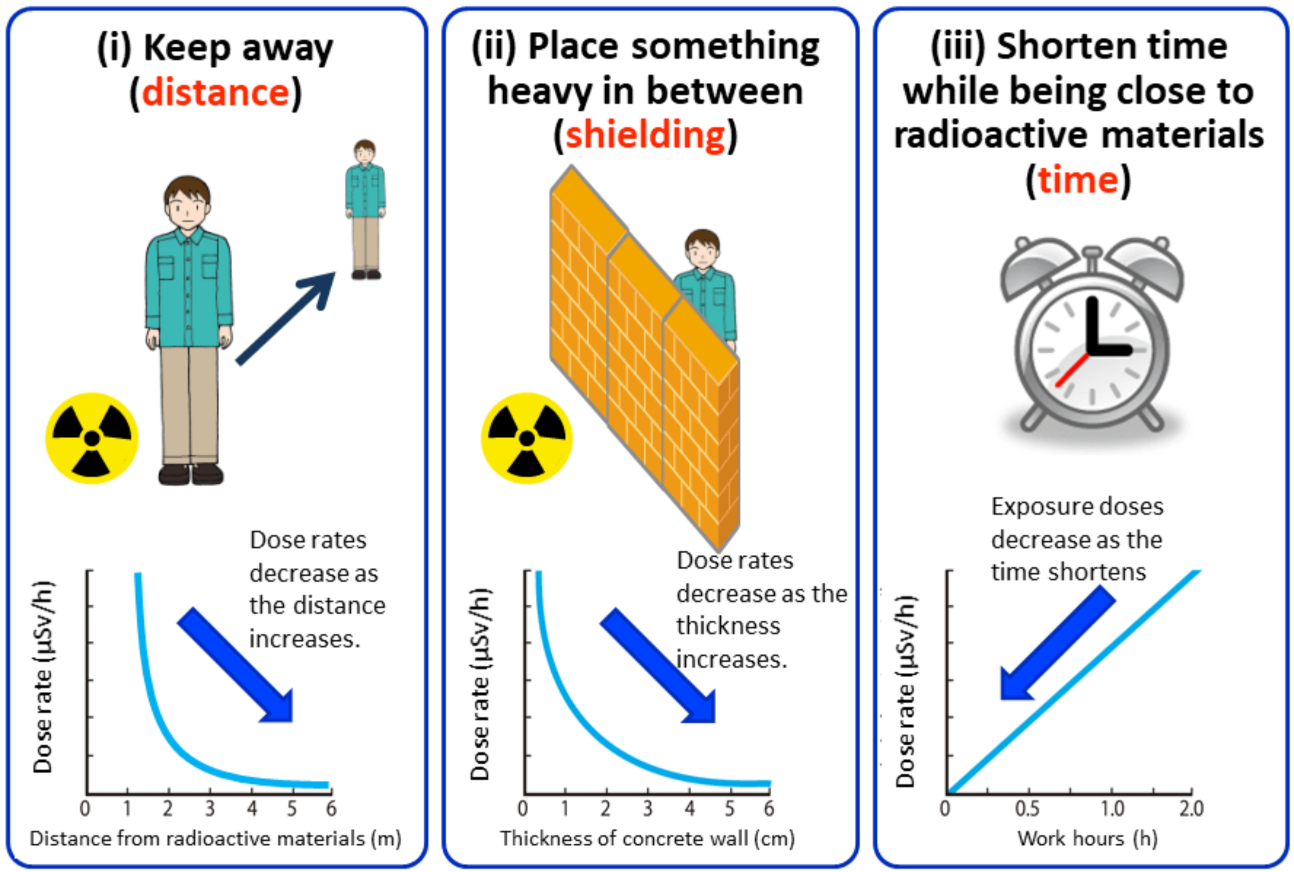
Dose Reduction Three Principles of Reduction of External Exposure



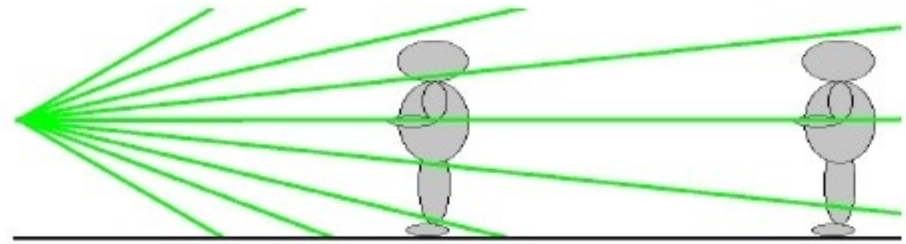
Source : R.D. Lanjekar and J.B Doshi, Safety Aspect of Nuclear Reactor

Source : https://www.env.go.jp/en/chemi/rhm/basic-info/1st/04-03-01.html

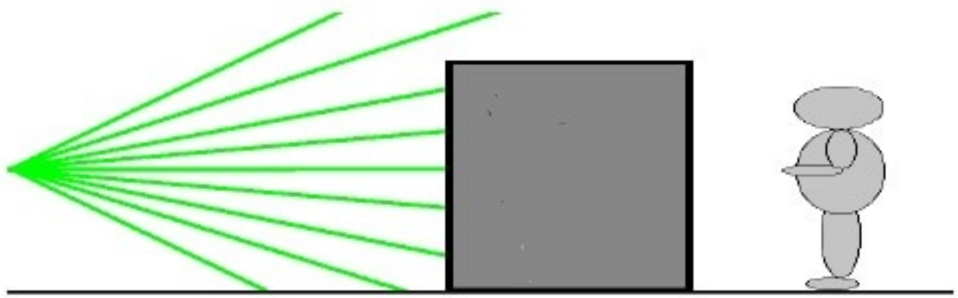
Principles of radiation exposure :

- Time

- Distance



- Shielding



Distance:

- Double distance = 1/4 dose.
- Triple distance = 1/9th dose.

Typical Transmission through Shielding:

- 0.25 mm lead rubber apron → 8.5%
- 0.35 mm lead rubber apron → 5%
- 2 x 0.25 mm apron → 2.5%
- 2 x 0.35 mm apron → 1.0%
- Double brick wall → 0.003%

Radiation hazards:

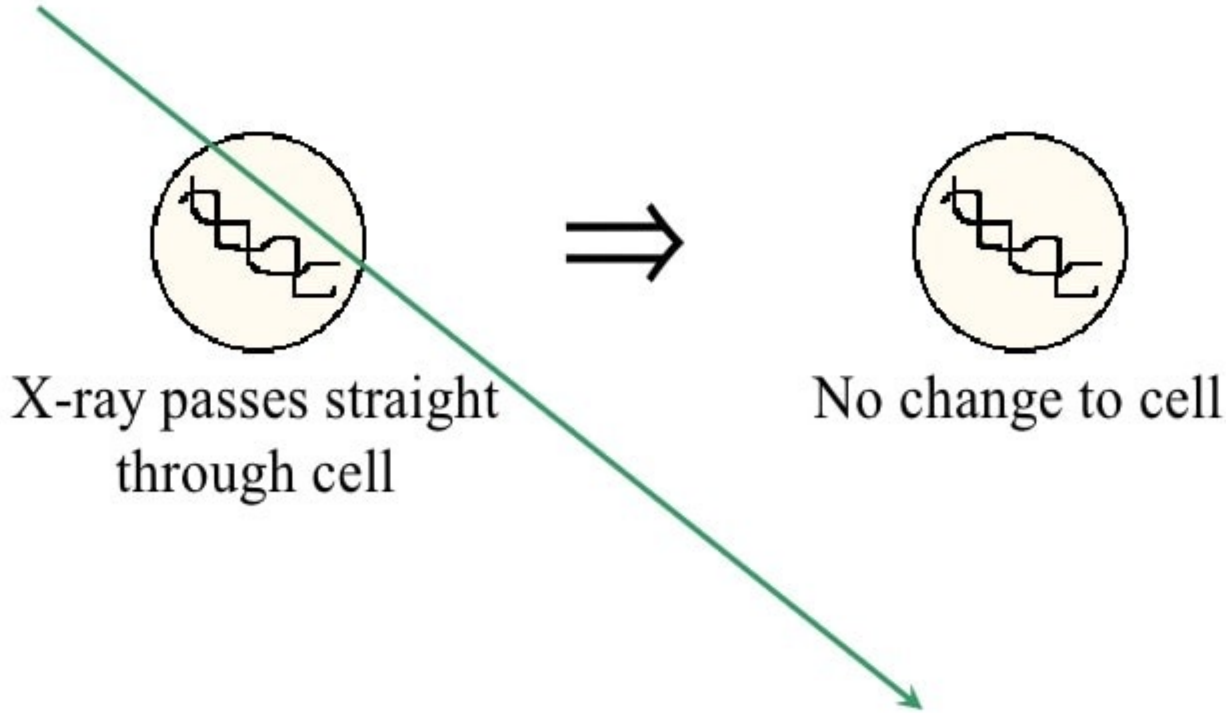
Ionising Radiations:

- **X-rays**
- **Gamma rays (γ-rays)**
- **Beta particles (β)**
- **Electron beams**

Ionising radiation can cause chemical reactions in the body's cells which may :

- Do no harm
- Kill the cell
- Cause the cell to multiply out of control (cancer)
- Cause the cell to malfunction in some other way.

Konsep Keselamatan (Safety)



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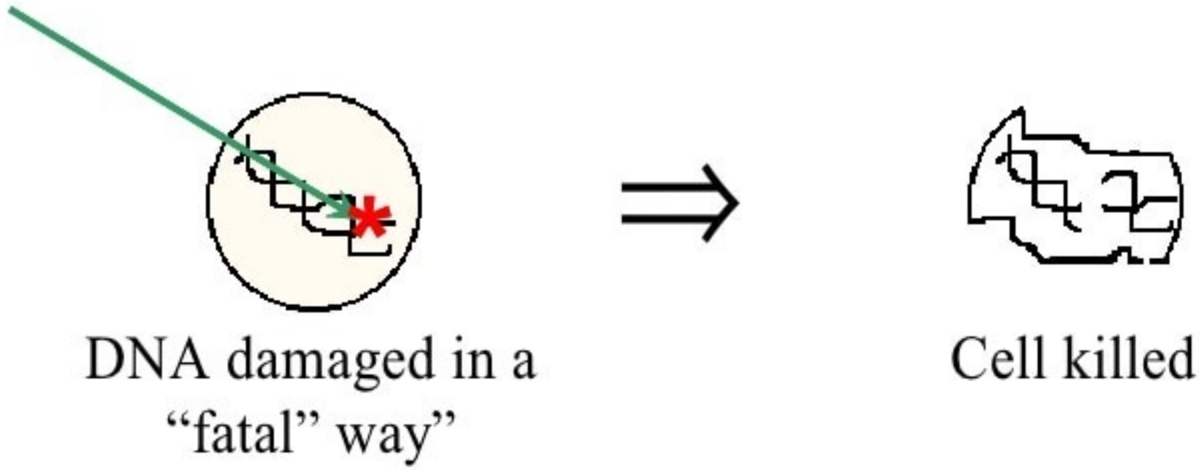
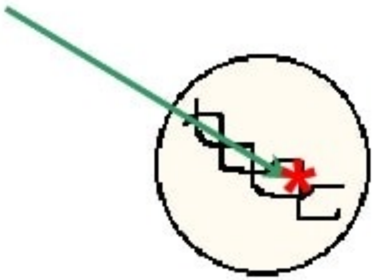
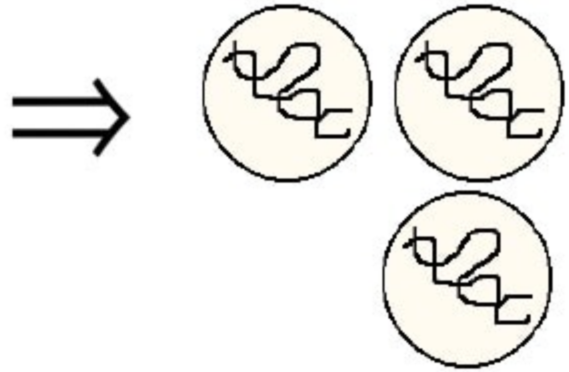
Konsep Keselamatan (Safety)



Konsep Keselamatan (Safety)



DNA damaged, causing cell to reproduce uncontrollably

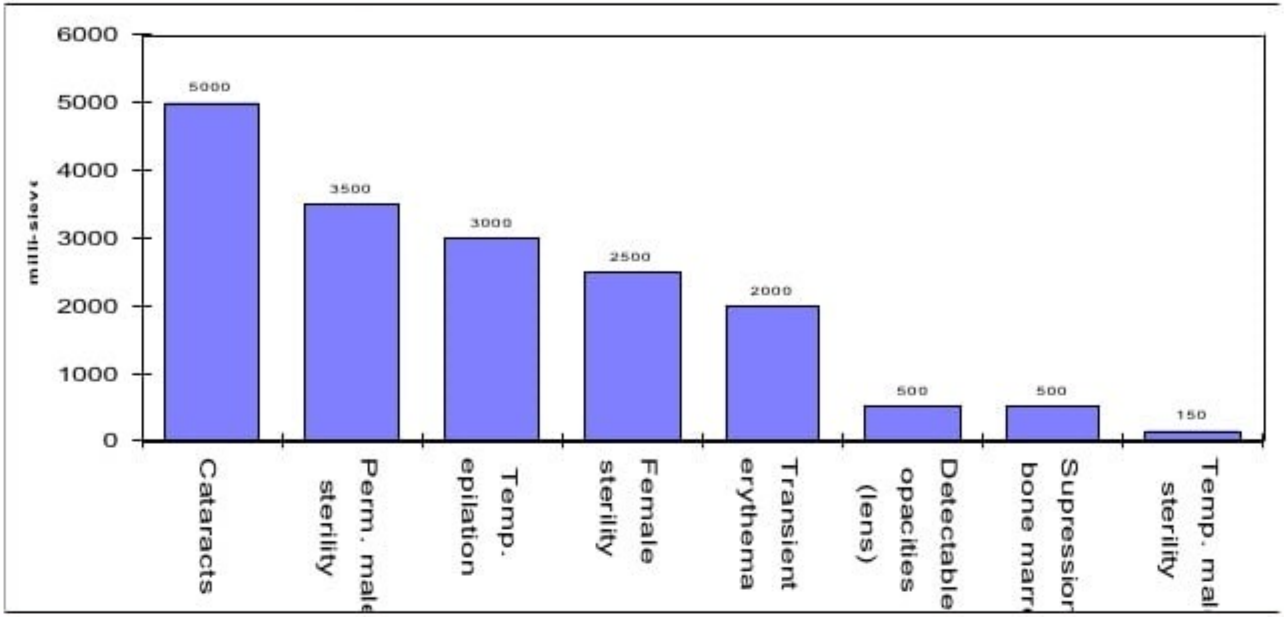


Cancer?

Where very large doses kill many cells leads to :

- Radiation “burns”
- Cateract
- Radiation sickness

Threshold risks very large doses only. The bigger the dose, the more severe the effect :

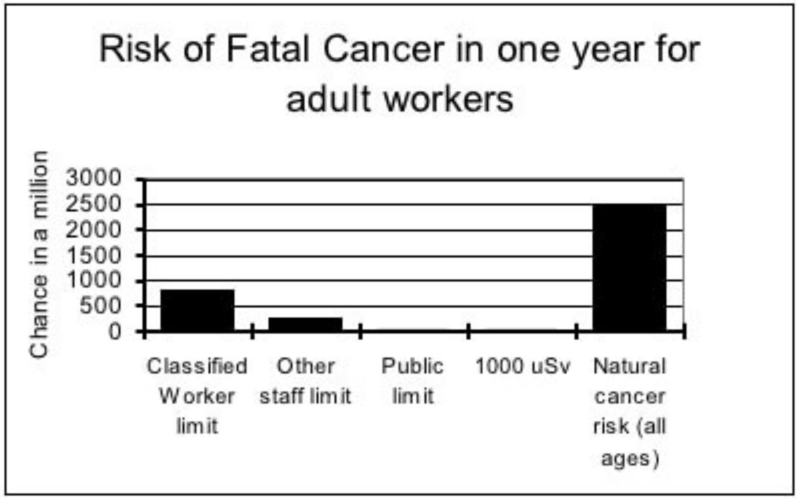


20

Cancer risks:

- It is assumed that any dose of radiation could potentially cause cancer.
- The bigger the dose, the more likely the effect will occur, (but it will probably never occur).

Risk of Fatal Cancer in one year for adult workers :



A bit like crossing the road - the more times you cross the more likely you are to be run over, but probably never will.

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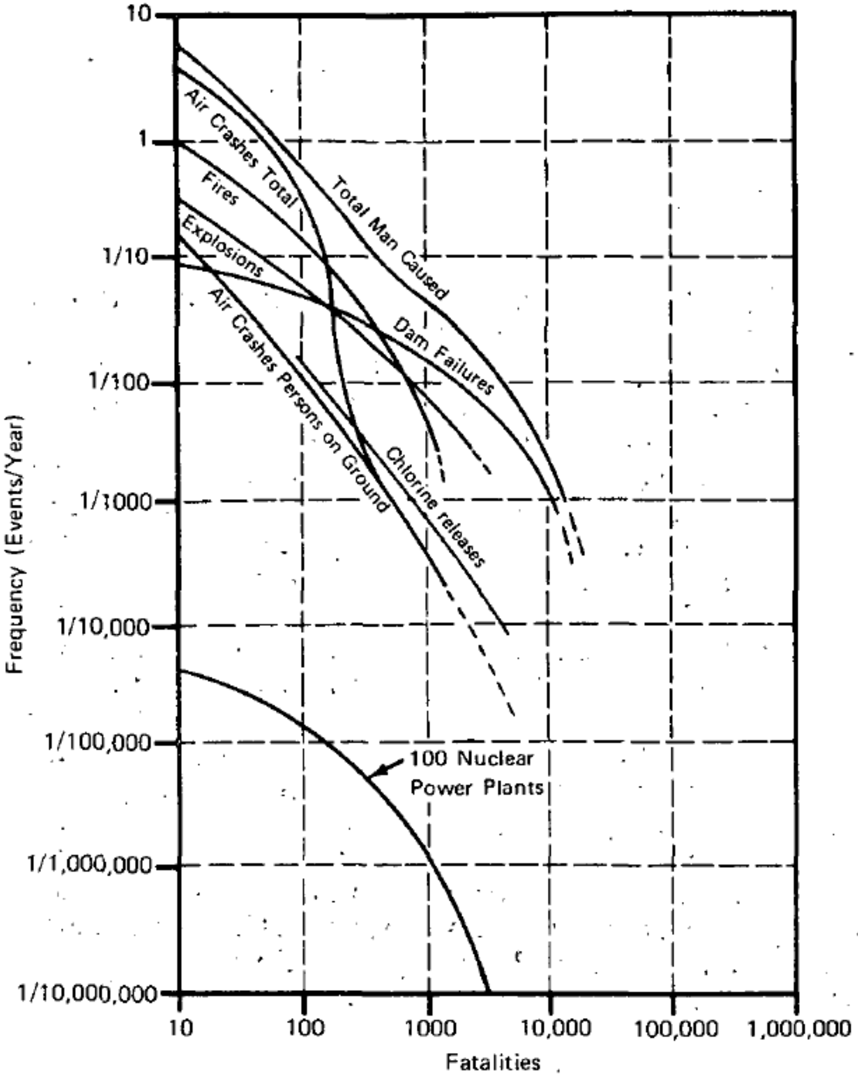
Conclusion:

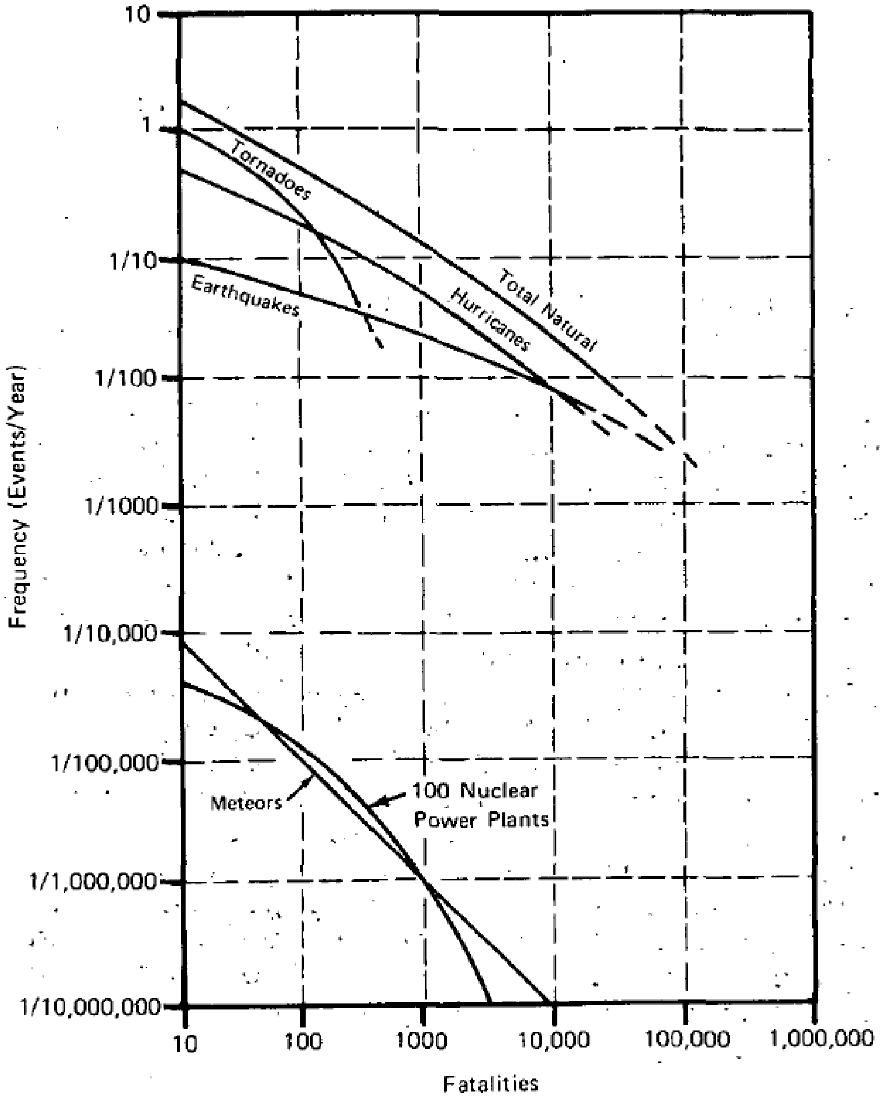
- The benefits resulting from the operation of the reactor facilities is one of the factors in judging safety of Nuclear reactor.
- Inherently safe reactors eliminates the inherent hazards of the reactor by eliminating the operator intervention in the safety aspects of the reactor.
- Nuclear wastes can be safely isolated from the environment so that they do not pose a danger to today's or future generations.

- This level of performance establishes the nuclear reactor as one of the best industry in the world in terms of personnel safety.

results comparing nuclear power plants and man-made events (WASH-1400)



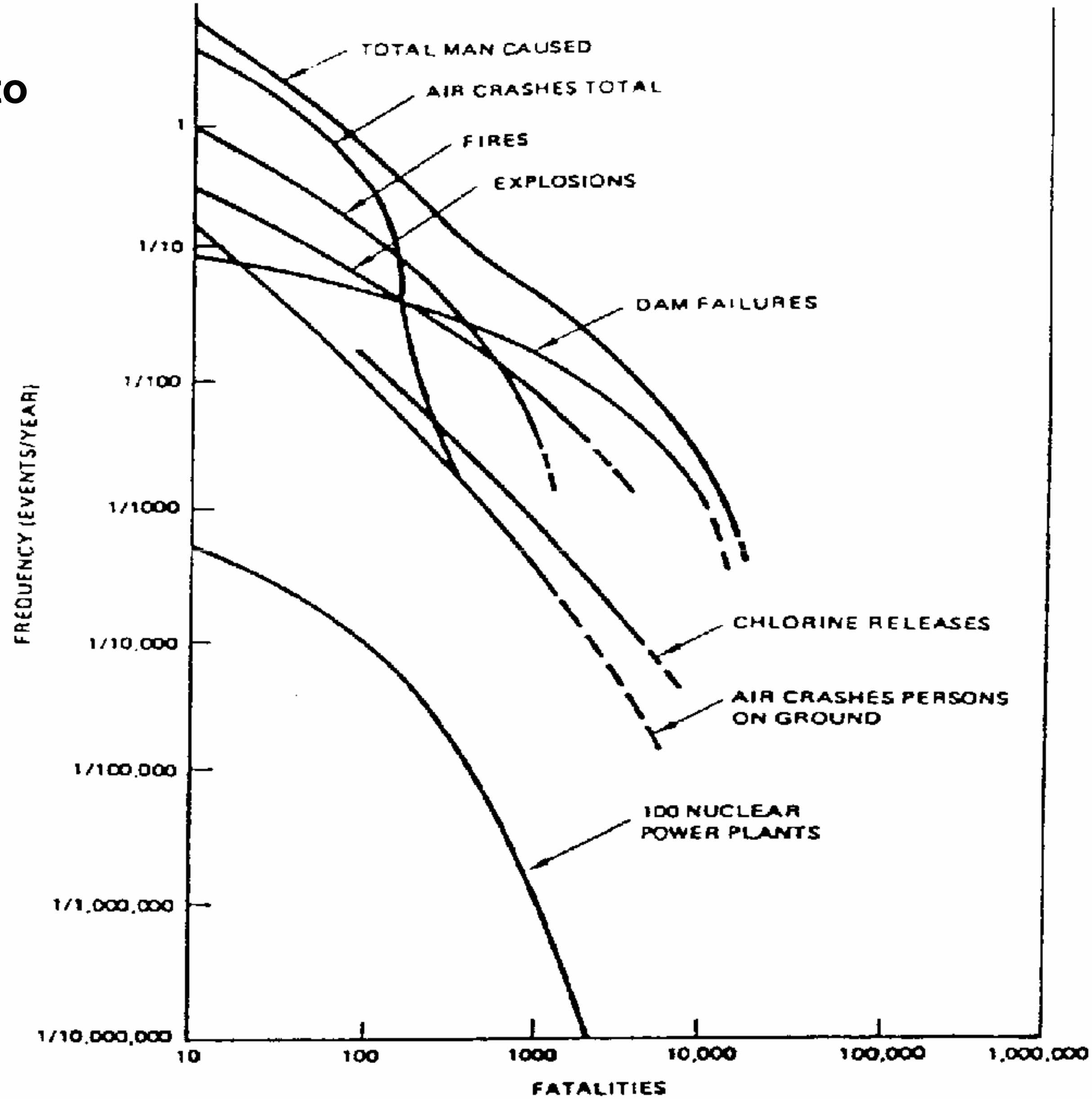
results comparing nuclear power plants and natural events (WASH-1400)



Risk Curves

Frequency of Fatalities Due to Man-Caused Events

This figure shows a number of risk curves for NPPs and man-caused events, such as fires and others. The way to read this figure is as follows: Select a number of fatalities, e.g. 1000. Then, the frequency of 1000 or more fatalities due to nuclear accidents is about one per million reactor years, while the frequency due to all man-caused events is about 8 per 100 years



Sumber : Probabilistic Risk Assessment Procedures Guide for NASA Manaers and Ptactitioners, August, 2002

Konsep Keselamatan (Safety)

Quantitative Safety Goals of the US Nuclear Regulatory Commission (August, 1986)

Early and latent cancer mortality risks to an individual living near the plant should not exceed 0 .1 percent o f the background accident or cancer
mortality risk, approximately
5×10^{-7}/year for early death and
2×10^{-6}/year for death from cancer.

•The prompt fatality goal applies to an average individual living in the region between the site boundary and 1 mile beyond this boundary.

•The latent cancer fatality goal applies to an average individual living in the region between the site boundary and 10 miles beyond this boundary.

Societal Risks

- *Annual Individual Occupational Risks*

- **All industries 7×10^{-5}**
- **Coal Mining: 24×10^{-5}**
- **Fire Fighting: 40×10^{-5}**
- **Police: 32×10^{-5}**
- **US President $1{,}900 \times 10^{-5}$ (!)**

- *Annual Public Risks*
  - **Total 870×10^{-5}**
  - **Heart Disease 271×10^{-5}**
  - **All cancers 200×10^{-5}**
  - **Motor vehicles: 15×10^{-5}**

Professor Andrew C. Kadak, Lecture Probalistic Safety Analysis, MIT Dept of NSE, 2008

Effects of Radiation

The biological effect of radiation is measured in Sieverts (Sv), a unit which combines the energy deposited in tissue and the effectiveness of that particular form of radiation in causing damage to cells.

Figure 3 gives a perspective on the range of actual doses, from normal activities to severe accidents. Sources: [CNSC, 2011], [Talbot, 2003], [Lewis, 1999], [TEPCO, 2011], [UNSCEAR, 2000].

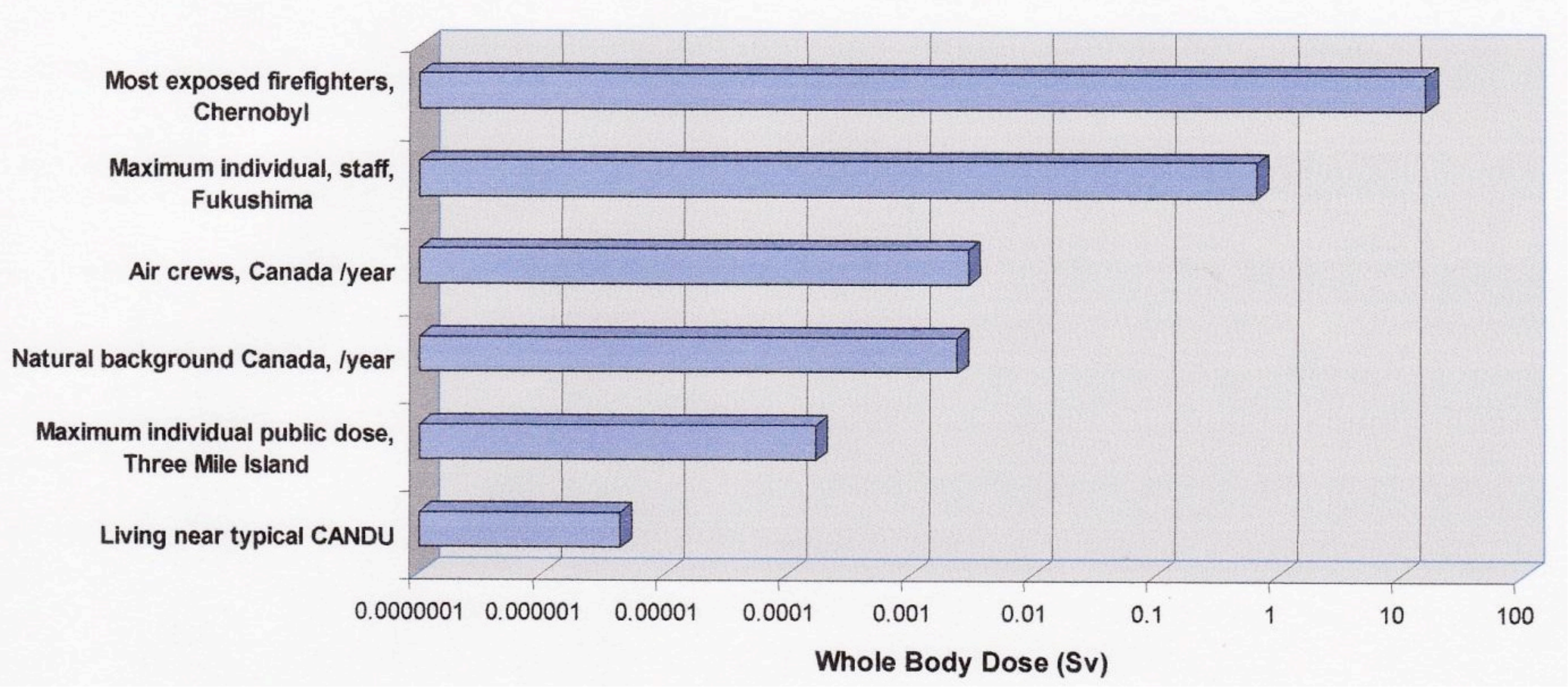
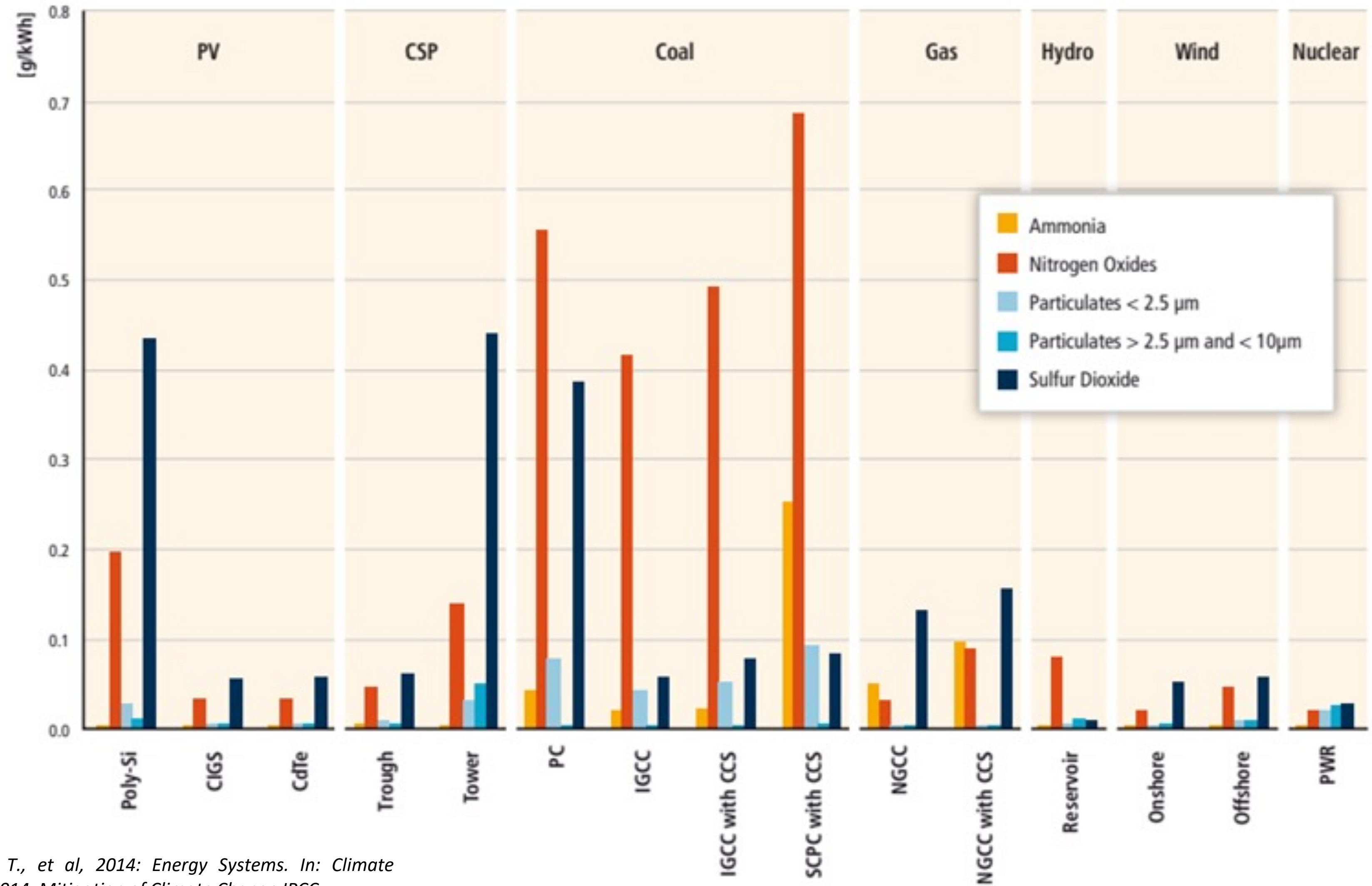


Figure 3 Examples of radiation dos

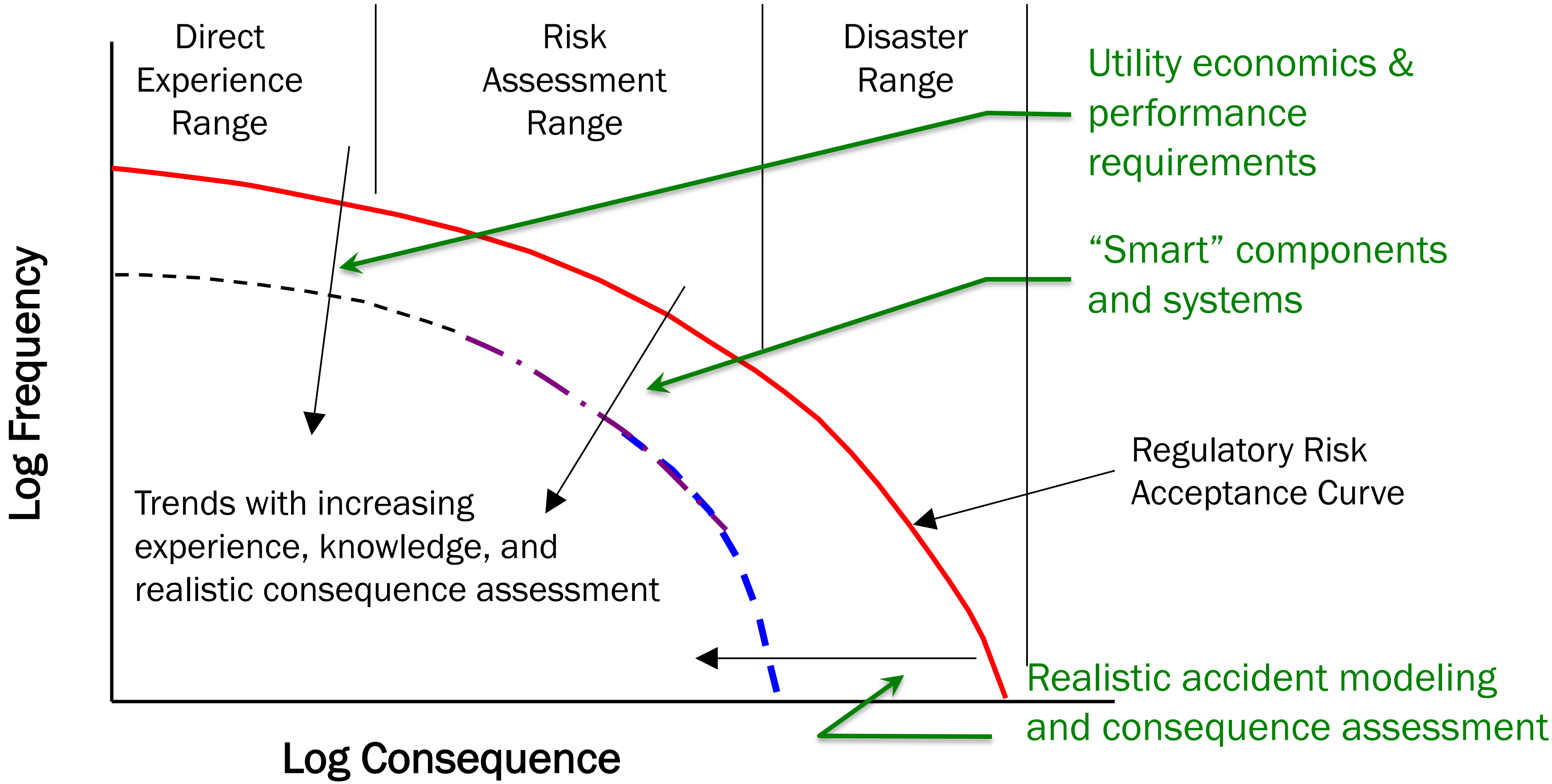
Sumber : CHAPTER 13. Reactor Safety Design and Safety Analysis , prepared by Dr. Victor G. Snell

Life Cycle Inventory Results of The Production of 1 KWh of Electricity for Important Air Pollutants Contributing to Particulate Matter (PM) Exposure



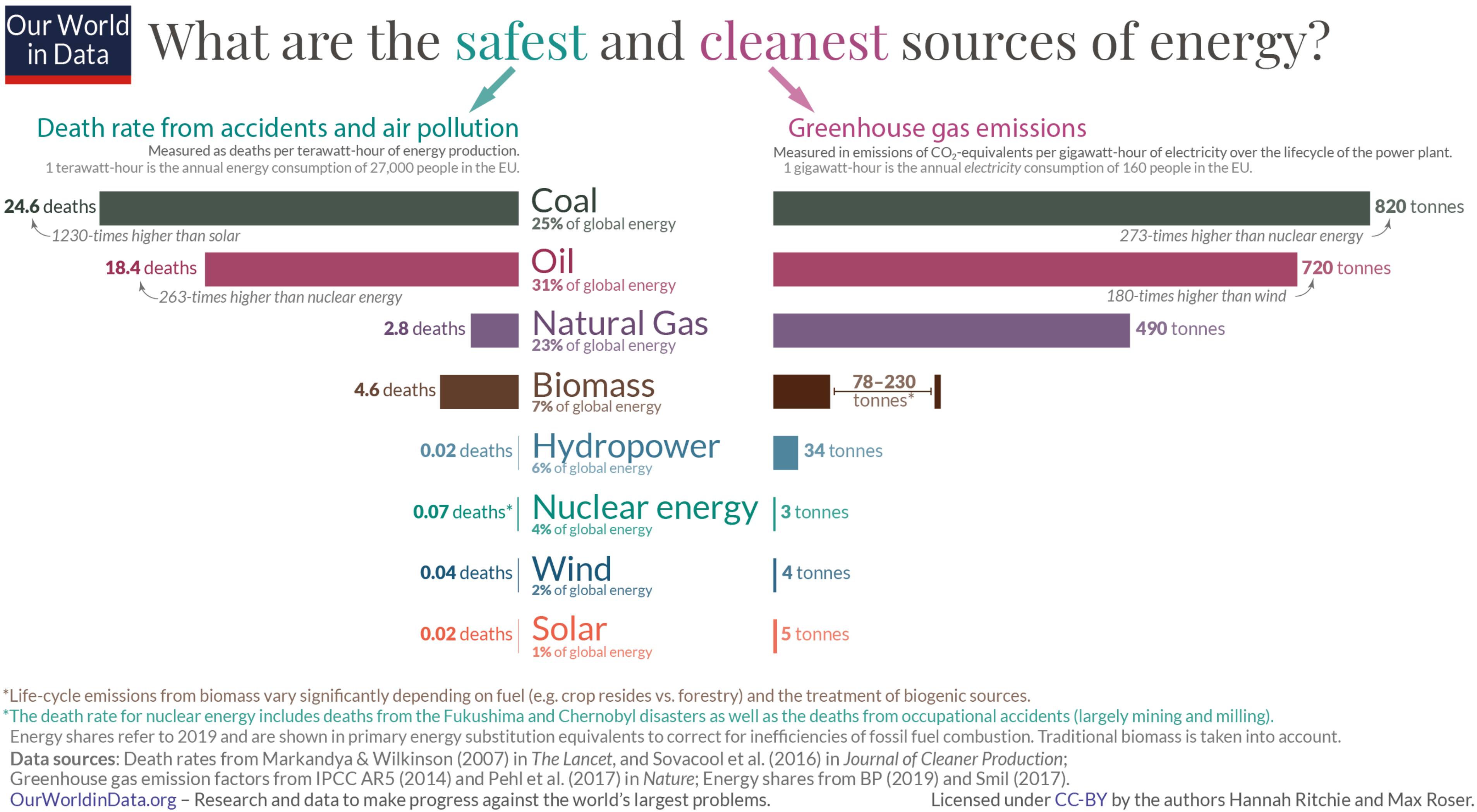
Bruckner T., et al, 2014: Energy Systems. In: Climate Change 2014: Mitigation of Climate Change IPCC

Notional Risk Curves, and Trends

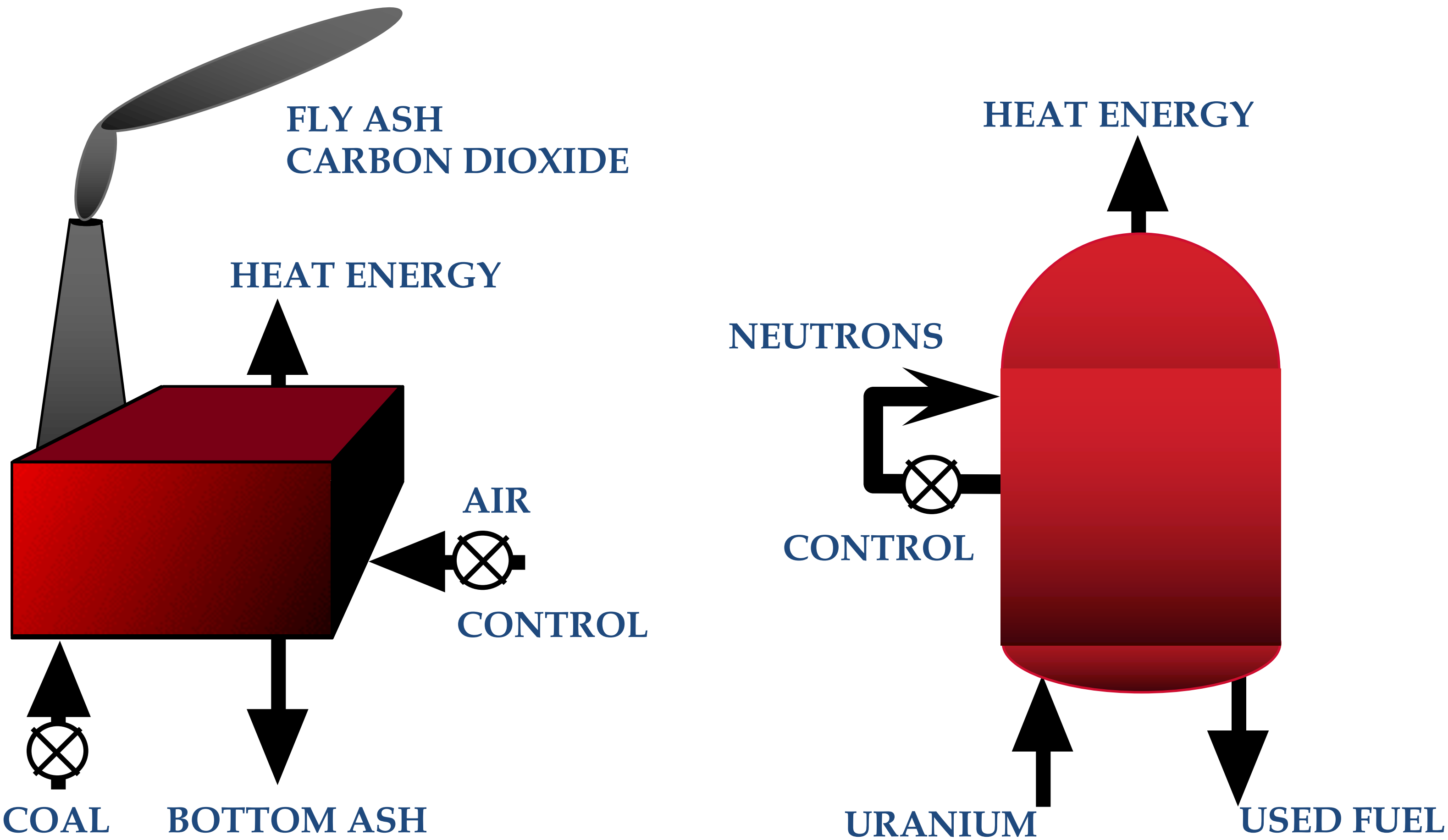


Sumber : Dan Meneley, PhD, Peng, Nuclear Safety or Risky Nuclear?, Revised and presented to the Ottawa Branch of CNS, April 21, 2011

Konsep Keselamatan (Safety)



Is Nuclear safety different? -- Yes



Sumber : Dan Meneley, PhD, Peng, Nuclear Safety or Risky Nuclear?, Revised and presented to the Ottawa Branch of CNS, April 21, 2011

Comparism of the Hazards of Using Nuclear Energy and Some Energy - Related Accidents in Terms of Frequency and Magnitude

the hazards of using energy in terms of accidents since 1975 to 2014

S/n	Place of Accident	Frequency (Year)	Magnitude (Number killed)	Comments
1	Banqiao, Shimantan & others, Henan, China	1975	30,000 immediate 230,000 total	hydro-electric dam failures (18 GWe lost)
2	Machchu II, Gujarat, India	1979	2500	hydro-electric and irrigation dam failure
3	Ortuella, Spain	1980	70	gas explosion
4	Donbass, Ukraine	1980	68	coal mine methane explosion
5	Israel	1982	89	gas explosion
6	Guavio, Colombia	1983	160	hydro-electric dam failure
7	Nile R, Egypt	1983	317	LPG explosion
8	Cubatao, Brazil	1984	508	oil fire
9	Mexico City	1984	498	LPG explosion
10	Tbilisi, Russia	1984	100	gas explosion
11	northern Taiwan	1984	314	3 coal mine accidents
12	Chernobyl, Ukraine	1986	47+	nuclear reactor accident, massive radioactive pollution
13	Piper Alpha, North Sea	1988	167	explosion of offshore oil platform
14	Asha-ufa, Siberia	1989	600	LPG pipeline leak and fire
15	Dobrnja, Yugoslavia	1990	178	coal mine
16	Hongton, Shanxi, China	1991	147	coal mine
17	Belci, Romania	1991	116	hydro-electric dam failure
18	Kozlu, Turkey	1992	272	coal mine methane explosion
19	Cuenca, Equador	1993	200	coal mine
20	Durunkha, Egypt	1994	580	fuel depot hit by lightning
21	Seoul, S.Korea	1994	500	oil fire
22	Minanao, Philippines	1994	90	coal mine
23	Dhanbad, India	1995	70	coal mine
24	Taegu, S.Korea	1995	100	oil & gas explosion
25	Spitsbergen, Russia	1996	141	coal mine
26	Henan, China	1996	84	coal mine methane explosion
27	Datong, China	1996	114	coal mine methane explosion
28	Henan, China	1997	89	coal mine methane explosion
29	Fushun, China	1997	68	coal mine methane explosion
30	Kuzbass, Russia/Siberia	1997	67	coal mine methane explosion
31	Huainan, China	1997	89	coal mine methane explosion
32	Huainan, China	1997	45	coal mine methane explosion
33	Guizhou, China	1997	43	coal mine methane explosion
34	Donbass, Ukraine	1998	63	coal mine methane explosion
35	Liaoning, China	1998	71	coal mine methane explosion
36	Warri, Nigeria	1998	500+	oil pipeline leak and fire
37	Donbass, Ukraine	1999	50+	coal mine methane explosion
38	Donbass, Ukraine	2000	80	coal mine methane explosion
39	Shanxi, China	2000	40	coal mine methane explosion
40	Muchonggou, Guizhou, China	2000	162	coal mine methane explosion
41	Zasyadko, Donetsk, E.Ukraine	2001	55	coal mine methane explosion
42	Jixi, China	2002	115	coal mine methane explosion
43	Gaoqiao, SW China	2003	234	gas well blowout with H2S
44	Kuzbass, Russia	2004	47	coal mine methane explosion
45	Donbass, Ukraine	2004	36	coal mine methane explosion
46	Henan, China	2004	148	coal mine methane explosion
47	Chenjiashan, Shaanxi, China	2004	166	coal mine methane explosion
48	Sunjiawan, Liaoning, China	2005	215	coal mine methane explosion
49	Shenlong/ Fukang, Xinjiang, China	2005	83	coal mine methane explosion
50	Xingning, Guangdong, China	2005	123	coal mine flooding
51	Dongfeng, Heilongjiang, China	2005	171	coal mine methane explosion
52	Bhatdih, Jharkhand, India	2006	54	coal mine methane explosion
53	Ulyanoyskaya, Kuzbass, Russia	2007	150	coal mine methane or dust explosion
54	Zhangzhuang, Shandong, China	2007	181	coal mine flooding
55	Zasyadko, Donetsk, E.Ukraine	2007	101	coal mine methane explosion
56	Linfen city, Shanxi, China	2007	105	coal mine methane explosion
57	Tunlan, Shanxi, China	2009	78	coal mine methane explosion
58	Sayano-Shushenskaya, Khakassia, Russia	2009	75	hydro power plant turbine disintegration
59	Hegang city, Heilongjiang, China	2009	108	coal mine methane explosion
60	Sangha, Bukavu, Congo	2010	235	petrol tanker accident and fire
61	Deepwater Horizon, Gulf of Mexico, USA	2010	11	Oil well blowout, over 4 million barrels of oil caused massive pollution in Gulf of Mexico
62	Pike River, New Zealand	2010	29	coal mine methane explosion
63	Taozigou, Sichuan, China	2013	28	coal mine methane explosion
64	Soma, Turkey	2014	301	coal mine methane explosion and fire

A.I. Oludare et al., Comparative Analysis of nuclear power generation and other power generation sources together with other social-economic development sectors in terms of accidents freque, 2018

Comparism of the Hazards of Using Nuclear Energy and Some Energy - Related Accidents in Terms of Frequency and Magnitude

Serious nuclear reactor accidents between 1952 – 2014

S/n	Nuclear Reactor	Frequency (Year)	Magnitude (Immediate Deaths)	Environmental effect	Follow-up action
1	NRX, Chalk R., Canada (experimental, 40 MWt)	1952	Nil	Nil	Repaired (new core) closed 1992
2	Windscale-1, UK (military plutonium-producing pile)	1957	Nil	Widespread contamination. Farms affected (c 1.5 PBq released)	Entombed (filled with concrete) Being demolished.
3	SL-1, USA (experimental, military, 3 MWt)	1961	Three operators	Very minor radioactive release	Decommissioned
4	Fermi-1 USA (experimental breeder, 66 MWe)	1966	Nil	Nil	Repaired and restarted, then closed in 1972
5	Lucens, Switzerland (experimental, 7.5 MWe)	1969	Nil	Very minor radioactive release	Decommissioned
6	Browns Ferry, USA (commercial, 2 x 1080 MWe)	1975	Nil	Nil	Repaired
7	Three-Mile Island-2, USA (commercial, 880 MWe)	1979	Nil	Minor short-term radiation dose (within ICRP limits) to public, delayed release of 200 TBq of Kr-85	Clean-up program complete, in monitored storage stage of decommissioning
8	Saint Laurent-A2, France (commercial, 450 MWe)	1980	Nil	Minor radiation release (80 GBq)	Repaired, (Decomm. 1992)
9	Chernobyl-4, Ukraine (commercial, 950 MWe)	1986	47 staff and firefighters (32 immediate)	Major radiation release across E. Europe and Scandinavia (14 EBq or 5.2 EBq I-131 equivalent)	Entombed
10	Vandellos-1, Spain (commercial, 480 MWe)	1989	Nil	Nil	Decommissioned
11	Greifswald-5, E.Germany (commercial, 440 MWe)	1989	Nil	Nil	Decommissioned
12	Fukushima 1-3, Japan (commercial, 1959 MWe)	2011	Nil	significant local contamination (630 PBq I-131 equivalent)	Decommissioned

Statistics of Coal Power and NPPs Accidents between 2000 to 2009

S/n	Year	Frequency (Number of accidents in Coal)	Frequency (Number of accidents in NNPs)	Magnitude (Deaths in Coal)	Magnitude (Deaths in NNPs)	Magnitude (Death rate per million tons of coal power accidents)
1	2000	2,863	Nil	5,798	Nil	5.80
2	2001	3,082	Nil	5,670	Nil	5.11
3	2002	4,344	Nil	6,995	Nil	4.93
4	2003	4,143	3	6,434	Nil	4.00
5	2004	3,639	Nil	6,027	Nil	3.01
6	2005	3,341	5	5,986	Nil	2.73
7	2006	2,945	8	4,746	Nil	1.99
8	2007	1,645	Nil	3,770	Nil	1.44
9	2008	1,531	Nil	3,210	Nil	1.18
10	2009	1,616	Nil	2,631	Nil	0.89
	Total	**29,149**	Nil	**51,267**	Nil	**31.08**

Frequency (Year)	Plant	Location	Magnitude (Description of loss)	Magnitude (Deaths)
2009	Savano – Shushenskaya Dam	Russia	2009 Sayano – Shushenskaya hydro accident, 6 GW power generation loss, 75 fatalities, due to turbine failure	75
2009	Itaipu Dam	Brazil	18 GW power generation loss due to storm damage of transmission lines	-
2000	Biedron Hydroelectric Power Station	Switzerland	1269 MW loss, penstock rupture, three fatalities, flooding and loss of generating capacity	-
1975	Banqiao Dam	China	26,000 dead from direct flooding, 145,000 dead from subsequent famine and epidemics, 11 million homeless. Caused loss of generation, dam failed by overtopping	171,000
1956	Schoellkopf Power Station	Niagara Falls, NY	Destruction of the plant as it fell from the gorge wall and collapsed into the river, caused by water seeping into the back wall of the power station. One worker was killed and damage was estimated at $100 million USD.	-
1952	Sui-ho, Fusen, Kyosen and Choshin Dams	Korea	Due to enemy bombing, attacked during the Korean War resulting in the loss of approximately 90% of North Korea's energy generation capacity	-
1943	Herdecke	Ruhr	132 MW power generation loss, due to overtopping after failure of Mohne dam	-

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Comparism of the Hazards of Using Nuclear Energy and Some Energy - Related Accidents in Terms of Frequency and Magnitude

Statistics of Gas Casualties in the World War I

Estimated gas casualties		
Nation	**Magnitude (Fatal)**	**Magnitude (Non-fatal)**
Russia	56,000	419,340
Germany	9,000	200,000
France	8,000	190,000
British Empire (includes Canada)	8,109	188,706
Austria-Hungary	3,000	100,000
USA	1,462	72,807
Italy	4,627	60,000
Total	**88,498**	**1,240,853**

Statistics of aircraft accident as at 30 January 1999 to 30 December 2011

Year	**Magnitude** (Deaths Aircraft Accident)	**Magnitude** (Deaths/Loss NNPs Accident)	**Frequency** (Number of accidents in Aircraft)	**Frequency** (Number of accidents in NPPs)
2011	828	Japan nuclear accident caused displaced of thousands of people and environmental defect	117	4 number of NNPs affected
2010	1,115	Nil	130	Nil
2009	1,103	Nil	122	Nil
2008	884	Nil	156	Nil
2007	971	Nil	147	Nil
2006	1,294	Nil	166	Nil
2005	1,459	Nil	185	Nil
2004	771	Nil	172	Nil
2003	1,230	Nil	199	Nil
2002	1,413	Nil	185	Nil
2001	4,140	Nil	200	Nil
2000	1,582	Nil	189	Nil
1999	1,138	Nil	211	Nil
Total	**17,928**	Billions of dollars loss	**2,179**	4

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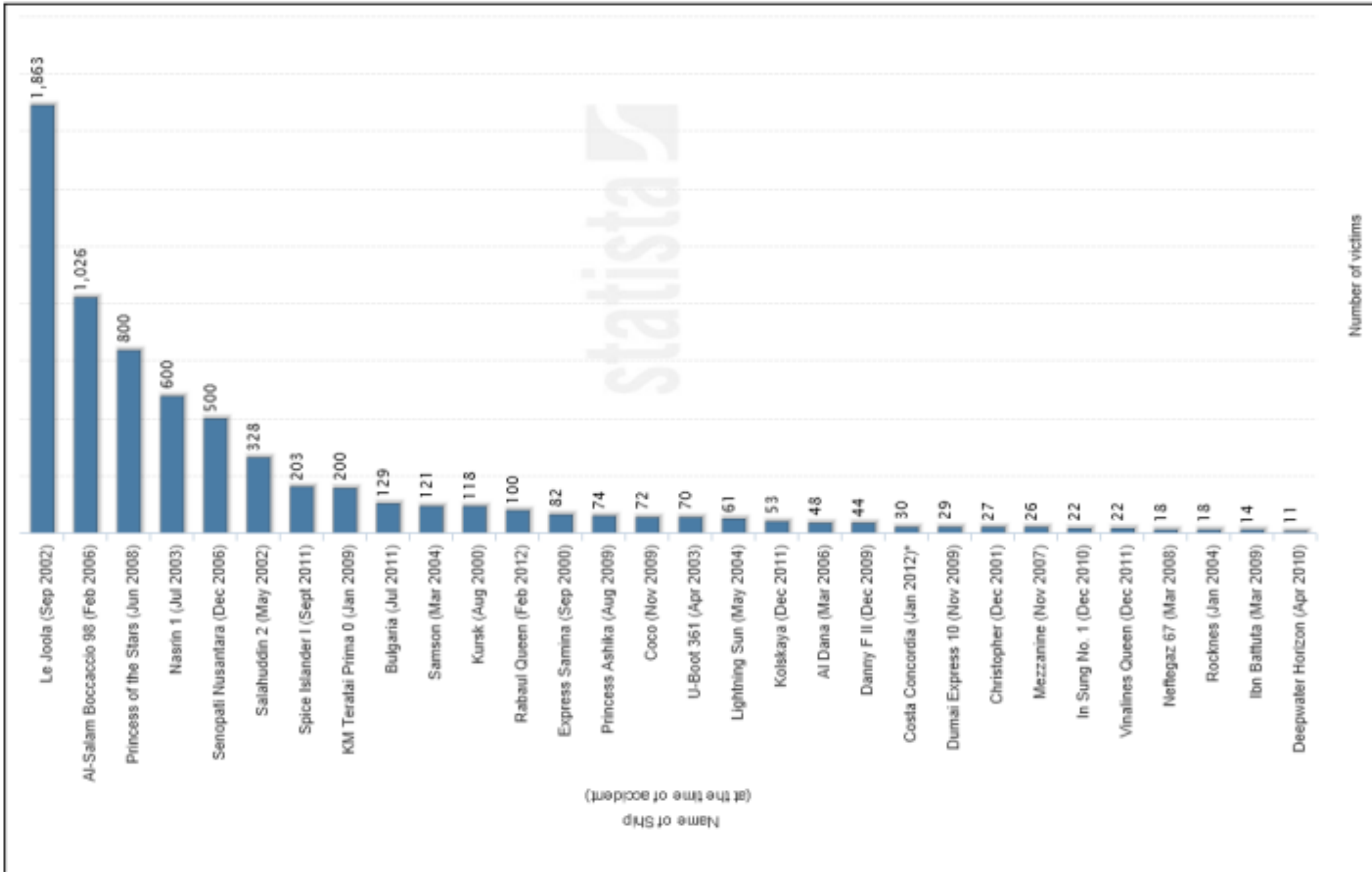
Worldwide ship accidents datasheet as at September 2002 to April 2010



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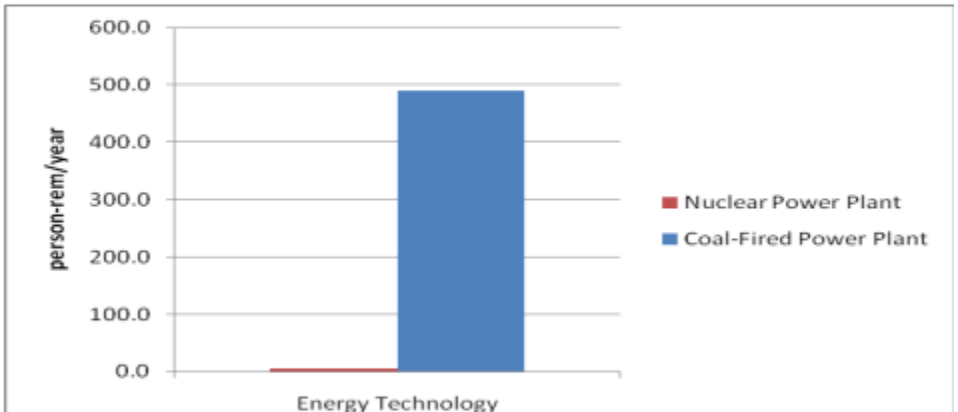
Comparism of the Hazards of Using Nuclear Energy and Some Energy - Related Accidents in Terms of Frequency and Magnitude

Short-Term Fatalities for Various Energy Technologies

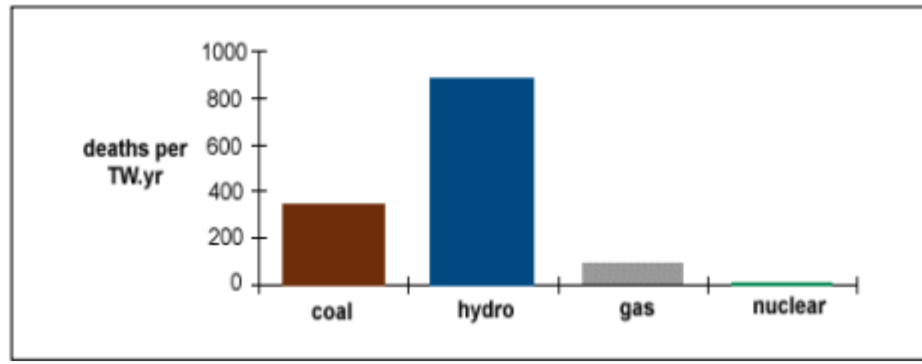
Short-Term Fatalities (1970 – 1992)					
S/n	Energy Description	Events	Fatalities		Average Facilities per GW(e) Per annum
			Range	Total	
1	Coal	133	5 - 434	6418	0.36
2	Oil	295	5 - 500	10 273	0.32
3	Natural gas	88	5 - 425	1200	0.09
4	Liquid Propane gas	77	5 - 100	2292	3.1
5	Hydro	13	10 - 2500	4015	0.8
6	Nuclear	1	31	31	0.01
The total is sum 10 times higher if accidents with less than five fatalities are included					

Comparing only radioactive emissions.

Summary of Maximum Individual Doses from Airborne Releases of a 1000 MWe Plant Energy Technology	Whole Body (Sv x 10-5)	Bone (Sv x 10-5)
Coal-Fired Power Plant	1.9	18.2
BWR	4.6	5.9
PWR	1.8	2.7



Radiation Exposure to the Public from 1000 MWe Power Plants



the deaths from energy-related accidents per unit of electricity considering 1943 accidents with more than five fatalities

Total expected radioactivity release from coal combustion from 1937 through 2040 is projected to be 477,027,320 millicuries. It is found that 1000 MWe coal-fired power plants expose the population to 490 person-rem/year, and 1000 MWe nuclear power plants expose the population to 4.8 person-rem/year

Hydro power generation has a record of few but very major events causing thousands of deaths. In 1975 when the Banqiao, Shimantan & other dams collapsed in Henan, China, at least 30,000 people were killed immediately and some 230,000 overall, with 18 GWe lost. In 1979 and 1980 in India some 3500 were killed by two hydro-electric dam failures, and in 2009 in Russia 75 were killed by a hydro power plant turbine disintegration.

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Summary of severe accidents in energy chains for electricity 1969-2000.

S/n		OECD		Non-OECD	
1	Energy chain	Fatalities	Fatalities/TWy	Fatalities	Fatalities/TWy
2	Coal	2259	157	18,000	597
3	Natural gas	1043	85	1000	111
4	Hydro	14	3	30,000	10,285
5	Nuclear	0	0	31	48

Comparison of accident statistics in primary energy production

S/n	Fuel	Immediate fatalities 1970-92	Who?	Normalised to deaths per TWy electricity
1	Coal	6400	workers	342
2	Natural gas	1200	workers & public	85
3	Hydro	4000	public	883
4	Nuclear	31	workers	8

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Semester 1 2022/2023
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^{232}Thank YoU^{238}
TeriMA Kasih
Merci

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